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THE PROGRESSION AND CHALLENGES IN THE IMPLEMENTATION OF A WASTE MANAGEMENT SYSTEM

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Abstract: This paper presents insights generated from an ongoing client-pilot program that is exploring how the Integrated Tailings Management System (HITMS), a digitally integrated software system developed to improve the workflow of Tailings Management Facilities by connecting data throughout the Tailings lifecycle, leading to greater coordination and operational excellence. While the industry tends to focus on specific moments in the tailings lifecycle, the development and implementation journey of HITMS revealed that much stronger and distinct value can be generated by connecting all aspects of Tailings Management in real-time, from dewatering and transport to deposition and storage, combining the Global Industry Standard on Tailings Management (GISTM) and custom performance protocols. By implementing the system at two geographically and culturally unique sites, HITMS is able to showcase how it can address the distinct needs of one site, while also having standardization that allows for the understanding and eventual rollup for a portfolio of sites. HITMS provides a comprehensive suite of tools to manage, integrate, and visualize field data, monitor asset performance and operating thresholds, optimize job scheduling, and ensure improved regulatory compliance. The challenges encountered include data integration and migration, integration of existing workflows and systems, implementation of a holistic approach, user experience and resistance to change, amongst others. During implementation, digital and tailings technical teams engaged with the pilot clients with the aim to solve their operational challenges and ensure that the experience can be extended to other tailings facilities. As the system is being implemented, modules have been developed with the required functionalities to provide a flexible system that can be managed and customized by the user.

INTRODUCTION

Tailings Storage Facilities (TSFs) remains a paramount challenge in the mining industry. Given the multifaceted interactions among various operational aspects, TSF management carries an inherently critical aspect of operational success. The complexity of TSF operations is exacerbated by the interaction of processes, which further increases asset and operational risks. Historical incidents underscore the criticality of addressing operational factors contributing to tailings failures, with a substantial portion attributable to human error, inadequate planning, insufficient or misinterpreted data, and suboptimal safety culture. These factors play a vital role in preventing structure failures and ensuring environmental and social sustainability.

Today's mining operators are seeking innovative and cost-effective solutions to minimize such risks, which may result in severe social, economic and environmental impacts on the industry and surrounding communities.

In addition, with the introduction of the Global Industry Standard on Tailings Management (GISTM) 2020, mining companies are attempting to implement the standards which will provide best management practices and, as a result, advanced understanding of the TSFs' failure modes. Based on our experience, this implementation comes with a significant transformation from the current management practices.

To accomplish such advancements, the creation of the HITMS was underpinned by a digital system that integrates a holistic approach to tailings management practices. This study presents the strategic objectives for which the system was created, and the implementation journey selecting two site pilot programs at mining sites with different profiles, diverse geographies, cultural background, and commodities. This approach aimed to gather comprehensive insights from operations

to enhance and enrich the system, which may be universally applied to tailings operations.

The implementation phase encountered challenges inherent to tailings management operations. As a result, the system was adjusted, refining and creating modules that target these challenges.

THE OBJECTIVES

The digital system is a collaborative effort between tailings management practice engineers and software developers. Identifying key objectives from the beginning of a multi-annual effort was crucial to achieve optimal outcomes from the proposed system. The tailings team has a focus on a holistic approach that set the basis for the technical objectives, in additional to several technological and organizational aspects, with the ultimate aim of benefiting tailings management from the operator's perspective. These were:

- Enhanced safety and reliability of TSFs.
- Improved operational effectiveness and efficiency.
- Strengthened governance and compliance.
- Sustained social license to operate within communities, and.
- Software data security and privacy.

The following objectives encompasses the approach and focus:

RISK MITIGATION AND SAFETY ENHANCEMENT

- Prioritize safety by proactively identifying risks throughout the tailings lifecycle, ensuring comprehensive risk assessment at every stage.
- Mitigate risks by focusing on the understanding of the critical controls and implement robust early warning systems.
- Ensure adherence to safety standards and regulations to maintain compliance and minimize risks.

EFFICIENCY ACROSS THE LIFECYCLE:

- Streamline processes from tailings dewatering, transport, deposition and water reclaim, from decommissioning to post-closure.
- Optimize water usage, swift incorporation of water reclaim and effluent treatment technologies and external sources reliance reduction.
- Foster operational excellence through efficient management practices.

REGULATORY COMPLIANCE:

- Implement a robust system for Self-assessment compliance with the Global Industry Standard on Tailings Management (GISTM).
- Track progress toward full compliance targets using a tried-out audit management tool.

TECHNOLOGY INTEGRATION:

- Seamlessly integrates with existing infrastructure (e.g., PI systems, data loggers).
- Utilize cutting-edge IT/OT protocols for data connectivity to ensure efficient communication amongst the system.

INTEGRATED MONITORING AND INSIGHTS:

- Convert raw sensor data into practical and actionable metrics.
- Enable real-time data monitoring, scalability as needed, and receive alerts to prevent potential issues.

ENHANCE CIRCULAR ECONOMY APPROACH:

- Efficiently and strategically manage tailings deposition.

- Mechanisms to track deposition plans aligned with the "Life of Mine" plan.

CUSTOMIZATION FOR SITE-SPECIFIC NEEDS:

- Tailor the solution to accommodate variations across diverse tailings facilities.

- Address unique operational requirements-specific to each site.

TRANSPARENCY AND STAKEHOLDERS ENGAGEMENT:

- Provide agreed public access to real-time relevant information for stakeholders.

- Engage transparently with stakeholders, including communities, regulators and investors.

LONG-TERM SUSTAINABILITY

- Balance economic expectations, capital costs, and operational costs to ensure long-term sustainability.

- Foster a culture of adaptability and continuous improvement to meet evolving standards and best practices.

In summary, a comprehensive digital solution offered by HITMS shall combine advanced analytics, flexibility, and risk reduction strategies to ensure sustainable and safe tailings management practices.

PILOT DEVELOPMENT

PILOT SELECTION

As an integral part of HITMS development, a pilot program was initiated by collaborating with established clients. The purpose was twofold: ensuring that the software functionalities and elements align closely with real operational needs and incorporating diverse operational elements into the system.

The clients have been selected considering various influencing factors and aspects on tailings facilities operations, such as:

- Geographies – cold and warm climate to capture operational nuances influenced by different environmental conditions.

- Technical requirements - Seismic region and commodities.

- Storage facilities in closure and operations.

- Level of instrumentation – manual vs automated.

- Organizational – small vs large vs complex operation.

This variability of operational factors has greatly enriched the pilot program, enhancing its value by enabling the capture of a wide array of operational requirements to be incorporated into the system and provide more comprehensive results.

CURRENT OPERATION ANALYSIS

The pilot program was structured from three pivotal pillars: technical, technological, and organizational.

From the technical point of view, these structures are well known to us as many parts of the tailings facilities have been designed by our Tailings Practice team. Therefore, the development team has focused on understanding the technicalities around the design and operations of the tailings facilities from the

dewatering, transport, and storage components' perspective. It has also considered the level of instrumentation and inspections based on both the Operation, Maintenance and Surveillance Manual (OMS) and the governance framework that the current operations adhere to within the GISTM framework.

The technological team was focused on the understanding of the level of automation of the facilities and data integration into the system. The team has also aimed to understand the existing way of managing data and how it is used for decision making. Additionally, discussions with Information Technology representatives from the clients provided a comprehensive knowledge of the systems connectivity and the data transfer.

As for the organizational aspect, the focus has been on analyzing and comprehending the existing organizational structure of the TSF, as the system has been developed to support operations. Additionally, it provides an overview of the status of the facility at all levels of the organization with the focus of minimizing the resistance to change from all levels.

ORGANIZATION OF THE WORK

A client-centric approach was prioritized throughout the development of the HITMS, placing pilot clients at the core of a comprehensive analysis. To fully understand all facets of their operations and requirements of all responsible parties, routine engagements were conducted with the operations teams and executives.

In addition, the development team conducted on-site visits that encompassed walk arounds, interviews, and briefings to make sure that all three pillars of the analysis would be well understood.

Overall, the work was structured in the following phases:

- Understanding of the existing operations and level of monitoring: Interviews and site visits were conducted to grasp the operational challenges and prevailing practices for operating the TSFs.

- Identifying operational deficiencies: Gap analysis exercise against best management practices. Collaborating with the operational team, optimal site-specific management practices for sites.

- Develop operational tools to tackle deficiencies: solutions development that can be seamlessly implemented and bring tangible value to operation efficiency.

THE CHALLENGES

Several challenges emerged during the development and the HITMS. Most of which were in the field of technical, technological, and organizational practices, where led to a noticeable disconnection between TSF operations and the overall lifecycle of tailings.

DATA INTEGRATION AND MIGRATION

Migrating data from existing digital or manual systems to the software may be complex. Inaccurate or incomplete data can hinder successful implementation. Challenges often faced during data migrating include:

- Availability and location – data required for the new system would be typically found fragmented, if not scattered across different databases and legacy systems, or even exist solely in paper records.

- Quality and accuracy – inaccurate or incomplete data can lead to incorrect insights and decisions.

- Format and standardization - data originating from various sources may have diverse formats and standards, making integration complex.

- Lack of common data understanding – variations in interpreting data among different stakeholders may affect system design and usage.

DISCONNECTED PROCESSES

Previous TSF disasters have demonstrated to both designers and operators that the stored tailings mass management within impoundment and stacks, the structural integrity of the retaining structures, the understanding of the chemical composition changes of the tailings and the side-wide water balance were evaluated in silos without a common integration. Unfortunately, this appears to be more the norm than the exception.

This disconnect has resulted in TSFs lacking adequate analysis of the critical controls, which are put in place to prevent the identified failure modes. Despite the existence of such controls, the absence or failure of a critical control element could significantly escalate risks within the structure.

Moreover, despite control levels being an integral aspect throughout the tailings lifecycle -encompassing milling, dewatering, transport, and ultimately the storage space within the TSF-, these are often overlooked.

Reality is that in today's current operations across the industry, the following is put forward:

- The process plant concentration drives dewatering and transport tailings to meet production demands.

- Modification on dewatering inputs that can potentially generate repercussions downstream (transport and deposition), are not well comprehended leading to sub-standard decisions.

This approach underscores the necessity for a tool that integrates all life cycle of tailings to ensure cohesive and informed decision--making.

POOR INSTRUMENTATION

Mining companies have on their own, or under the advice of consultants, implemented various types of instruments and engaged with different suppliers to gain a thorough understanding of the potential failure modes of the TSF. In many cases, staff turnover diverged strategies, or inadequate advice from suppliers/consultants have led to the installation of non-compatible instruments and systems that cannot properly transform the data into information. Consequently, this mismatch hinders the capacity to make informed decisions.

Furthermore, the installation of a supplier's software that provided visualization tools for their instruments, lack integration with existing other visualization tools already in place at the operation. This creates an additional effort from mining operators to gather information from scattered data and sources. For this reason, a centralized, agnostic platform becomes imperative for operations.

LACK OF PLANNING

The mining world is evolving, prompting projects to aim and reuse tailings from current or decommissioned TSFs by employing new technologies. This is driven by the shifting demands, cost dynamics, and ore availability, which calls for a circular economy within tailings management.

However, the current reclamation of tailings lacks complete understanding in terms of the required ore's location, as the deposition plans were not tracked or linked to the Life of Mine Plan (LOM), historically speaking. Consequently, this absence of detailed comprehension often compels expensive characterization campaigns of the TSF, resulting in cost and resource allocation. There is a need for a more efficient reuse and implementation of the circular economy; therefore, there is an imperative need for a system capable of tra-

cking deposition against planned strategies for a proper business plan to mature when the matter is to repurpose tailings. This would ensure an informed and cost-effective approach to TSFs utilization.

POOR OPERATIONS AND SURVEILLANCE SYSTEM

As a continuous evolving system, TSFs and its associated infrastructure requires control under an operation, maintenance, and surveillance manual (OMS). Nonetheless, operators encounter challenges that impede the effective execution of OMS:

- Insufficient tools for field inspections and data recording. This shortfall leads to unreliable data sets or inaccurate information.

- Untrained personnel lacking understanding of TSF global facility management often fail to gauge the severity of observations. This gap may potentially lead to underestimated observations or ranked deficiencies.

- Centralized reporting tools have not been provided to users to facilitate task and information is transferred in systems that do not keep track record.

The deficiencies outlined above significantly impede a well-rounded implementation of the OMS, ranging from simple observations to comprehensive tracking and reporting.

The Mining Association of Canada (MAC, 2019) highlights the critical role of OMS as follows, "The development and implementation of OMS activities, described in a site-specific OMS manual, is essential to implementing a tailings management plan, meeting performance objectives, and managing risk. Companies that do not effectively implement OMS activities cannot adequately understand their risks, proactively manage tailings, make informed decisions about tailings management, or have any assurance that tailings and associated risks are being effectively managed".

LACK OF GOVERNANCE

Reputable companies have concentrated efforts in recent years to adhere to the requirements stated on the GISTM conformance protocols. The commitment aims to manage TSF risks and strive to achieve zero harm to both people and the environment. Encouragingly, recent press releases indicate a positive outcome, meanwhile many mining entities are on the verge of achieving full compliance with GISTM.

For this path to GISTM auditing and compliance, all requirements stated in the standard need to be met. Moreover, implementing a centralized tool that synthesizes all GISTM requirements in a single interphase would facilitate monitoring and auditing progress towards attaining full compliance.

RESISTANCE TO CHANGE

If a centralized digital solution is compared to the more manual or scatter operational tools for tailings operations can create organizational resistance as it can be seen as a change in operations and a learning curve to apply the new system. The challenges identified in this transformational space include:

- Traditional mindset and familiarity.

- Fear of job disruption.

- Trust of automated processes.

- Data security and privacy concerns.

- Time needed to make the change.

- Legacy processes and inertia; and;

- Unclear company goals.

INTEGRATION WITH EXISTING WORKFLOWS

Current operational workflows in many tailings facilities will be in legacy system or even manual processes. These workflows, over time, have become customary practices rather than explicitly defined procedures, which might pose challenges to:

- Understanding of workflows as a routing activity.
- Disruption of operations; and;
- Customization and fit for purpose.

CUSTOMIZATION FOR SITE-SPECIFIC NEEDS

Developing a system capable of accommodating diverse operational requirements while ensuring seamless integration across facilities can be complex, especially when the integration is trying to customize the requirements to then escalate them to other TSFs. As different operations are studied, it is possible to notice that, there are numerous factors that contribute to the complexity of customization, including:

- Diverse site conditions – Each mining site has unique characteristics (geology, climate, topography).
- Cultural differences – based on the location or legacy operations, different approaches to operations and safety culture can create gaps in the requirements.
- Regularity compliance – Different regulatory bodies and compliance standards.
- Training and skilled labour force – available in-house personnel for training and deployment of the system.
- Cost management – high degree of customization can lead to high cost of the system.

THE SOLUTION

The development team understood the challenges of implementing modern technologies for tailings management during the pilot phase. They designed an integrated system that not only solved the existing problems, but also improved the user's process and experience. This system was the outcome of the cooperation between skilled specialists in mine waste and water management, the digital team, and the active pilot clients. The system reflected a vision for holistic tailings management, covering every aspect and dimension of mine waste management throughout its life cycle. Moreover, the system also eliminated unnecessary processes that were the result of system limitations, rather than user needs, and streamlined the workflow for optimal efficiency and effectiveness.

This approach is essential to meet the rising expectations of regulators and the pursuit of operational excellence, as it offers operators a holistic, data-driven, and technology-enabled way of managing tailings effectively.

The solution simplifies the work of tailings management by using advanced analytics and a configurable platform. It connects our technology with any TSF operator's existing infrastructure and monitors data in real-time. It also alerts the operators of any potential issues and helps them prevent them. The solution focuses on what is important by making straightforward the standard criteria of GISTM. It gives the operators and decision-makers a clear and comprehensive view of the entire TSF operation. It also guides them to comply with the criteria and meet the audit requirements. The solution is a web-based software that can be easily deployed in any operation, regardless of its size or scale. It tracks all the aspects of tailings operations in real-time and provides insights for improvement.

CORE ELEMENTS

The following core elements have been developed to address the challenges and deliver the desired tailings management tool. These elements are interconnected, forming a comprehensive framework for TSF management.

A brief description of each core elements with its primary features is presented below:

Data Engine

To solve the challenge of data migration and integration, a built-in data engine has been designed to set up and manage all device connections within a single platform. The connectivity to the Edge device leverages Google Cloud Platform. Once the data is acquired it is processed in Azure providing a secure platform and preparation for use with the latest AI services. Data preparation requires end users the flexibility to manage data coming into the system as not all sources of data are trusted by users or setup correctly. This includes:

- An Edge device for connectivity and processing speed.

- Selection of key tags needed, not all data from the device and adding attributes that make it easier for all users to understand (label, unit type, description).

- Custom calculations not done by the sensor (like hydrostatic water level from a piezometer).

The system must integrate manual data to be reliable and trustworthy, especially for historical data, device validation, or device downtime. This means dealing with different file data formats. Therefore the system has included a mobile field application to help users with their field work and inspections. To gain user acceptance, the system simplify and standardize operations with preconfigured actions and inspections. The system also minimize manual entry with one-click inspection reports. Furthermore, automatically linking manual readings to the right metric(s)

Integrated Monitoring

As part of the approach to solve the disconnected processes in many TSF operations, the solution was devised integrating all monitoring from a holistic point of view. As a result, the HITMS generates metrics, providing users with contextualized data to easily determine the appropriate action. The system will allow the user to:

- View the status of ad-hoc metrics in geospatial context.

- 2D and 3D visualization, including deposition areas, drone and satellite overlay. This could be also expanded into staged construction management for the containment earth structures.

- Location of sensor, manual data collection and inspections data.

- View metric visualizations / details and investigate warnings as needed; and

- Separate tracking of equipment data and the metrics where the data becomes easier to be understood and followed by all users.

Moreover, specific data models were created to track and monitor critical metrics across your site, such as Particle Size Distribution (PSD) deviation model, major weather even model, among others.

By consolidating multiple monitoring systems into one sole platform, the system will provide better reassurance and ease the transition process that generally arises with implementing new systems inside organizations.

Operational Management

To address the issues with poor operations performance against the OMS Manual, better understand compliance and ensure high operational standards. The system integrates an Operational Management module where the operational requirements of the OMS are captured in an easily accessible interface. Extracting the measurable metrics out of the OMS and being able to track operations against planned. The system will allow to:

- Integrate OMS manual with a predefined OMS structure (per MAC guidelines).

- Link to current OMS manual for reference as needed.

- Easy to view / export for reporting purposes.

Water Management and Deposition Management

The primary goals of the system is to provide insights to support decision-making processes, crucially needed due to the identified challenge of inadequate planning.

With the introduction of a real-time water management module and a deposition management module, operations can react promptly to situations while strategizing for future capacities, such as addressing recirculation issues.

- Easily track deposition in geospatial context and investigate warnings.

- Track deposition by area or tailings facility for each construction stage.

- Status of manual spigots (e.g., open / closed) can easily be entered via the field app or directly into the system.

Additionally, deposition management supports circular economy, tracking tailings deposition allowing, characterization of tailings for future reclamation.

Custom Applications

The challenges related to the system application across various sites and scalability have been addressed through the introduction of custom applications that provide flexibility for the user to visualize and manage the data accordingly.

By creating custom monitoring dashboards to bring together the metrics, insights, and other context you need for the TSF operations.

- Dashboards can be created for individuals or groups, or for specific purposes (e.g., EOR review, ITRB, etc.).

- Quickly and easily add metrics, insights, and other context, such as images, text, document links, etc.

Moreover, the system facilitates the integration of existing operational processes by allowing the creation of work items and workflows, ensuring seamless management and approval of significate changes within the system.

Auditing & Governance Standards

To address complexities associated with assessing compliance against the GISTM and tracking actions for adherence standards, a module aimed at tracking governance performance against the GISTM was created. This module provides a robust governance framework for all operations.

The system facilitates both internal or external GISTM audits and track progress towards compliance targets over time, by:

- Self-evaluate GISTM compliance based on evidence criteria developed by tailings experts.

- Launch audits and assign to internal or external auditors as needed.

- View breakdowns of compliance by topic and requirement.

THE RESULTS

The HITMS system has delivered valuable results by detecting and resolving issues that were previously unnoticed, especially in data management and quality, which improved decision-making processes. However, the system also encountered some challenges with the current data, process, and infrastructure, which required more time and effort to address. These challenges were also related to the change management aspect, as the system introduced new ways of working and thinking for the users. Despite these difficulties, the system has started to show its benefits and potential for enhancing tailings management.

The system has achieved the following successes with our pilot client:

- It connected all data sources with the system through the edge device.
- It consolidated all tailings information in one location.
- It generated insights from various data sets for early warning system.
- It handled notifications based on design intent.
- It integrated site wide water balance for optimal resource planning and environmental compliance.
- It provided dashboards for different organizational levels and roles.
- It linked to the current OMS manual.
- It made reporting easy and accessible.

The full pilot program will reveal more results, with the confidence that the system meets the expected value.

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