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A proposal for determining fall of ground potential risk in underground mines through numerical QA/QC and geotechnical risk rating method

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Abstract

Fall of ground (FOG), a prominent catastrophic risk in underground mines, poses a significant threat to the underground personnel, production, equipment, and company finances and reputation. Mining companies employ various methods and techniques to prevent and critically control these risks. These include safety by design, excavation methods, ground support, training and competency, all of which necessitate quality control (QC) and quality assurance (QA) activities to verify their efficiencies and performances and to identify areas for improvement through monitoring.

Many mining companies use QC methods without QA, often referring to them as QA/QC. However it is crucial to understand that QC detects defects while QA prevents defects. Both approaches are essential for a comprehensive risk assessment strategy.

Testing the final products at the end of the production line differs from the proper QA/QC application, which involves testing every component before assembly, and the final product once completed, and managing all activities by allocating resources for ultimate efficiency and to prevent defects.

Installed ground support elements are some final products mining companies use to prevent FOG. Testing the final product (i.e. rockbolt pull test, shotcrete strength test) with QC methods only while those areas are already accessible is not like testing an aeroplane full of passengers right after it comes off the production line or testing a car after the sale. Can mining companies set their acceptable quality limits (AQL)? Can only QC methods be called QA/QC? Can QA/QC activities be numerically scored for each critical control implemented to assess FOG potential? Can numerical scores be used to identify the geotechnical risk rating (GRR) to determine the FOG risk and its probability?

This paper introduces a specific QA/QC methodology designed to manage and confirm the efficiencies and performances of the implemented critical controls. It also presents a unique numerical approach utilising the GRR process to assess potential FOG risk. The aim is to identify the areas where proactive action is needed and evaluate the probability of FOG in underground mines.

Keywords: *geotechnical risk rating, fall of ground, quality assurance, quality control, underground*

1 Introduction

Quality management (QM) is critical in any industry to ensure that products meet or exceed customer expectations while decreasing cost without compromising safety. QA and QC are two fundamental elements within the broader field of QM. While the terms are often used interchangeably, their strategies, processes and objectives differ significantly. This analysis has explored the nuances between QA and QC, providing insights into their development and methodologies, and the potential for their future integration. As industries continue

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to evolve, so will the strategies employed to ensure the quality of products and services, potentially leading to more sophisticated integrated approaches to QM.

This paper aims to dissect these differences and propose a new system to numerically assess QA and QC activities for underground mines to determine the probability of the fall of ground (FOG) potential. The proposed numerical method can also be adapted to assess any risk in any industry for any product.

2 Historical background

The quality movement can trace its roots back to medieval Europe, where craftsmen began organizing into unions called guilds in the late 13th century, which were responsible for developing strict rules for product and service quality, and inspection committees enforced the rules by marking flawless goods with a special mark or symbol (ASQ n.d.). The most significant shift in QC practices occurred with Shewart's (1931) introduction of statistical quality control techniques in the 1920s. His approach relies heavily on the statistical detection of defects, primarily in the finished product, aiming to filter these out before the product reaches the consumer. As this paper explains, the author thinks such methods based on only QC without QA have no chance to flourish and lose efficiency over time.

QA emerged prominently in the mid-20th century, influenced significantly by the work of quality pioneers including Deming (1986) and Juran (1999). QA focuses on preventing defects through a continuous process improvement approach and systematic activities, including method standardisation, staff training, and product design improvements. Collectively, this enhances the overall quality of outputs without focusing on inspecting the final product (International Organization for Standardization [ISO] 1999).

3 Philosophical and operational differences

QA is proactive, focusing on preventing problems through planned and systematic procedures including documentation standards, procedure standards and audit controls. In contrast, QC is reactive, aiming to identify and correct finished product defects through inspections and testing.

QA's preventive nature allows for a reduction in production costs and increases in consumer confidence due to consistently higher quality products. It fosters a quality organisational culture where continuous improvements are encouraged and emphasised (Quality Digest 2009).

Implementing QA can be resource intensive, requiring significant investment in training and developing comprehensive quality systems. Moreover, the benefits of QA practices may take time to be visible as the focus is on long-term quality improvements and requires management-level direct support.

QC delivers tangible, immediate results by spotting defects before products are delivered to customers. This safeguards the consumer and the company's reputation. QC is also relatively less expensive and easier to implement than comprehensive QA systems.

The major drawback of QC is its focus on end-product evaluation, which may allow systemic production errors to persist. It also relies heavily on inspection and testing, which can be costly if excessive.

Both QA and QC have their respective strengths and weaknesses, tailored to different aspects of the QM spectrum. QA's system-wide approach offers a holistic strategy focused on preventing errors. In contrast, QC provides a more targeted, immediate method of detecting and correcting product defects before they reach the consumer.

4 Fall of ground risk in underground mining

The mining company's primary target is to meet production objectives safely. Understanding and managing exposure to the highly complex hazard of rock failure is crucial to ensuring people's safety. This complexity has led to the development of numerous advanced tools, methods, and sophisticated computer models to address these hazards.

Given the abundance of available resources and the high stakes involved, site geotechnical engineers and responsible managers can quickly feel overwhelmed by the challenge of controlling a phenomenon that cannot be measured with certainty, is subject to constant (often immeasurable) changes and poses significant risks to human life (Potgieter & Grubb 2019).

5 General QA/QC applications in underground mining

Many mining companies employ QC methods to prevent, assess and critically control ground collapse; a failure mostly referred to as FOG risk potential caused by underground excavations. It is crucial to note that these are distinct from QA activities, and understanding their boundaries and limitations is critical to practical implementation.

Despite the availability of several ground support systems and elements in the industry, mining companies primarily depend on two types of ground support: sprayed concrete and wire mesh as surface support and rockbolts as tendon support. These systems reinforce underground excavations and play a crucial role in preventing potential FOGs, instilling a sense of security in our mining practices.

Many mining organisations consider a separate QA/QC department unnecessary and expensive. This may be correct for small organisations but certainly is not valid for a larger mine that installs 30,000 rockbolts and sprays 6,000 m^3 of shotcrete a month. If this is the case, the question is, 'What is the correct percentage of the required QC tests for the organisation's final products that quality should meet?'

Determining the sampling quantity required to represent the entire batch without comprehensive statistical data is difficult. However, as a rule of thumb with no scientific base, 10% of random sampling is considered enough to represent the entire installation throughout the month. Given that some very large mining operations install 30,000 rockbolts in an average month, the calculation in Table 1 shows the required headcount and time to achieve that.

Table 1 Example of required headcount for installed rockbolts' quality control (QC) testing in a very large mining operation

Installed rockbolts per month	QC test target	Required QC tests per day	Required time (minute) per QC test	Required time (hours) per day	Shift work hours per day	Required headcount per day
30,000	10%	100	15	25	8	3.125

Even testing an installed rockbolt often takes more than 15 minutes, given that the above number of ~3 persons dedicated to testing installed rockbolts daily will be considered unattainable by many mining organisations. In addition, the above is only for installed rockbolts; the other ground support elements (shotcrete, wire mesh, cable bolts and grout) still require QC testing.

The mine technical team's first reaction will be to reduce the sampling quantity to as low a number as possible to make testing achievable. Reducing the sampling quantity is not wrong but requires the science of QA/QC behind it; otherwise the testing activity becomes just a ticking box.

On many occasions QC tests are conducted on the ground support elements installed some time ago. Suppose the QC test on the already installed ground support indicates a defect and the area is a primary access road or, worse, a busy intersection. In that case additional measures will be required to assess the risk. Given that the installed ground support has a defect and cannot perform as expected to prevent FOG, the area will require additional inspections and assessment. In the end someone needs to make the call to barricade the area or leave it open. Each decision brings separate consequences and complications.

All the above mentioned scenarios have occurred or are currently unfolding in many underground mines. It is akin to testing an aeroplane full of passengers right after it comes off the production line, or a car after the sale, and then trying to return it to safety. However, any compromise in QC practices can lead to significant economic and reputational disturbances within the business, underscoring the urgency and importance of QA/QC roles in the mining industry.

6 Proposed QA/QC applications in underground mining

This section proposes and discusses a new QM system (QMS) for mining operations.

The mining organisation's first steps should be to separate the QA and QC activities, set acceptable quality limits (AQL) and combine them under a QMS umbrella.

Considering the mining industry's current level of need for a QMS compared to that of the civil infrastructure industry, a significant evolution is required. When an organisation focuses primarily on a robust QMS, the costs will initially rise. Still, the quality will improve over time, the overall cost will decrease and ultimately, organisational reputation will improve.

Despite being the results of years of hard work, the proposed method is surprisingly straightforward.

As a first step a mining organisation can set its AQLs for each activity to be used as a critical control checkpoint and specify when and how the frequency of those checks will be changed according to QC check switch rules, as demonstrated in Figure 1 as an example.

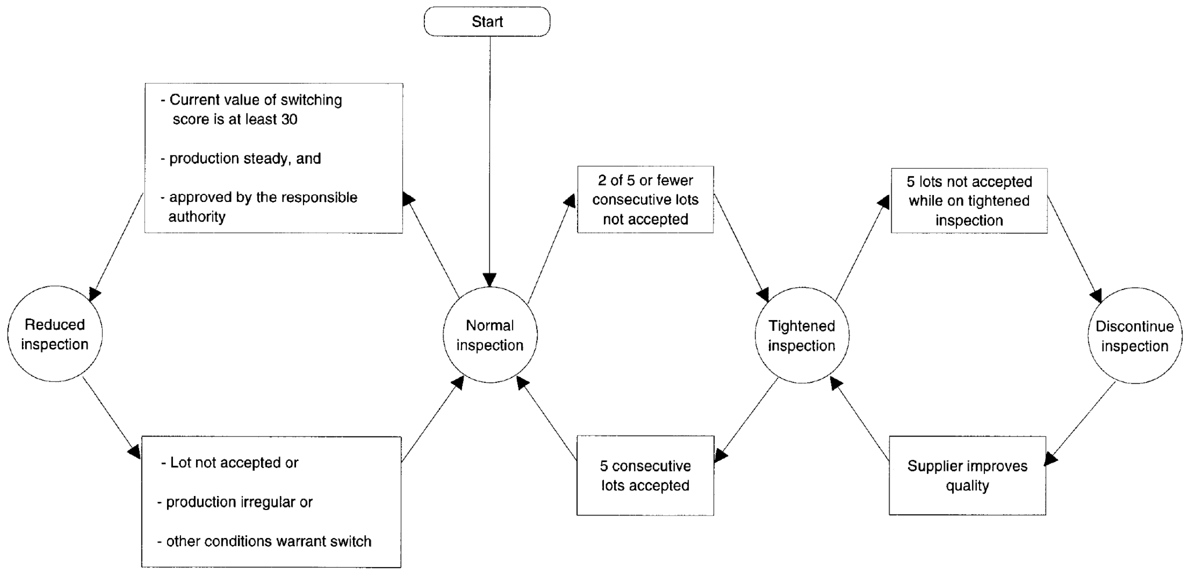

Figure 1 Quality control check switch rules (ISO 1999)

- **Lot:** A group of checks, as far as practicable. It consists of items of a single type, grade, class, size and composition, all manufactured under uniform conditions with essentially the same conditions (i.e. pull tests performed on the same bolts installed by the same equipment and personnel under the same conditions).
- **Normal to tightened:** When the normal inspection is carried out, tightened inspection is to be implemented as soon as two out of five (or fewer than five) consecutive lots have been non-acceptable on the original inspection (ignoring resubmitted lots or batches for this procedure).
- **Tightened to normal:** When the tightened inspection is carried out, normal inspection is to be reinstated when five consecutive lots have been considered acceptable during the original inspection.
- **Normal to reduced:** When normal inspection is being carried out, reduced inspection will be implemented if all the following conditions are satisfied:
    - The current value of the switching score is at least 30, meaning 30 lots have passed and been accepted.

- ○ Production is at a steady rate.
- ○ Reduced inspection is considered desirable by the responsible authority.

- **Reduced to normal:** When reduced inspection is being carried out, normal inspection will be reinstated if any of the following occur on the original inspection:
  - ○ A lot is not accepted.
  - ○ Production becomes irregular or delayed.
  - ○ Other conditions warrant that normal inspection will be reinstated.
- **Discontinuation of inspection:** Suppose the cumulative number of lots not accepted in a sequence of consecutive lots on the original tightened inspection reaches five. In that case the acceptance procedures should not be resumed until the supplier has taken action to improve the quality of the submitted product or service. The responsible authority has agreed that this action is likely to be effective. Tightened inspection will be used as if 'normal to tightened' has been invoked.

The quantity of accepted or not accepted lots mentioned in Figure 1 are for a start only and can be changed and modified depending on the quality score.

The QA/QC switch rules are to manage resources efficiently for where QA/QC needs to be more focused. The AQL is a parameter set according to the organisation's risk appetite. It should not be confused with the process average, which describes its operating level. Under this system the process average is expected to be better than the AQL to keep quality at the desired level.

Since AQL is a numerical variable, the corresponding variable must also be numerical, hence the QA/QC score.

The author hypothetically created QA/QC checks, frequencies, AQLs, and weight percentages for a stope mine named 'X mine' to better explain the proposed system.

X mine is a stoping operation that requires robust planning and design work and uses backfill. The system proposed by the author in Table 2 is designed for the geotechnical department. It considers the mine design/study and operational aspects but is not limited to these.

Table 2 Proposed numerical QA/QC scoring system with set acceptable quality limits (AQL) for X mine (continued next page)

Area	Class	Activity	Reduced frequency	Normal frequency	Tightened frequency	Weighting	Score 1 or 0	Result	AQL
Mine design	QA	Geological block model – update	Quinquennial	Triennial	Annually	25.0%	1	25.0%	16.5%
	QA	Structural model – update	Quinquennial	Triennial	Annually	10.0%	1	10.0%	6.6%
	QA	Hydrogeological model – update	Quinquennial	Triennial	Annually	10.0%	1	10.0%	6.6%
	QA	Geotechnical block model –update	Quinquennial	Triennial	Annually	25.0%	0	0.0%	16.5%
	QA	Geotechnical numerical model – mine scale	Quinquennial	Triennial	Annually	20.0%	0	0.0%	13.2%
	QA	Geotechnical procedures – review	Triennial	Annually	Semi-annually	10.0%	1	10.0%	6.6%
								55.0%	66.0%
Ground support	QA	Material procurement – contract technical review pre-bidding	–	Contract	–	2.0%	0	0.0%	1.3%

Area	Class	Activity	Reduced frequency	Normal frequency	Tightened frequency	Weighting	Score 1 or 0	Result	AQL
	QA	Material procurement – contract technical review post-bidding	–	Contract	–	4.0%	0	0.0%	2.6%
	QA	Design basis – review	Triennial	Annually	Semi-annually	15.0%	0	0.0%	9.9%
	QC	Material supply – raw material	Quarterly	Monthly	Biweekly	2.0%	0	0.0%	1.3%
	QC	Material supply – manufacturing	Annually	Quarterly	Monthly	2.0%	0	0.0%	1.3%
	QA	Material supply – storage (factory)	Annually	Semi-annually	Quarterly	2.0%	0	0.0%	1.3%
	QA	Material supply – transport	Annually	Semi-annually	Quarterly	2.0%	0	0.0%	1.3%
	QA	Material supply – storage (site)	Annually	Quarterly	Monthly	2.0%	1	2.0%	1.3%
	QA	Installation – operator training and competency	Triennial	Annually	Semi-annually	5.0%	1	5.0%	3.3%
	QA	Installation – equipment regular maintenance	Quarterly	Monthly	Biweekly	5.0%	1	5.0%	3.3%
	QA	Installation – equipment audits	Quarterly	Monthly	Biweekly	5.0%	0	0.0%	3.3%
	QA	Validation – regular inspections	Quarterly	Monthly	Biweekly	5.0%	1	5.0%	3.3%
	QC	Validation – regular laboratory and in situ tests	Quarterly	Monthly	Biweekly	49.0%	1	49.0%	32.3%
								66.0%	66.0%
Backfill	QA	Design basis – review	Triennial	Annually	Semi-annually	15.0%	1	15.0%	9.9%
	QC	Material supply – raw material	Quarterly	Monthly	Biweekly	5.0%	1	5.0%	3.3%
	QC	Material supply – producing	Quarterly	Monthly	Biweekly	5.0%	0	0.0%	3.3%
	QC	Material supply – reticulation	Quarterly	Monthly	Biweekly	5.0%	0	0.0%	3.3%
	QA	Installation – operator training and competency	Triennial	Annually	Semi-annually	15.0%	0	0.0%	9.9%
	QA	Installation – equipment regular maintenance	Quarterly	Monthly	Biweekly	2.0%	0	0.0%	1.3%
	QA	Installation – equipment audits	Quarterly	Monthly	Biweekly	2.0%	1	2.0%	1.3%
	QA	Validation – regular inspections	Quarterly	Monthly	Biweekly	2.0%	0	0.0%	1.3%
	QC	Validation – regular laboratory and in situ tests	Quarterly	Monthly	Biweekly	49.0%	1	49.0%	32.3%
								71.0%	**66.0%**

The proposed system is simple. Each QA or QC activity has a check frequency, depending on switch rules and percentage weighting. Users need to enter the 'score' in the binary system, which can be either 1 if the check is completed or 0 if it is not completed or failed. The result will be compared as a percentage against the previously set AQL levels.

This system is also designed to guide the user on where to focus on improving quality, but more is needed as these are individual QA/QC activities, as seen in Table 2. Completing these checks alone cannot satisfy the overall AQL level for the total QMS, as shown in Table 3. Table 3 requires the user to input the average QA/QC score from each area activity in Table 2.

Table 3 Proposed total quality management system scoring

Area	Weighting (%)	Score (%)	Result (%)	Acceptable quality limit (%)
Mine design	20.0	55.0	11.0	13.2
Ground support	55.0	66.0	36.3	36.3
Backfill	25.0	71.0	17.8	16.5
			65.1	66.0

The author acknowledges that while drill and blast (D&B) design and execution are other significant factors that might result in FOG, they are not included in this paper as D&B alone is a complex underground mining activity that requires detailed research in order to implement an adequate QMS. Nevertheless, the designed and installed ground support system must deal with the potential FOG caused by the poor D&B design and execution.

Given that a FOG is likely to be caused by inadequate mine design, ground support or backfill considerations, the geotechnical risk rating (GRR) (based on the final score of the QA/QC activities against the AQLs) is to provide a numerical assessment tool to the user so they can determine the area where additional attention is required and assess the overall probability of a FOG potential, either for a specific area where checks are completed or for the entire mine where all checks are included. The schematic representation of the GRR is shown in. Figure 2

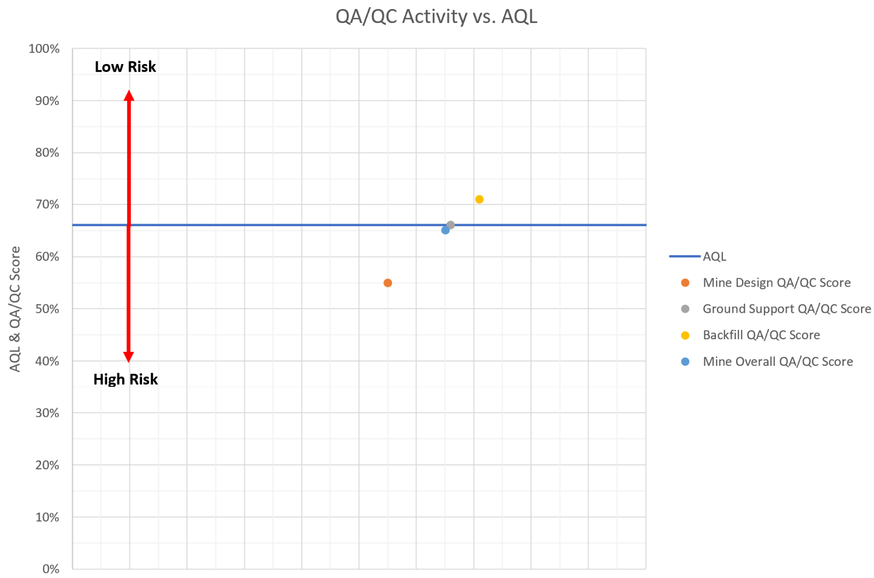

Figure 2 Proposed schematic representation of the geotechnical risk rating based on QA/QC scoring and acceptable quality limit (AQL)

The AQL limit of 66% is based on the weight given for each area activity in Table 3, using the organisation's risk appetite as an example. This method allows organisations to assess whether or not their AQLs are set for soft targets (i.e. lower than 50%).

7 Conclusion

QM is critical in any industry. It ensures products meet or exceed customer expectations while decreasing cost without compromising safety. QA and QC are two fundamental elements within the broader field of QM.

Considering the mining industry's current level of need for a QMS compared to that of the civil infrastructure industry, a significant evolution is required. When an organisation focuses primarily on a robust QMS, the costs will initially rise. Still, the quality will improve over time, the overall cost will decrease and, ultimately, organisational reputation will improve.

Both QA and QC have their respective strengths and weaknesses and are tailored to different aspects of the QM spectrum. QA's system-wide approach offers a holistic strategy focused on preventing errors. In contrast, QC provides a more targeted, immediate method of detecting and correcting product defects before they reach the consumer.

An integrated system could combine QA's comprehensive, preventive nature with QC's immediate, corrective actions, leading to more robust, efficient, and cost-effective QM practices.

The mining organisation's first steps should be to separate the QA and QC activities, set AQLs and combine them under a QMS umbrella.

The numerically scored QA/QC activities are a powerful quantitative tool for the end user in assessing the safety of every related activity in and around the mine, from feasibility to mine closure.

Although the proposed QMS must be tested in an operational mine with all possible aspects, the GRR based on the final score of the QA/QC activities against the AQLs can be used as a numerical assessment tool to determine the areas where additional attention is required and assess the overall potential risk probability either for a specific location or for the entire mine, or projects.

The future of the proposed QMS could see further integration with a leveraging technology such as Artificial Intelligence (AI) and data analytics to predict and prevent quality issues before they occur. AI can significantly enhance QA and QC processes by enabling predictive and prescriptive analytics. AI algorithms can analyse historical data to identify patterns and predict potential quality issues before they occur. For example, machine learning models can be trained to recognise process defects by analysing all available data and identifying anomalies that could lead to quality failures.

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