THE ROLE AND CHALLENGES OF DIGITAL TRANSFORMATION IN GEOTECHNICAL RISK MANAGEMENT IN MINING INDUSTRY

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ABSTRACT

Historically, the mining sector in Brazil and worldwide is one of the last to implement innovative processes and technologies in its operations. In the current Brazilian context, due to the catastrophes that have occurred in recent years, Risk Management of Geotechnical Mining Structures (pits, dams, piles, tunnels and other retaining structures) faces some basic challenges to advance on digital transformation process. These challenges are bottlenecks to the achievement of the main goal of promoting operational efficiency needed for a predictive management system and, consequently, delivering safer mining to society. Key bottlenecks include: superficial risk assessment with ineffective controls; poorly defined processes with ineffective data entry and delivery; superficial indicators (data), lack of data engineering concepts; many manual inputs throughout the process, culminating in many error inputs and inefficiency; and, ultimately and most important, inefficient, untraceable risk information and communication flows at all levels of corporate governance. The objective of this work is to present a methodology and case study applied to deal with these specific challenges in Risk Management of Geotechnical Mining Structures, using techniques already established in other sectors, as well as new technologies available and viable in the market. Specific objectives include: efficient risk analysis methodologies and practices for the identification and implementation of efficient controls; methodologies and practices for mapping effective processes; use of data engineering techniques for switching and correlation of indicators; elimination or reduction to acceptable levels of manual inputs throughout the process to promote team efficiency and optimization and, finally, use of applied technologies (software, sensors and equipment) that allow the systematization of data acquisition, correlation and interpretation, workflows and predictive and online risk indicator updating.

1. BACKGROUND

The process called “digital transformation” is a key element for companies to get inserted in the fourth industrial revolution, or industry 4.0, independently of the economic sector. According to Deloitte’s Managing Risk in Digital Transformation Report (2018), digital transformation brings forth unmatched opportunities and capabilities for growth and value creation. Furthermore, the report lists critical approaches for risk areas beyond traditional risk in order to meet the desired objective:

Contextual Risk: 1) Adequacy of selection of digital enablers of the digital program, in the context of business objectives 2) Setting the tone of risk management at the design stage of digital program 3) Prioritization of initiatives ensuring minimal impact or disruption of service.

Implementation Risk: 1) Risk-based architecture for the digital enablers, w.r.t. technology, operations, vendors, compliance, security and resiliency 2) Right digital technologies for different business processes 3) Culture of ‘digital mindset’ and a secure usage of the digital components

Governance Risk: 1) Effective governance around the Digital transformations to ensure cross functional synergies and eliminate risks arising due to inter dependent processes 2) Risk management framework that can be used by the organization for managing risks that may arise in any future digital initiatives

In another report, nine principles are listed as key points for Risk intelligent companies (Deloitte 2009):

1 MS, Engenheiro Mecânico – EMPRESA
2 PhD, Engenheiro Elétrico - EMPRESA
3 MS, Consultor - EMPRESA

- Common definition of risk, which addresses both value preservation and value creation, across the organization;
- Common risk framework supported by appropriate standards is used throughout the organization to manage risks.
- Key roles, responsibilities and authority relating to risk management are clearly defined and delineat ed within the organization;
- Common risk management infrastructure is used to support the business units and functions in the pe rformance of their risk responsibilities;
- Governing bodies (e.g. boards, audit committees, etc.) have appropriate transparency and visibility into the organisation's risk management practices to discharge their responsibilities;
- Executive management is charged with primary responsibility for designing, implementing and main taining an effective risk program;
- Business units are responsible for the performance of their business and the management of risks they take within the risk framework established by executive management;
- Certain functions (e.g. HR, finance, IT, tax, legal, etc.) have a pervasive impact on the business and provide support to the business units as it relates to the organization's risk program;
- Certain functions (e.g. internal audit, risk management, compliance, etc.) provide objective ass urance as well as monitor and report on the effectiveness of an organisation's risk program to gover ning bodies and executive management.

Bringing this context into Operations Risk Management, a well structured Risk Management Strategy increase organization's ability to achieve the business objectives and face events, internal or external, including risks arising due to inadequate controls in the operating procedures.

The ICE Report (2017) on digital transformation focused on the importance of consider infrastructure as a service, "delivering infrastructure based on outcomes for users drives us toward whole life decisions and recognizing the value of the entire data estate. This approach makes best use of the endless flow of data, information and knowledge we can use to improve the services we deliver."

Atkins and Ritchie (2019), discuss the gaps in board assurance on technical and operational risk in mining, especially for geotechnical risk. They mention mine accidents and disasters are due to geotechnical engineering issues such as tailings dam failures, e.g. Samarco 2015 (Morgenstern et al. 2016), Rockfalls, e.g. Beaconsfield 2006 (Chandler 2009) and Inrush, e.g. Bronzewing 2000 (Hope 2002).

2. THE ROLE AND CHALLENGES OF DIGITAL TRANSFORMATION IN GEOTECHNICAL RISK MANAGEMENT

In Geotechnical Risk Management, as well as other sort of Operational Risk Management, prior to defining a digital transformation process, it is fundamental to note that a successful prevention and mitigation strategy depends on an assertive risk assessment, clear and objective processes with efficient deliverables and clear risk governance and communication.

Baecher and Christian (2003) define risk as the product of probability and consequence:

$$\text{Risk} = (\text{probability} \times \text{consequence}) = (pc)$$

According to Lupo (2019) qualitative measure of likelihood of failure is common in geotechnical engineering due to uncertainties and natural variability of geomaterials, although the usage of quantitative measures are increasing, assuming the data is statistically significant and representative.

Probability of occurrence	Damage loss				
	Insignificant <$0.01M	Minor $0.01M–$0.10M	Moderate $0.10M–$1.0M	Major $1M–$10M	Catastrophic >$10M
Certain	Low	Medium	High	Extreme	Extreme
Likely	Low	Medium	High	High	Extreme
Possible	Low	Low	Medium	High	High
Unlikely	Low	Low	Medium	Medium	High
Rare	Low	Low	Low	Medium	Medium

Figure 1: Example of a Qualitative Risk matrix (Joughin et al. 2016)

Specifically for risk related to Geohazards, it is imperative to determine type o failure mechanism as well as scale and velocity of an eventual incident in order to evaluate likelihood and potential damages to public safety, safety of construction or operational personnel, impact costs, threaten the integrity of assets and associated infrastructure, and impact the environment. Porter et al. (2014) gathered some hazard classes and typologies, as shown below.

Table 1: Hazards classes and types (Porter et al., 2019)

Hazard class	Type/name	Hazard class	Type/name
Geotechnical	Frost heave Thaw settlement Solifluction Rockfall Rock slide/creep Earth slide/creep Earth flow Debris slide	Hydrotechnical	Debris flow Scour Channel degradation Bank erosion Encroachment Avulsion Shoreline wave erosion Tsunami/landslide-generated waves
Seismic and tectonic	Strong ground motion Liquefaction Lateral spreading Surface fault rupture Volcanic eruption	Other ground movement	Surface water erosion Groundwater erosion Ground subsidence (karst/mines/groundwater withdrawal/soft soils)
Snow and ice	Snow avalanche Icefall and ice avalanche	Geochemical	Acid rock drainage and metal leaching

In terms of processes mapping and data workflows, defining fault tree events, FMEA and other tools, for each failure mechanism, as well as intelligent data acquisition and communication flows, efficient key indicators and acceptance criteria, are fundamental steps to get into digital transformation's world. Terbrugge et al. (2006) exampled a process definition for risk management in geotechnical risk management.

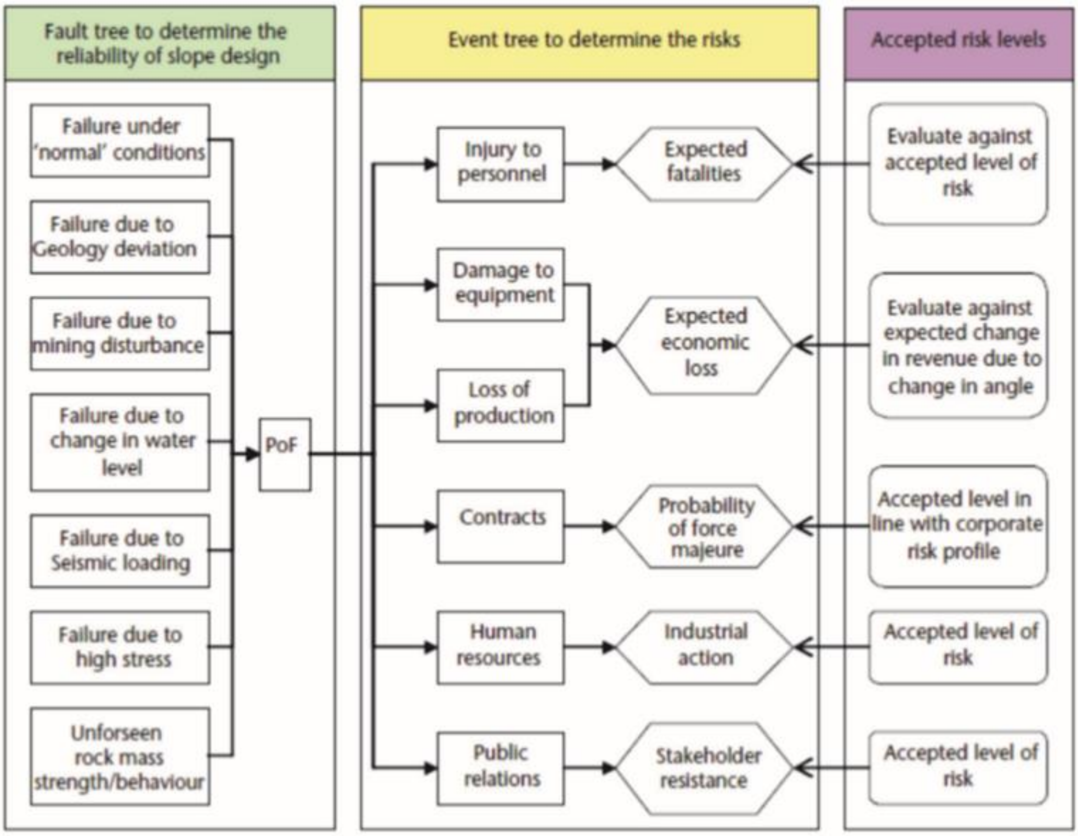

Figure 2: Risk processes including fault trees and acceptance criteria (Terbrugge et al., 2006)

The standard ISO 31.000:2018 (Risk Management Guidelines), summarizes risk management in a cycle process which includes scope, context and criteria definition, monitoring and review, recording and reporting, communication and consultation, as shown in Figure 3.

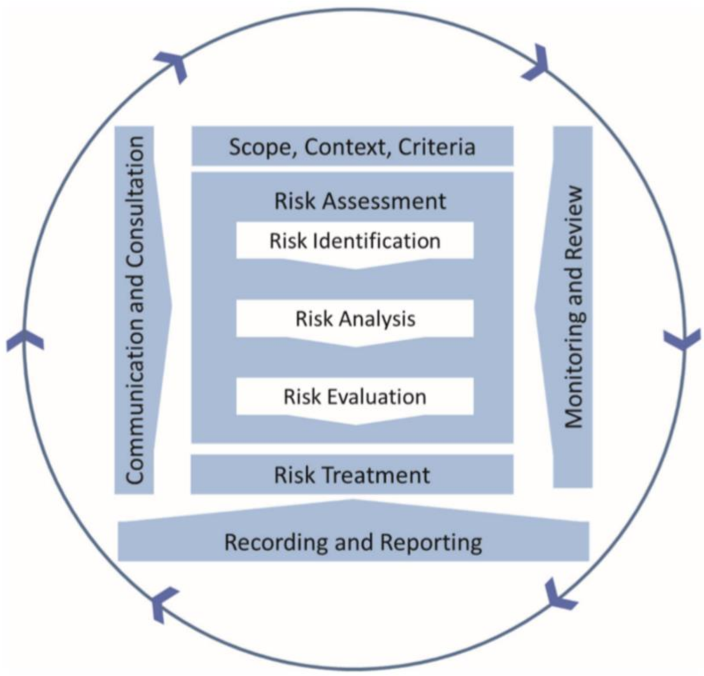

Figure 3: Risk-management process (ISO 2018) .

As regards to governance and decision making, Zio and Pedroni (2012) defined a decision-making process that provides a technically defensible basis for making decisions and helps to identify the greatest risks and prioritize efforts to minimize or eliminate them. Basically, its composed of a set of model (risk metrics with low grade of subjectivity), consequences considerations such as cost, feasibility and stakeholder concerns.

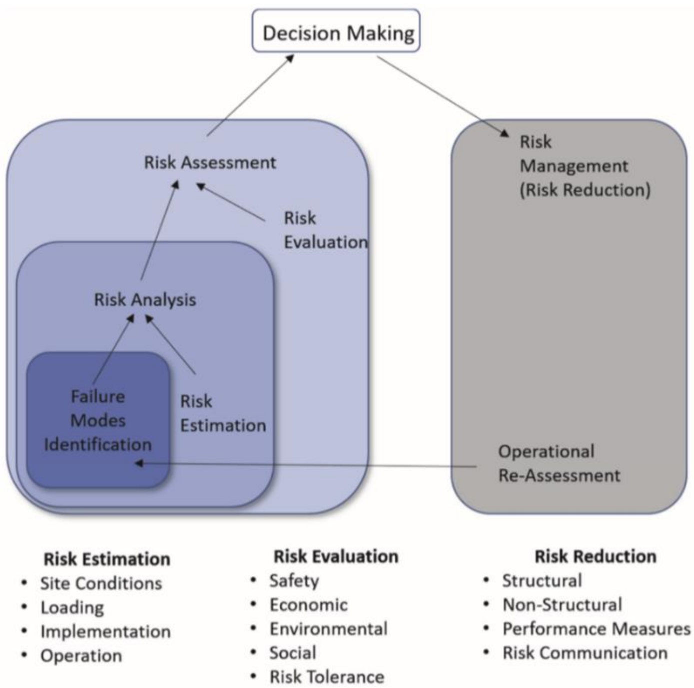

Figure 4: Risk-informed decision-making framework (FERC 2016).

Human factors must be strongly considered in governance processes as well. According to Lupo (2019), "when qualitative or quantitative measures of risk are employed, it is inevitable that the human element of judgement will be required" and "what one person considers a high risk, another person may see as a low risk. In this context, it is easy to see how cognitive biases can shape the outcome of risk assessments and the RIDM (Risk - informed decision - making) process".

Once risks are well assessed, processes are well defined and governance issues are well addressed, the adoption of technologies to promote digital transformation can be clearly chosen, in order to achieve more efficient risk management. The adoption of app's for collecting georeferenced and typological geotechnical data, based on risk, is the most evident step towards digital era. However, the design of collection device, database, workflows and Kpi's must be thought in chain, using data engineering methodologies.

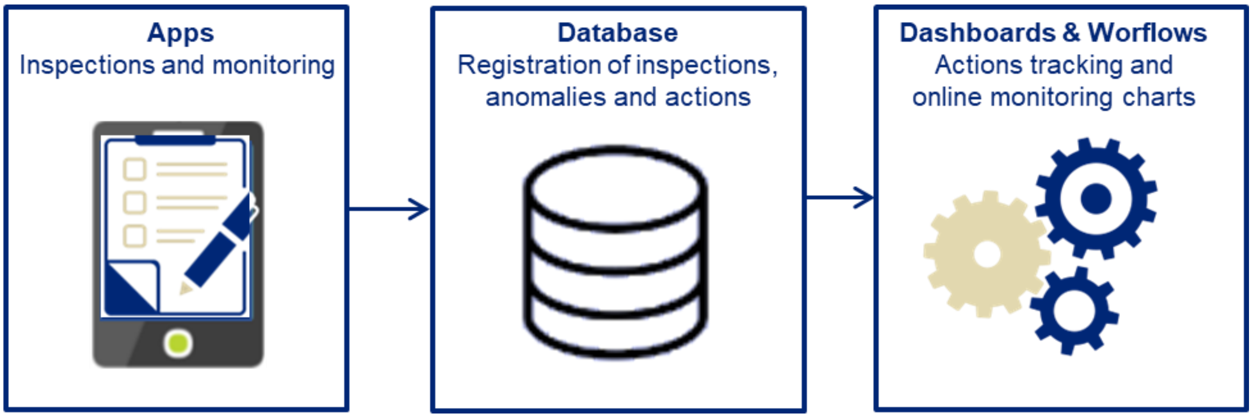

Figure 5: Schematic flow of information, since data collection, passing through database registrations, up to online dashboards and workflows.

Along the last decades, technologies related to sensors for monitoring of geotechnical structures have been improving rapidly, including field instruments and remote sensing technologies for detecting a wide range of indicators for decision making. Once again, it is crucial to have failures modes well addressed, as well as triggers for decision making, in order to choose the right set of sensor technologies for an efficient monitoring purpose. The Table 2 traces a parallel of sorts of sensor technologies and its indicators, precision, frequency of measures, flexibility, cost and alarm capability.

Table 2: Comparative table of monitoring technologies, indicators, precision, frequency, flexibility, cost and alarm capability.

	Indicador	Abrangência	Precisão	Frequência	Flexibilidade	Custo	Alarme
InSar (Satelliite)	Deslocam.	G. Áreas	mm	15 dias	Alta	$$	Não
Radar (SSR)	Deslocam.	P. Áreas	mm	Cont.	Média	$$$	Sim
Prismas (Est. Robótica)	Deslocam.	P. Áreas	mm	Cont./dias	Média	$$$	Sim*
Laser (Lidar)	Deslocam.	P. Áreas	mm	Dias/meses	Média	$$$	Não
Inclinometros	Deslocam.	Ponto	<1º	Cont./dias	Baixa	$	Sim*
Tilt Logger	Deslocam.	Ponto	<1º	Cont./dias	Baixa	$	Sim*
Celulas de Carga	Tensão	Ponto		Cont./dias	Baixa	$	Sim*
Piezômetros	P.Pressão	Ponto	cm	Cont./dias	Baixa	$$	Sim*
Medidores de Nível de Água	N.A.	Ponto	cm	Cont./dias	Baixa	$	Sim*
Geofísica (Eletroresist.)	N.A.	P. Áreas	dm	Cont./dias	Media	$	Sim*
Medidor de Vazão	Vazão	Ponto		Cont./dias	Baixa	$$	Não
Drones	Visual	G. Áreas		Dias/meses	Alta	$	Não

3. CASE STUDY

The selected case study is focused on the Geotechnical Risk Management Process in Iron Ore Brazil (IOB), from Anglo American, comprising Minas-Rio complex (Open Pit Mine, Waste Dumps, Slurry Pipeline, including Pump Stations, Tunnels, Retaining Walls, Natural and Cut Slopes besides the Port). The Figure 6 shows, schematically, the coverage of Geotechnical Risk Management in IOB, showing the structures, tools and staff involved in the process.

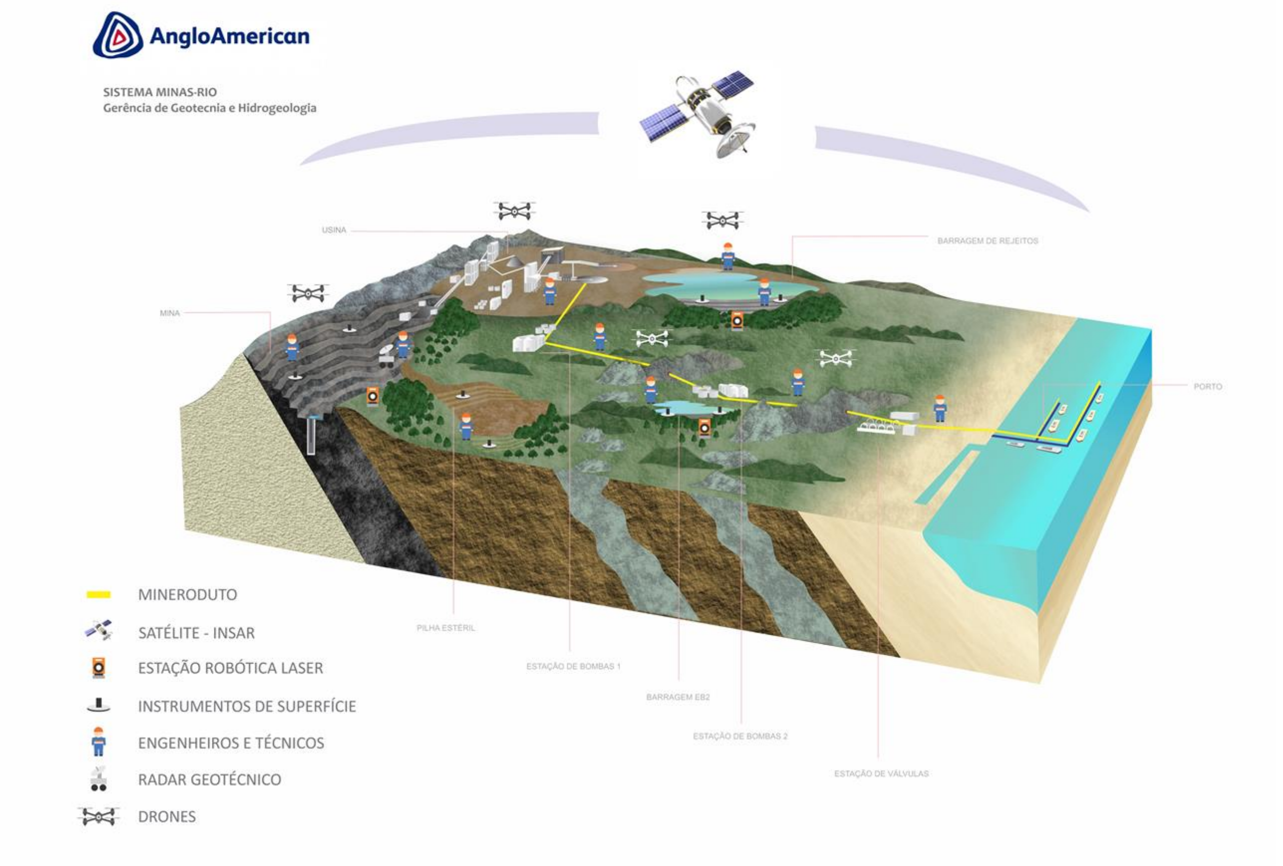

Figure 6: Schematic image of geotechnical risk management coverage in IOB.

The risk assessment process is composed of fault tree events for each failure modes, as well as bow tie analysis, FMEA, HAZOP and RBS (Risk Breakdown Structure). This set of tools is aimed to assess the risk from different perspectives (based on the same context, scope and criteria) besides the best visualization for each purpose (ex. RBS is better for visualizing risk issues versus deliverables) although the controls are the same.

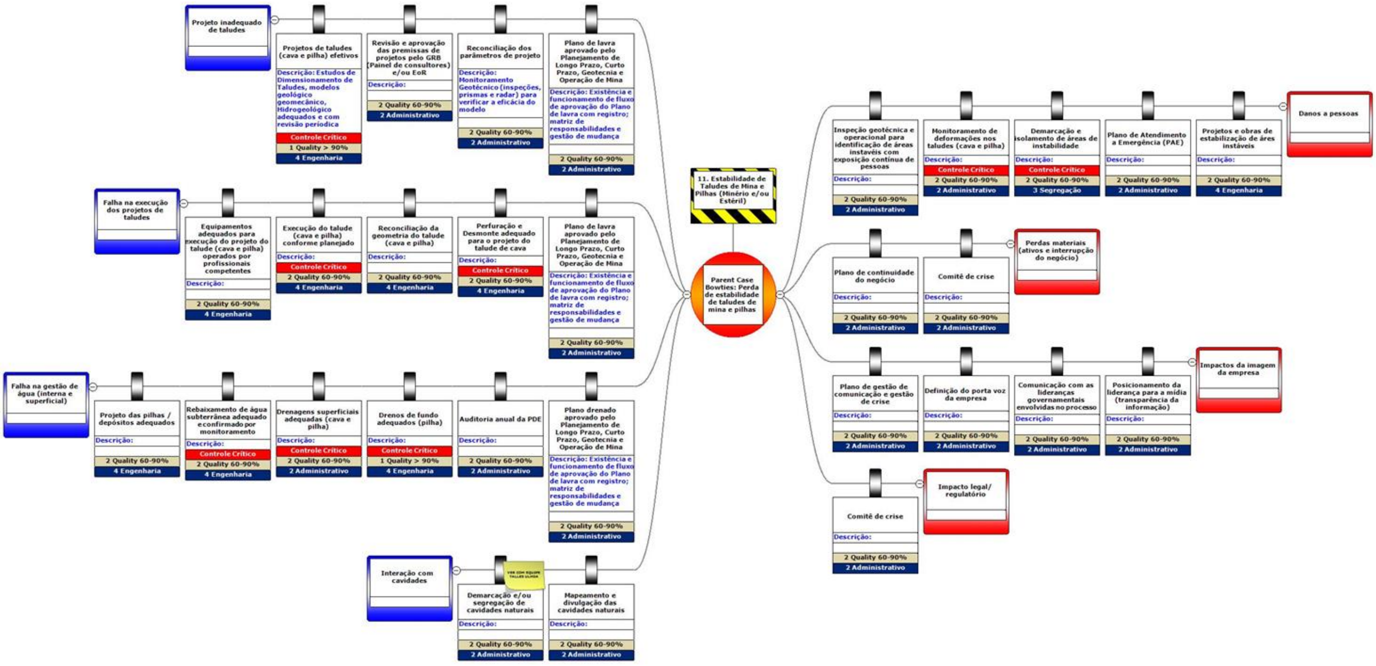

Figure 7: Bow tie risk assessment on geotechnical structures (mine and waste dumps).

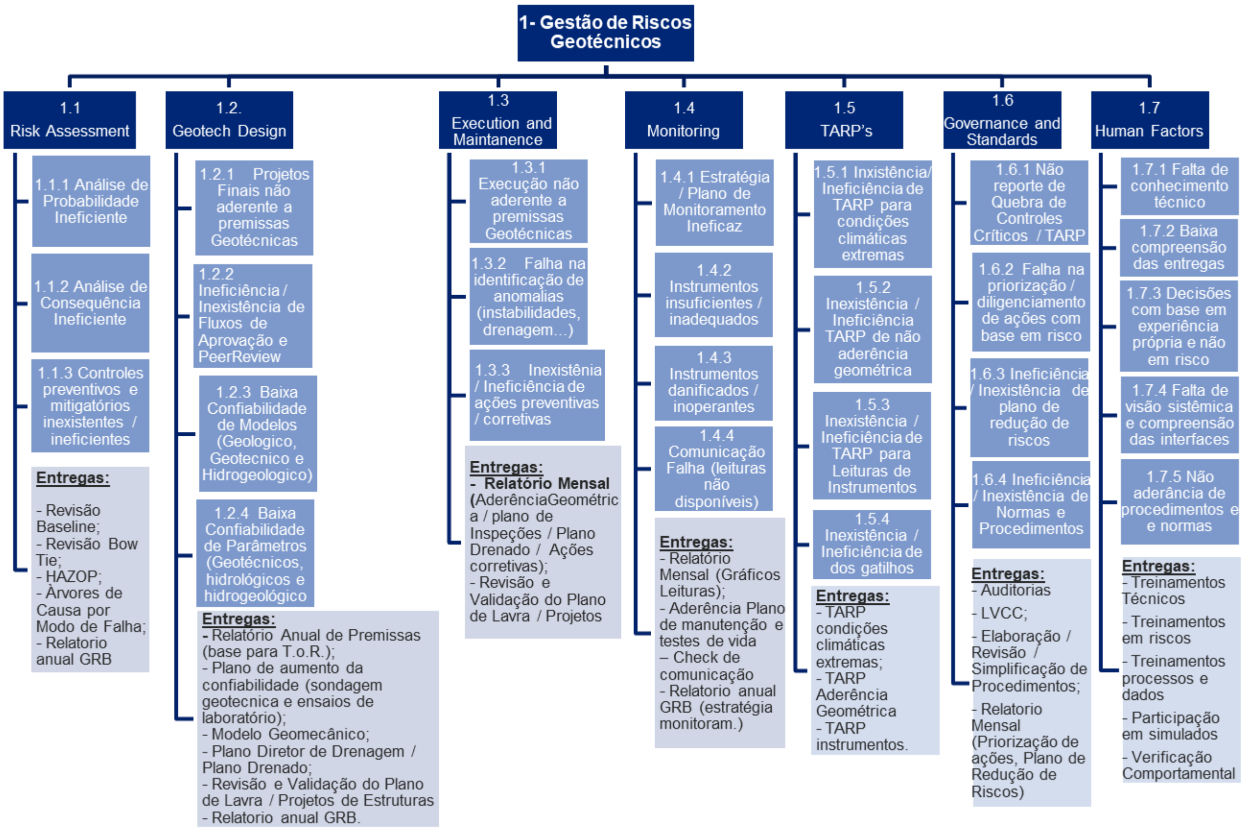

Figure 8: Risk Breakdown Structure correlating risk themes and deliverables.

The process mapping, as discussed previously, is a crucial task for achieving an efficient risk management. In the present case study, the corporate guideline are followed focusing on structures with potential damages 4 or 5 (high or very high). The whole process can be summarized as below:

1. Parent Bow Tie: Common Risk Assessment for all Business Unit, where minimum mandatory critical controls (M2C2) for geotechnical structures;

2. Business Unit Bow Tie: Specific Risk Assessment for each Site, where structures and domains are individualized, as well as likelihood and vulnerability contexts are taken into account to determine specific set of controls, including, necessarily, M2C2;

3. Geotech Design: Confidence of designs, including reliability of data, parameters, models, stability analysis and engineering solution, followed by PDCA (plan, do, check and act) to increase reliability continually;

4. Execution and Maintenance: Confidence of actual structures, including reliability of existing engineering devices, such as drainage and concrete devices, followed by PDCA (plan, do, check and act) to increase reliability continually;

5. Monitoring and TARP: Confidence of monitoring devices and trigger measures, including reliability of existing devices, efficiency of triggers, followed by PDCA (plan, do, check and act) to increase reliability continually;
6. Governance: Confidence of risk management process, including prioritization of actions by risk level and criticality of identified anomalies, followed by PDCA (plan, do, check and act) to increase reliability continually.

The Figure 9 shows, schematically, the risk management process.

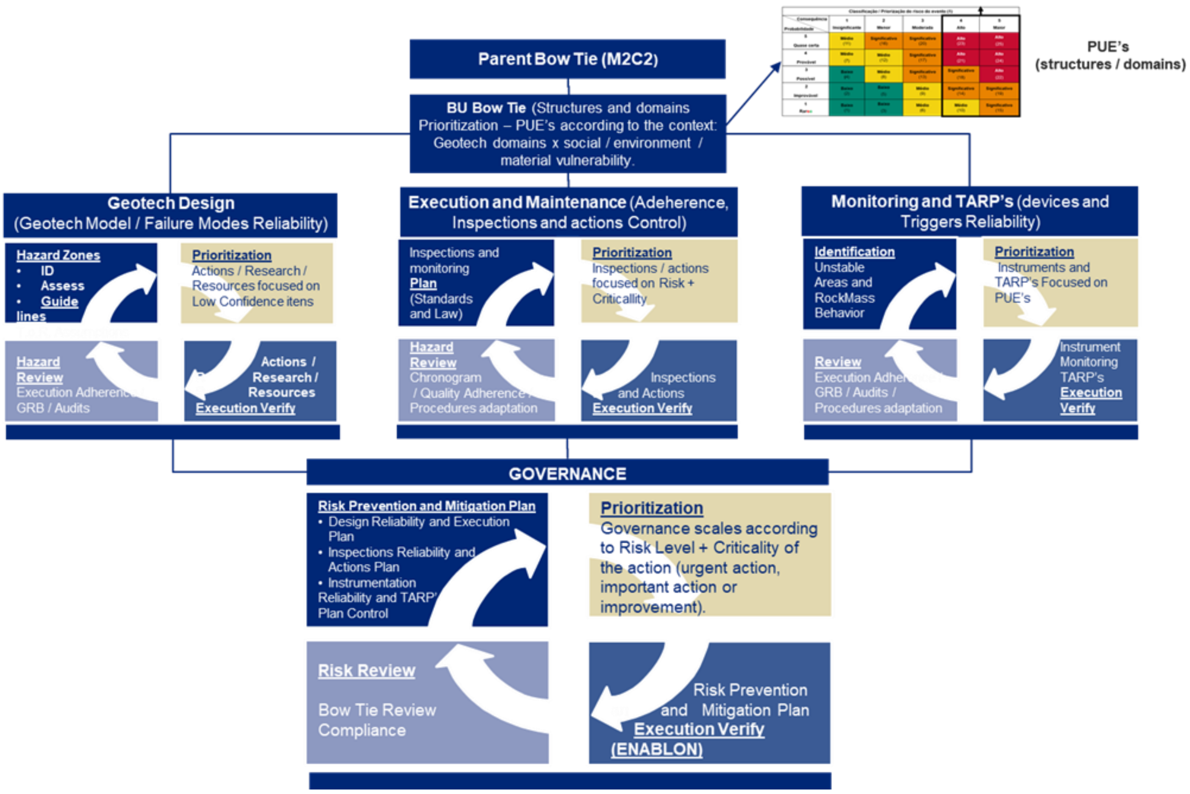

Figure 9: Risk Management Process Flow in IOB.

Finally, once risk assessments and processes are built, it is time for choosing appropriate technologies for monitoring, data acquisition and storage, as well as intelligent information flows. In a mining complex, each structure has its peculiarity, as regards to indicators (by failure mode), frequency of measures, alarm capability, precision and cost x benefit. The final task is to identify hazard situations, sometimes to prevent undesired event to occur and sometimes to mitigate potential damages to people, environment and asset / production. The Figure 10 relates sorts of structures present in IOB versus types of monitoring devices, as well as key indicators, existence and flow to identify hazard situations.

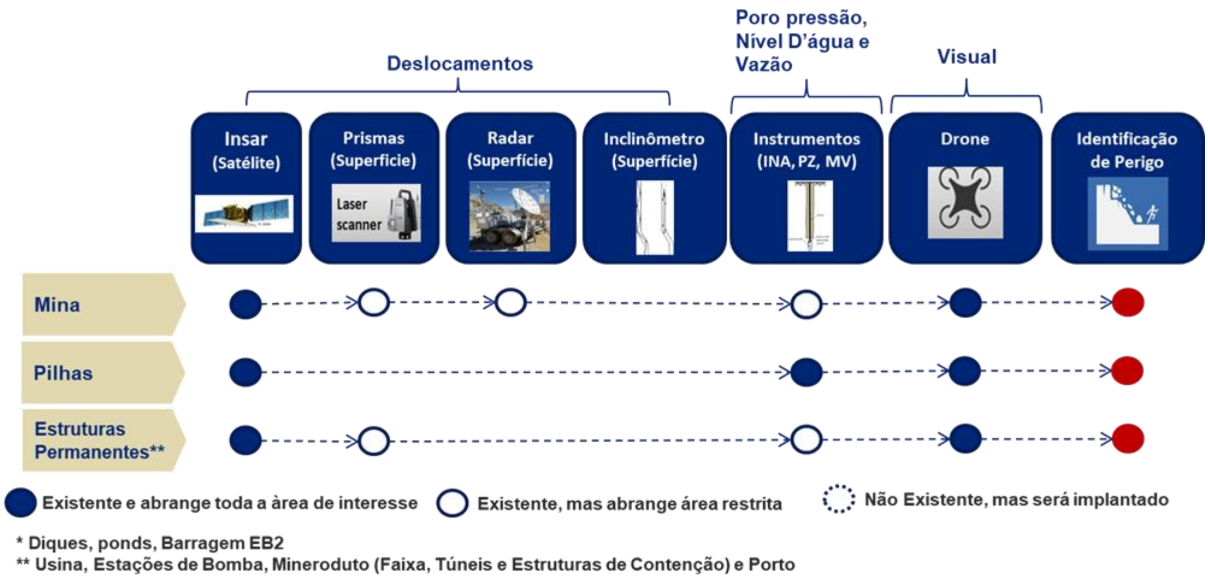

Figure 10: Schematic image of monitoring tools per structure and flow for hazard identification.

For data acquisition, database and intelligent information flows, the focus are predictive systems to relate inspections and monitoring plans, anomalies and actions plan prioritized by risk rating and anomalies criticality. The Figure 11 exemplifies a interactive dashboard, including inspections adherence to plan, number of anomalies by type and actions plans per risk and criticality.

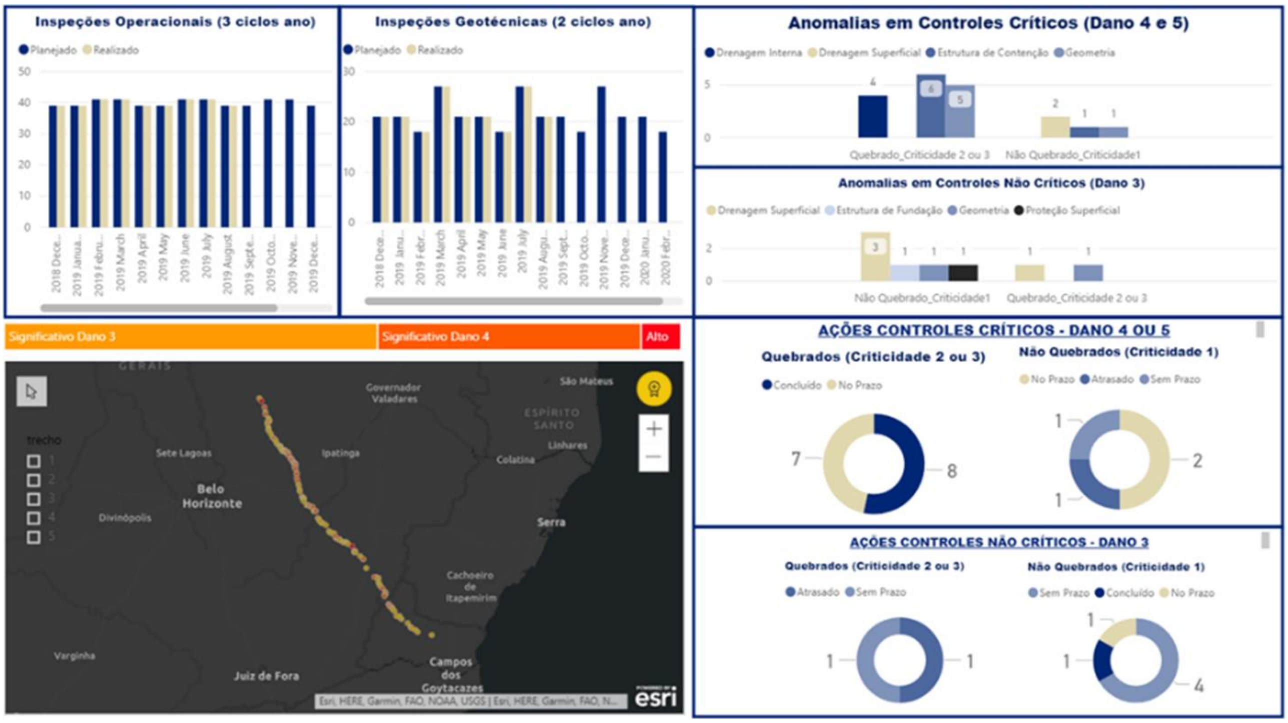

Figure 11: Dashboard of inspections adherence to plan, number of anomalies by type and actions plans per risk and criticality.

For continuous improving purpose, stablish a development roadmap is essential in order to promote, continually, enhancements in risk management process. This roadmap includes minimum tasks for achieving each level of maturity (Basic, Intermediate and Advanced) for different lines of development (Risk Analysis, Risk Assessment and Risk Management) being an excellent tool for resources prioritization along the years. The Figure 12 shows the roadmap for IOB, up to the state of art risk management (Advanced) which comprises machine learning, neural networks and other for fast and reliable information for decision making.

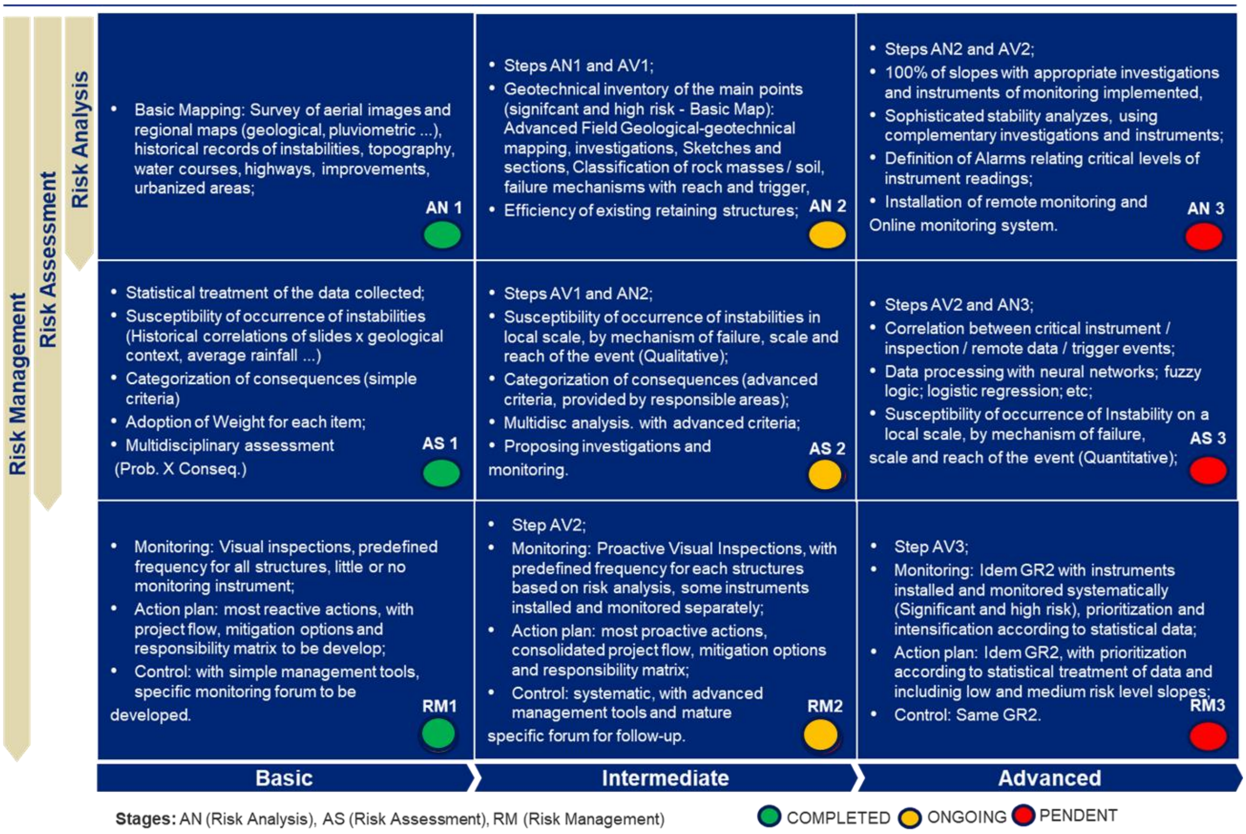

Figure 12: Roadmap of development for geotechnical risk management process in IOB.

4. CONCLUSION

The world's economy is dramatically changing towards to industry 4.0 and the main bottleneck for this is digital transformation. In other terms, powerful ways of collecting, analyzing and process data in being available and there is increasing pressure for the geotechnical engineering community to engage in this digital transformation, especially in mining sector due to needs for improve risk management. However, structural measures are fundamental for implementing digital processes, as efficient risk assessments and controls, intelligent process mapping, efficient indicators and deliverables definition, intelligent data engineering concept beyond others. The ultimate task of risk management is to become risk information trackable and communication flows, at all levels of corporate governance, efficient for assertive decision makings. Thus, concepts on operational risk management, especially for geotechnical structures, were brought up in this paper and a real case study was shown, focused on Anglo American's Geotech assets in Iron Ore Brazil (IOB) business unit. The entirely risk process where covered, since risk assessments methodologies up to governance criteria, exposing the importance of each step of building a reliable risk management, prior to selecting and implementing digital transformation measures. Finally, a roadmap was presented, empowering the concept of continuous improvement for the achievement of promoting the operational efficiency essential for a predictive management system and, consequently, delivering safer mining to society.

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