INCREASE THROUGHPUT, REDUCE ERROR AND STABILIZE CIRCUITS WITH EXPERT SYSTEMS

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SGS

ABSTRACT

This document outlines the value of design, implementation, and performance of expert systems in the mineral processing industry. It outlines the processes involved in capturing and using the existing knowledge-base within a mill to design a rules-based expert system that can be combined with existing monitoring technologies. The benefits of the system are examined including a stabilization of circuits, improved product or concentrate grade, and increased throughput.

The extensive tuning and training/regimes supplied by SGS are examined as well as the hierarchical decision process employed by the expert system. Specific examples of how expert control systems operate in grinding circuits are illustrated, along with the many efficiencies and monetary benefits such systems generate.

CONTENTS

I. EXECUTIVE SUMMARY

Expert systems represent a judicious use of financial capital where throughput increases of 5-6% after installation can yield substantial additional revenue. Conversely, lack of stability within processing circuits can result in sub-optimum throughput rates, equipment damage, or the production of a poor quality product thus compromising revenue and profitability. Expert systems will:

- Reduce gross operator error, corresponding damages and unscheduled downtime
- Stabilize existing or future processing circuits
- Optimize product quality
- Improve throughput.

EASY TO INSTALL

Expert control systems have proven successful at both large and small scale operations. The technology and software they incorporate is mature, robust and proven at operations worldwide. Typically, installation will involve a knowledge capture process and design stage followed by an interface setup and tuning process. Training and final calibration are optimized through live feedback sessions prior to final project acceptance and handover to operational staff.

YOUR REAL-TIME EXPERT OPERATOR

Expert systems use fuzzy logic[1] and are governed by a hierarchical decision structure designed to ensure corrective action on those process conditions with the highest priority first. Fluctuations within circuits are reduced, concentrate quality is improved, and throughput is optimized by:

- Monitoring process variables and determining their effect both up and downstream
- Prioritizing unstable conditions
- Providing the most beneficial corrective action from a range of possible solutions.

IMPORTANCE OF A TRUSTED TECHNICAL PARTNER

An experienced provider will train your operators and administrators to ensure they can properly interact with your expert system. Staff will be shown the operational specifics of the system and to ensure you fully understand its decision-making criteria and its inherent capabilities.

II. IMPORTANCE OF ACHIEVING AND MAINTAINING CIRCUIT STABILITY

In mills without expert systems, process control is maintained through judicious process set-point selection while operators provide ongoing monitoring. While skilled operators can fulfil this need for satisfactory circuit control most of the time, they cannot optimise all process set-point variables all day without interruption. It is also difficult to provide technical consistency across a range of operators with varying experience levels. This lack of stability for grinding and processing circuits can lead to internal as well as downstream problems.

PROBLEMS ARISING FROM A LACK OF CIRCUIT STABILITY

- Typically, most mills operate at the edge of their operators' capacity to maximize production. Lack of constant real-time feedback results in circuits that are constantly in a state of flux between semi-overloaded and under-loaded conditions. This dynamic fluctuation results in a product of variable size – either too coarse or too fine – with a corresponding fluctuation in throughput. Long term averages may be on target but the highs and lows significantly challenge the flotation and dewatering circuits resulting in an average or poor quality concentrate.
- Individual cells within flotation circuits may oscillate between a hard pull and no pull at all. This fluctuation in performance impacts recovery of downstream circuits (such as cleaners), the performance of regrind circuits, and the overall recovery of the mill. It can also present a challenge for concentrate launders and other components within the circuit because they are not designed for the highs and lows but rather for typical material flows.
- Sub-optimum stability causes the equipment to suffer from the strain of extreme operation. An under-filled mill can lead to steel-on-steel collisions resulting in damaged grinding media and ultimately damaged grates and lifters. The results can lead to poor overall mill performance or unscheduled downtime for repairs. Ultimately the result is damage not only to the mill but also associated equipment such as pumps and cyclones as steel enters this equipment.

The threat of major damage and downtime typically results in a mill operating sub-optimally in an attempt to control the peak conditions that lead to full-overloads. Mill control in this manner does not maximize throughput and leads to circuits that are unstable and compromise throughput quality.

[1]Fuzzy logic resembles human decision making by generating precise solutions from uncertain or approximate information. Expert systems will utilize fuzzy logic applications along each step of a hierarchical decision structure designed to take corrective action on those conditions with the highest priority first.

III. INTRODUCING EXPERT SYSTEMS

Today's expert system technology is proven to be effective at both small and large scale operations. Properly employed, it is the control strategy that provides the largest improvement in circuit stability and production rates both immediately and over time.

Expert systems consist of a rules-based fuzzy logic control strategy that pushes against process constraints to improve throughput while maintaining process parameters within safe and sustainable levels – at all times. The development of rules-based fuzzy logic applications in circuit control has matured to the point that circuit condition definitions and their place in the logic structure can be reliably incorporated into expert systems. Significant operational improvements can then be realized when expert systems are combined with:

- Existing monitoring technologies
- In-house operational expertise
- Advanced system and mineral processing experience.

DESIGN AND DEVELOPMENT

The implementation of an expert system requires the acquisition and incorporation of existing operational knowledge from your site with the required technical expertise to ensure sustainability from a technical and a personnel perspective. The main deliverable at the end of the knowledge capture phase is a complete logic repository for the expert system. Functional specifications for interfacing with the mill's control systems are also created. The logic rules are presented in a clear, concise manner to identify each component within the coded application. This must then be reviewed and approved before proceeding to the installation and tuning phases.

The full life-cycle of the implementation process follows these steps:

STAGE 1: KNOWLEDGE CAPTURE

Knowledge Capture is the design phase when the various circuit process states are identified and rules for the decision making and control strategy are defined. Circuit instrumentation is critically examined to ensure all components can achieve the stated objectives of the control strategy. Measured variables are examined for reliability and the knowledge capture process begins.

The knowledge capture process consists of interviews with the integration team and your operations personnel including superintendents, control room operators, shift supervisors, electricians and senior metallurgists. Current operational practices along with potential alternative strategies are discussed and logged. The process of understanding and unitizing process operations continues with an analysis of critical variables such as mill power draw, mill discharge density, cyclone feed density, cyclone pump amperages, etc.

Once this assessment is complete, the process knowledge allows the expert system to:

- Quantify the current state of component circuits
- Consider the presence of upstream and downstream constraints
- Decide on the best corrective action to optimize throughput.

Control is accomplished through a set of logic rules that manipulate the set-points of key operating variables within the circuit.

During this stage, all critical measurements are validated. Deficiencies in instrumentation, calibration, and reliability are identified. While it is true that a strong instrumentation base is required for a robust supervisory control scheme, validation techniques and the use of software sensors can compensate if needed. Accordingly, a secondary set of logic rules can be created by using a combination of variables to estimate and partially replace parameters for which measurements are considered unreliable or for those where no direct measurements are available. With your approval, these compensating techniques become part of the final expert system design.

STAGE 2: INSTALLATION OF APPLICATIONS - SET UP OF INTERFACE AND INITIAL TUNING

This second phase involves interfacing the expert system with the mill's operations as per the functional specifications. The system's connectivity is tested by monitoring the measured and manipulated variables to ensure they are reliable and properly filtered for use by the logic system.

Once commissioned, the calibration of the expert system begins by using actual circuit feedback as the key indicator to confirm all logic.

The initial collaboration with your site personnel on a "live" application often uncovers additional opportunities for improvement. These opportunities can involve the taking of secondary measurements such as:

- Sound readings of your SAG mill
- Raising of tonnage limits previously considered safe during manual control of operations
- Determination and incorporation of new constraints.

During this stage, your operators and administrators are trained to ensure they learn how to properly interact with the regulatory control system. The training component allows your operational personnel to understand the expert logic and its decision-making criteria. Staff are shown the specifics of tuning the applications within the expert system and become aware of its inherent capabilities. At the end of this stage, the expert system runs with the on-site assistance of the administrators and a period of monitored testing starts.

STAGE 3: FINAL TUNING OF APPLICATION

Here, the system tuning is finalized and the personnel training completed. After reviewing operational data, the integrator will use statistics to define "holes" in the logic of the expert system that indicate certain operational states have not been properly accounted for in the logic rules. These are remedied before proceeding and all final training is completed.

Then the process of project handover begins. The expert system is now ready for acceptance testing to ensure all necessary components have been installed in accordance with the original plans, designs, regulations and specifications. The original design is compared to the final product and changes noted. Following the final site visit, testing begins based on the acceptance criteria such as desired performance targets or Key Performance Indicators (KPIs).

IV. EXPERT SYSTEMS IN ACTION

Expert systems employing rules-based fuzzy logic can be applied to most grinding circuits. The primary objective is generally to increase throughput while still maintaining the cyclone overflow product size within an acceptable range. The secondary objective is to achieve a high level of utilisation of the expert technology. Installations in primary ball mill circuits and SAG/Ball Mill circuits have often witnessed throughput increases from 5-6% and realised expert system utilisation higher than 90% for the time the grinding circuit was available for advanced control operation.

PRIMARY BALL MILL EXPERT STRATEGY

A ball mill control strategy first determines the current state of a number of process variables and the rate of change of specific important variables within the circuit. The system then uses a hierarchical decision structure (figure 1) to prioritize these variables and take actions to control the conditions of highest priority first. For example, an upward trend in mill load can first be addressed by manipulating water flows before reducing the mill feed tonnage. This flexibility allows the system to respond appropriately to a wide variety of process states.

Primary Ball Mill Examples

The first state in the decision hierarchy confirms whether the ball mills are operational and available. If true, the control system will continue to evaluate downstream operational states, and any associated control actions will be implemented whenever a true result is achieved.

For a ball mill circuit, several measurements are considered when defining the process states:

- Power draw
- Mass-flow to cyclone
- Sump level
- Mill discharge as % solids
- Cyclone feed as % solids
- Cyclone overflow particle size.

Expert fuzzy logic is used to determine the process variables in an evaluation hierarchy. For example, a high mass rate to the cyclone can imply a high load, but if the overflow particle size is on-target then less weighting is given to the high mass situation. This means that the expert fuzzy logic response will be mitigated by the presence of an on-target, validated, overflow particle size.

In "Overload" situations, the expert system implements control actions based on the current power draw, circulating load levels and rates of change of circuit values. The control actions range from a partial flushing without a feed tonnage decrease, to a feed tonnage reduction with a full mill flushing. The existence of multiple possible actions ensures that the appropriate control procedure is taken in relation to the severity of the condition.

Once at the "OK Load" state, the expert system attempts to optimize and increase tonnage with the knowledge that the recirculation load is not increasing. The expert system simultaneously verifies that other key variables such as power draw, sump pump amps, and cyclone feed density are stable. In scenarios where densities are out of range, the expert system corrects the situation by modifying the water addition at the ball mill feed location or cyclone feed sump. Simultaneously, the stability of variables such as cyclone overflow particle size, recirculation load, sump levels and pump amps are measured and verified.

Finally, the "Low Load" state considers high ball mill power draw. In this state, the feed tonnage increase applied by the expert system is more aggressive when compared to the "OK Load" state since the expert system is 100% certain that the circuit is under-loaded.

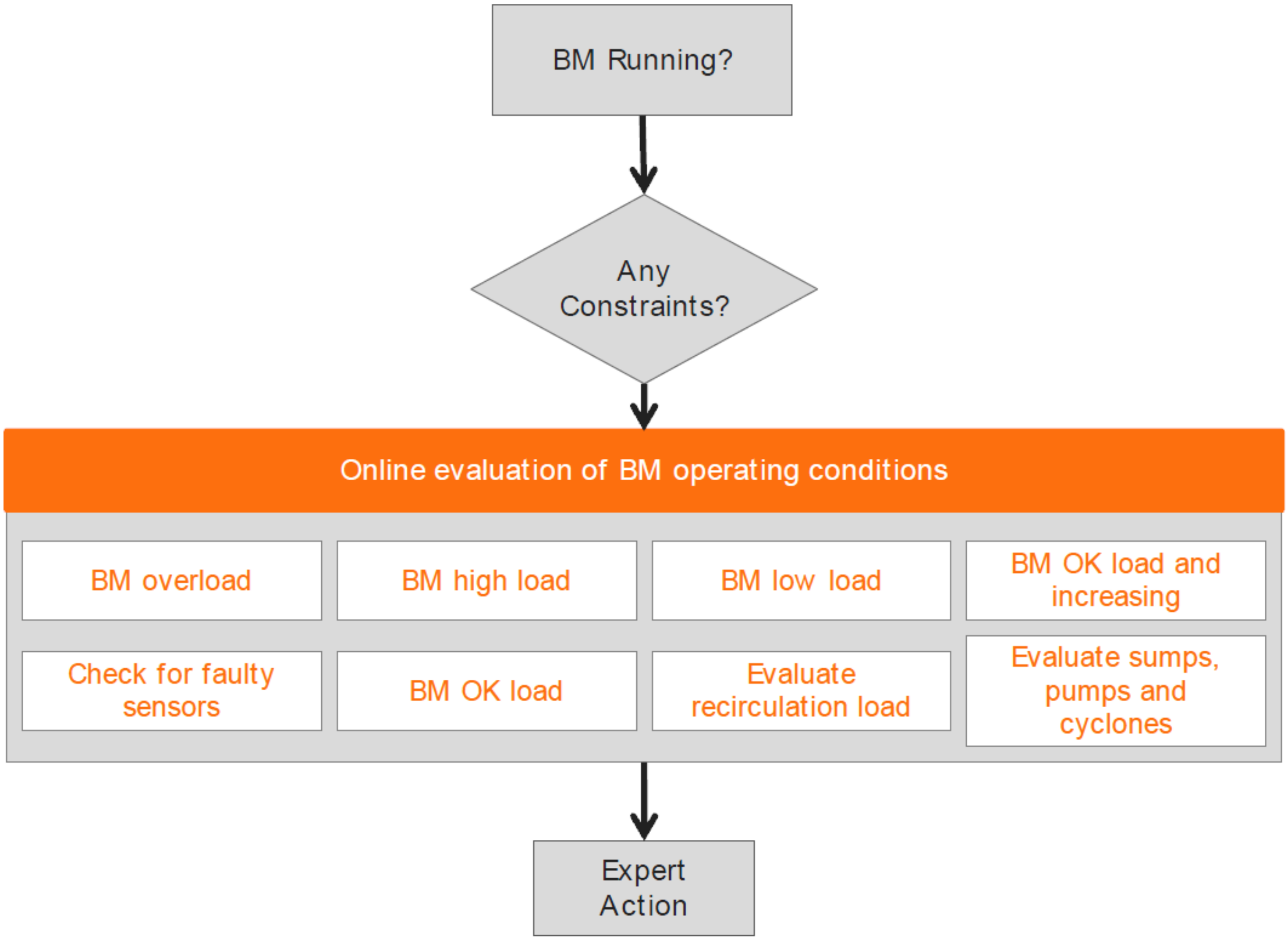


Figure 1. Primary Ball Mill Expert Logic Overview

SAG/BM CIRCUIT EXPERT STRATEGY

A SAG mill expert strategy can use a set of mutually exclusive power or load state definitions arranged in a matrix for the entire set of SAG operating conditions (figure 2). The expert logic used for a SAG/BM circuit considers both downstream and upstream constraints so that variables like slurry density and rate of feed-solids remain in an optimum state.

SAG/BM Circuit Examples

The matrix considers the state (high, ok, low) and the trend (increasing, stable, and decreasing) of both the mill power and pressure. This results in a series of logic rules. Each rule first considers the state of the SAG mill solids and the possible presence of downstream constraints (flotation constraints or ball milling constraints) before implementing a control action. The use of a dashboard view (figure 3) allows for easy identification of the process state and the rules that would be implemented next. This visibility is critical to properly tuning the SAG rule-base.

The expert logic is designed to implement multiple actions based on different operating scenarios. For instance, when the SAG power draw is increasing and high, the first option considered by the expert would be to change the coarse-to-fine ratio of material coming through the feeders. The second option would be to adjust the feed water and the third and final option would be to reduce tonnage in a timely manner.

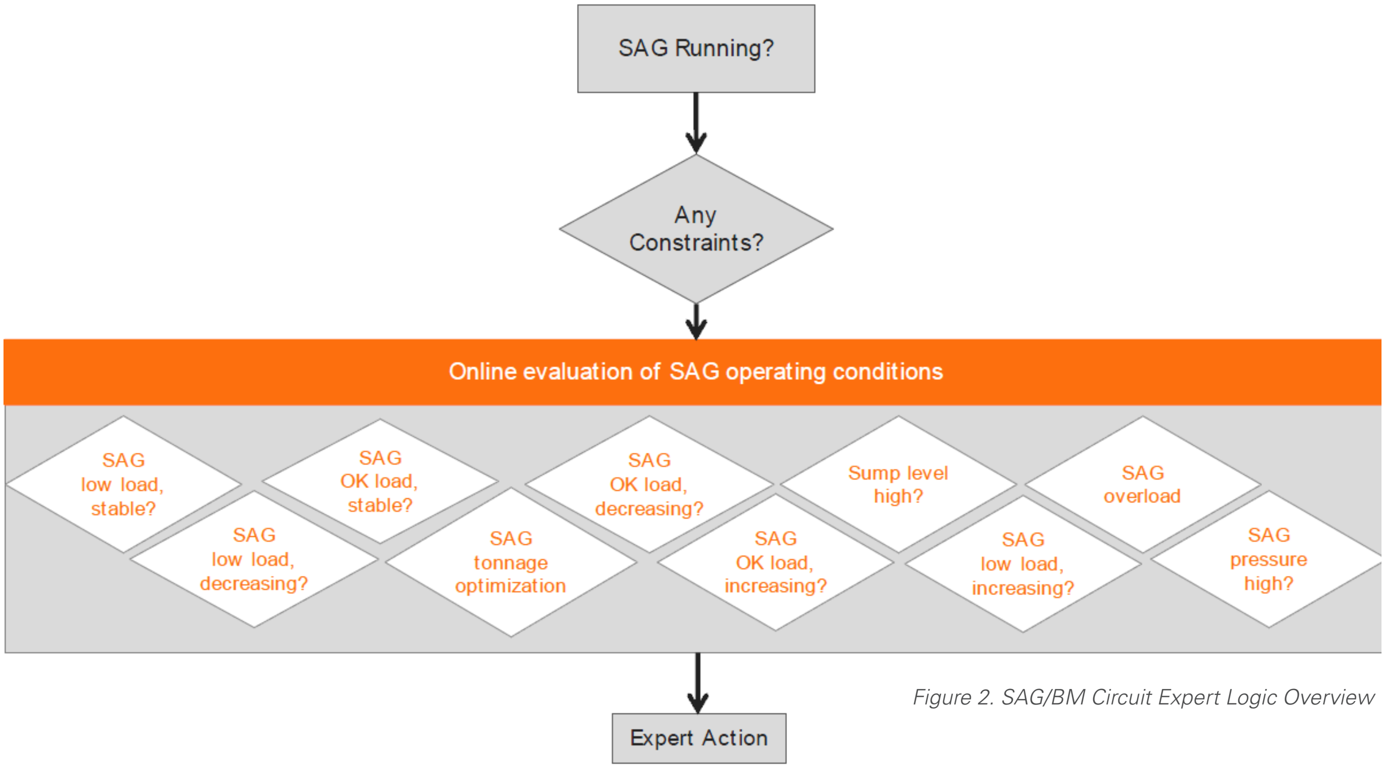


Figure 2. SAG/BM Circuit Expert Logic Overview

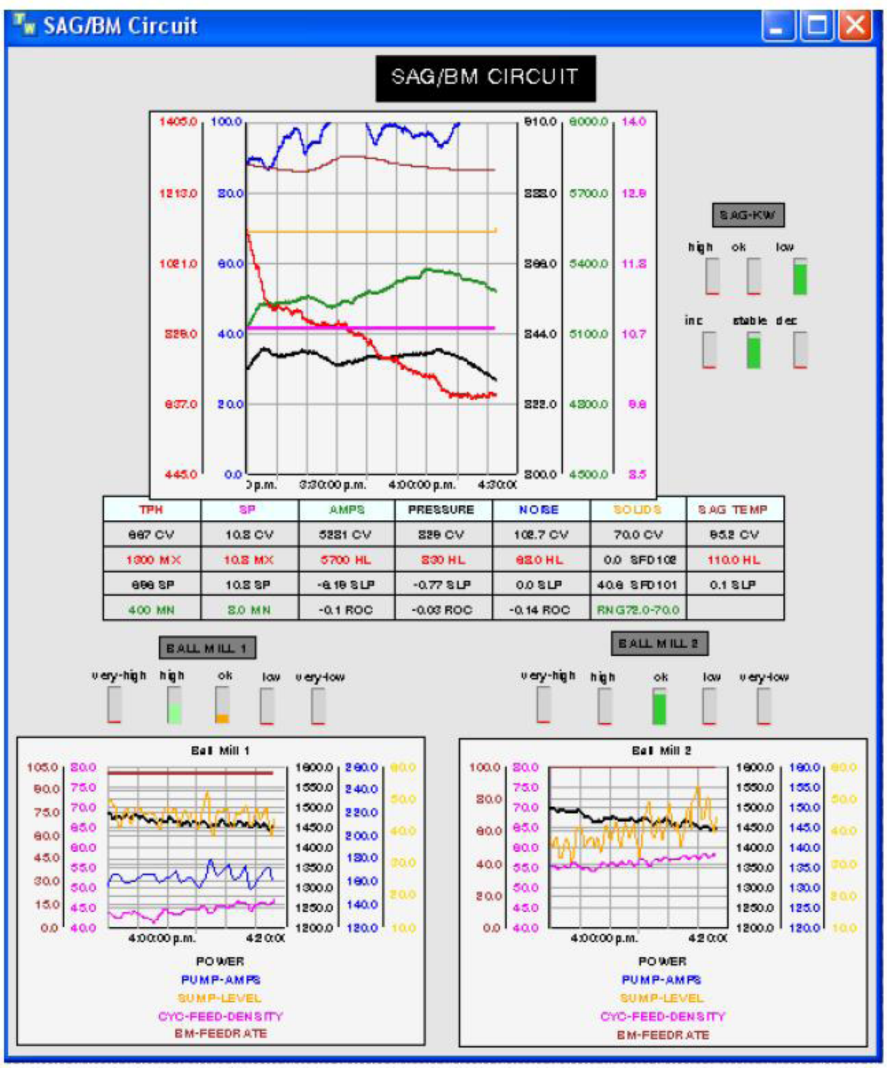


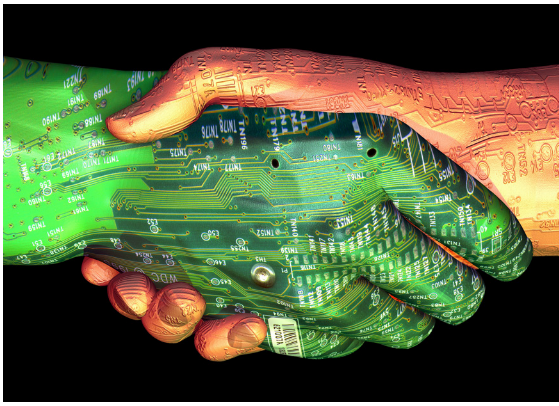
Figure 3. SAG/BM Circuit Expert Dashboard

V. CONCLUSION

Mineral processing operations involve massive capital outlays and high operating costs due to ever increasing energy and material costs. Effective use of processing circuits and equipment is a must in these environments when even small increases in throughput can amount to millions of dollars in added revenue.

Expert systems using rules–based fuzzy logic control allow existing operations to increase their throughput by as much as 6% after installation and tuning. Expert systems technology and the incorporation of fuzzy logic have earned a reputation for robustness, sustainability and flexibility within the minerals industry. A well-designed and installed expert system will reduce gross operator error, stabilize existing or future processing circuits, and optimize product quality and throughput.

With decades of practical experience and a unique depth and breadth of operational expertise, SGS understands your plant processes. We have completed over 90 successful installations across the globe, and can help push your processes to new levels of performance and optimization. Our proven 3-step methodology seeks to extract best operating practices from your personnel, program it for automatic decision making and combine it with our in-house expertise. The result is a product that encompasses your operating philosophy and reinforces the operators' confidence and beliefs. SGS expert systems are always on duty, optimizing your output on every shift.



ABOUT SGS

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To meet the challenges of the minerals sector, we are constantly expanding our service offering across our global network of industry experts and cutting-edge facilities - delivering competitive advantage to you at every stage.

At the exploration stage, we offer a wide variety of services, including geochemical testing, resource calculations and Technical Reports, geometallurgy, scoping studies and flowsheet development, piloting and environmental services. Our specialists are on hand to advise you the most suitable technologies for your project and provide data and flowsheets to help progress your project.

For start-up and operational mines, SGS provides a comprehensive suite of services covering on-site laboratories, water treatment, commissioning and in-plant operational support, process consulting, debottlenecking, equipment optimization and expert systems. Our advanced systems expertise can help you to be more successful by developing and implementing technology-enabled solutions.

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