

# TBM RISKS EVALUATION FOR THE MONCENISIO TUNNEL IN THE NEW TURIN LYON BASE -ITALIAN SECTOR

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**ABSTRACT:** The Moncenisio Tunnel, a key section of the New Turin–Lyon Base Tunnel, presents highly variable geological conditions, with  $\approx 85\%$  of the alignment in hard rock (UCS up to 150 MPa) and sections in soft ground with groundwater pressures of 6–7 bar. These conditions require TBM solutions capable of rapid adaptation to diverse excavation scenarios. By correlating excavation diameter with geological parameters, the most suitable TBM specifications can be defined, reducing downtime and improving efficiency. A structured risk assessment, based on risk sheets consolidated into a central register, allows for systematic identification and prioritization of potential issues affecting safety, cost, schedule, and quality. The combined technical and risk-management approach provides a comprehensive framework to ensure resilience of the project

## 1. INTRODUCTION

The new Lyon–Turin railway line (NLTL) is a key strategic infrastructure of the Mediterranean Corridor, one of the nine priority axes of the Trans-European Transport Network (TEN-T). This European project aims to promote the mobility of passengers and goods through rail transport, considered the most environmentally sustainable mode, by reducing reliance on road transport and the resulting greenhouse gas emissions.

Within the TEN-T network, the new Lyon–Turin connection occupies a strategic position at the crossroads of Europe’s main north–south and east–west communication axes. It represents the central link of the Mediterranean Corridor, which serves approximately 18% of the European Union’s population and crosses regions accounting for about 17% of European GDP. The completion of the line therefore forms part of a development strategy that goes beyond the national interests of France and Italy, promoting cooperation among Alpine countries aimed at economic and social growth and at a structural shift in transport habits, particularly significant in a sensitive area such as the Alpine arc.

The Lyon–Turin railway line extends for a total length of approximately 270 km between the two cities, with about 70% of the route located in France and 30% in Italy. The core element of the project is the cross-border section, extending for about 65–67 km between Saint-Jean-de-Maurienne (France) and Susa/Bussoleno (Italy), almost entirely underground. The main structure of this section is the Mont Cenis Base Tunnel, which is 57.5 km long, with approximately 45 km in France and 12–12.5 km in Italy.

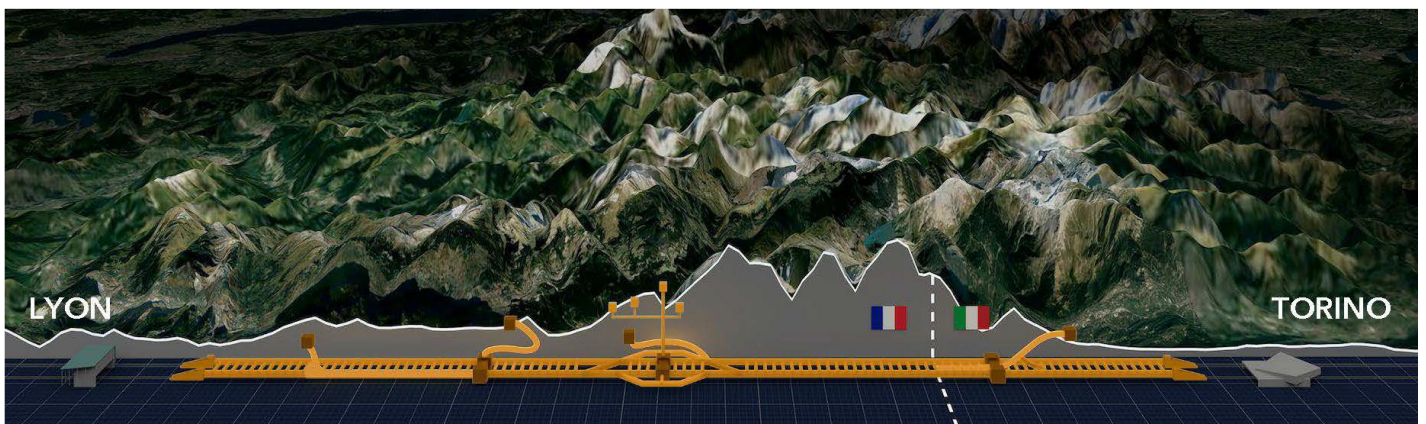


Figure 1: Moncenisio Base Tunnel

The base tunnel consists of two single-track railway tubes, connected by safety cross-passages every 333 m, with reduced spacing of 50 m in the underground safety areas. The typical cross-section includes the running track, a service walkway, and a maintenance and evacuation walkway. Designed for mixed passenger and freight traffic, the tunnel will allow operating speeds of 220km/h for passenger trains and 120 km/h for freight trains and will also be suitable for large-gauge freight convoys.

The safety and functionality of the infrastructure are ensured by numerous ancillary works, including four intermediate access points, centralized ventilation systems, and three main safety sites. The intermediate accesses are located at Saint-Martin-la-Porte, La Praz, and Avrieux in France, and at Clarea in Italy, and they play an essential role during excavation, operation, and emergency situations.

Overall, the Lyon–Turin project represents one of the most important infrastructure developments currently underway in Europe. Beyond its technical significance, it constitutes a cornerstone of the European strategy for sustainable mobility and transport decarbonization, while simultaneously strengthening the continent’s logistical competitiveness and the economic, social, and cultural ties between France and Italy.

This article presents a structured methodological framework based on risk analysis to support the technical assessment and definition of the Tunnel Boring Machine (TBM) characteristics required for mechanized excavation in complex underground works. The proposed approach is applied to the specific case of the TBM to be used for the excavation of section CO034 along the Italian stretch of the Lyon–Turin railway line, an infrastructure characterized by significant geological variability, high overburden, and stringent safety and operational requirements.

The study adopts a risk management process consistent with internationally recognized standards and best practices for underground construction, including the principles of ISO 31000 and the recommendations and guidelines issued by the International Tunnelling and Underground Space Association (ITA/AITES). In accordance with these references, the methodological framework is articulated into three complementary levels: risk identification measures, preventive measures, and corrective (or mitigation) measures.

Risk identification measures are aimed at systematically recognizing and classifying potential hazards associated with geological and geotechnical uncertainties, TBM–ground interaction, machine performance, and construction logistics. These measures include the interpretation of geological and geotechnical investigation data, the analysis of expected and worst-case ground scenarios, the review of comparable tunnelling projects, and expert-based evaluation of potential failure modes, in line with ITA recommendations for risk management in tunnelling projects.

Preventive measures are defined to reduce the likelihood of occurrence of the identified risks and are directly incorporated into the selection, design, and configuration of the TBM. In accordance with ITA/AITES guidelines, these measures address key machine features such as cutterhead geometry and tooling selection, installed thrust and torque capacity, face support and ground conditioning systems, segmental lining installation, and the configuration of back-up and auxiliary systems. Preventive actions also include operational planning, monitoring and instrumentation strategies, and organizational procedures intended to ensure safe and efficient excavation under the anticipated range of ground conditions.

Corrective measures are finally introduced to manage residual risks that cannot be fully eliminated at the design stage. These measures are consistent with ITA recommendations on contingency planning and adaptive construction management, and include predefined response strategies for unexpected ground behaviour, equipment malfunctions, or deviations from predicted excavation performance. Corrective actions encompass adaptive operational procedures, maintenance and repair strategies, contingency tooling, and emergency response plans aimed at minimizing impacts on safety, schedule, and costs.

By integrating risk identification, preventive, and corrective measures within a coherent risk-based framework aligned with ISO and ITA/AITES guidelines, the article demonstrates how risk analysis can

be effectively used as a decision-support tool during the design and planning phases of mechanized tunnelling. The proposed methodology enhances the robustness of TBM selection and configuration, improves safety and reliability, and contributes to more effective control of construction risks, time, and costs. The results confirm the value of risk-informed approaches for large-scale underground infrastructure projects and provide a transparent and reproducible methodological reference for similar tunnelling applications.

## 2. GEOLOGICAL CONTEX

The Mont Cenis Tunnel layout crosses an extremely complex geological context, both in terms of lithological variety and in geological-structural terms. The area involves the Western Alps and the Pennine Front which separates the Outer Alps to the West from the Inner Alps to the East (Figure 2). Starting from the west, the Saint Jean de Maurienne portal is built in the alluvial deposits and in the Saint-Julien-Mont-Denis alluvial cone (0). From there, the tunnel crosses the flysch of the Ultradelfinese Zone (1) and once it has crossed the Pennine Front, the tunnel continues into the Sub-briaçonnais Zone (2) whose main lithologies are limestone, dolomite and anhydrite; after crossing the Houiller Front, the tunnel meets the schistose-arenaceous units of the Houiller Bri-anzonese Sector (3). Then, there is the internal Brianzonese Zone of the Vanoise (4) consisting of mica schists, limestones, dolomites and anhydrites followed by the Schistes Lustrés stratum on the Gypsum Nappe (5), represented by carbonate rocks and anhydrites. Then, there is the internal Brianzonese Zone of the Ambin massif (6) composed by mica schists and gneisses. In the following metres, the tunnel enters the Tectonic Flake Zone (7), which constitutes a break-off horizon between the Ambin massif and the Piedmont Zone. The Tectonic Flake Zone is characterised by phylladic limestones, albitic and/or chloritic gneisses and tectonic breccias. Then, the Base Tunnel crosses the loose alluvial deposits of the Cenischia torrent sole (0). This is followed by the Piedmont Zone (9) with calcschists and Charbonnel gneiss, in contact with ultrabasic rocks. The above ground section in the Susa Plain (0) will be built on alluvial.

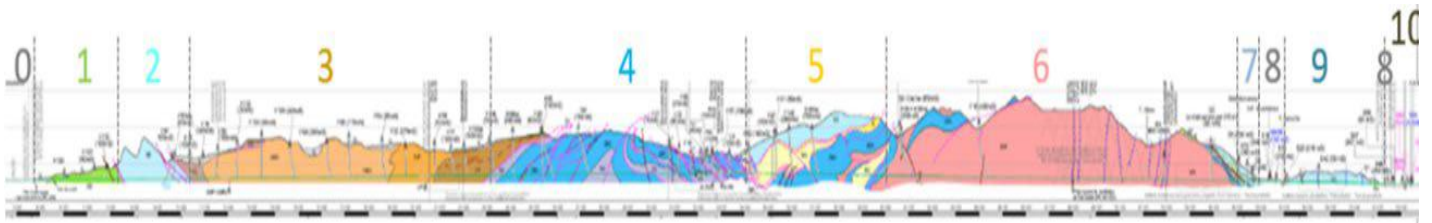


Figure 2: Geological units of the Mont Cenis Tunnel and the Interconnection Tunnel. deposits. Finally, the Interconnection Tunnel will pass through the phyllosilicate-rich calcschists of the Dora Maira Massif (10).

Within this complex geological context, the section identified as **C0034** represents a critical central segment of the Base Tunnel alignment. This lot specifically covers the stretch from the **Ambin Massif**, through the **Tectonic Slice Zone**, and into the **alluvial deposits of the Cenischia valley**.

The **TBM assigned to lot C0034** must cope with a wide range of geological and geotechnical conditions over relatively short distances:

- First, it excavates the hard and polymetamorphic rocks of the Ambin Massif, characterized by complex structural fabrics.
- Next, it encounters the highly sheared and heterogeneous materials of the Tectonic Slice Zone, including calcschists, altered gneisses, and carbonate tectonic breccias, requiring careful control of face stability and variable support systems.
- Finally, it advances into loose, poorly compacted, and water-sensitive alluvial deposits in the Cenischia valley, under a relatively shallow overburden of 50–60 m, demanding rigorous groundwater management and settlement control.




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Contesto e Incertezze all'origine dei rischi / Contexte et incertitudes à la base de risques				<b>RISCHIO / RISQUE</b>  TRA1 - Stato di fratturazione del massiccio/orientazione sfavorevole dei piani di discontinuità e/o dei piani di scistosità	
A - Distacco di blocchi plurimetrici al fronte B - Instabilità della volta a causa di diedri plurimetrici C - Grado significativo di fratturazione del massiccio roccioso				<b>Origine del rischio</b> Source du risque	
				Tecnica di cantiere / Technique de chantier	
				Geotecnico e idrogeologico / Géotechnique et hydrogéologie	
<b>Tratta di riferimento / Section de référence</b>					
Pk iniziale PM initial				Pk finale PM ifinal	
<b>Valutazione del livello di criticità del rischio / Evaluation du niveau de criticité du risque</b>					
Probabilità di accadimento (P) Probabilité de survenance (P)	2,5	Identificazione del livello di rischio / Identification du niveau du risque			
Impatto costi Impact couts	2,5	Molto bassa (<1)			
Impatto tempi Impact délais	2,5	Bassa (1-4)			
Impatto sicurezza e salute lavoro Impact sécurité et sante lieu travail	0	Medio (4-9)			
Impatto ambiente Impact environnement	0	Alta (9-16)			
Impatto qualità Impact qualité	0	Molto alta (>16)			
Impatto sociale Impact social	0				
Impatto reputazionale Impact réputationnel	0				
Impatto risultante (I) Impact résultant (I)	2,5				
Livello di rischio (P x I) Niveau de risque (P x I)	6,3				
<b>Azioni di Rilevamento / Actions de Détection</b>					
Disposizioni di monitoraggio del rischio volte a rilevare il prima possibile verificarsi dell'evento temuto				Responsabile delle azioni Responsable des actions	
Programma di indagini all'avanzamento e monitoraggio - Opuscoli 15-16 CCT				GPT CO3-4	
<b>Azioni di Trattamento / Actions de Traitement</b>					
Descrizione azioni da implementare Description des actions à mettre en oeuvre		Responsabile delle azioni Responsable des actions	Tempi di attuazione Délais de mise en	Statuto Statut	data di chiusura
Adattamento sezioni tipo (vedi disegni)		GPT CO3-4	31/08/2026	in corso / En cours	
Prescrizioni per bullonatura di diedri instabili (CCT-Opuscolo 5)		GPT CO3-4	31/08/2026	in corso / En cours	
Eventuale supporto della volta con infilaggi		GPT CO3-4	31/08/2026	in corso / En cours	
Adattamento sezioni tipo con calcestruzzo proiettato al fronte		GPT CO3-4	31/08/2026	in corso / En cours	
Eventuale bullonatura del fronte		GPT CO3-4	31/08/2026	in corso / En cours	
<b>Livello di rischio residuo dopo l'adozione delle azioni di trattamento / Niveau de risque apres la mise en oeuvre des actions de traitement</b>					
Probabilità di accadimento (P) Probabilité de survenance (P)	2,0	Identificazione del livello di rischio / Identification du niveau du risque			
Impatto risultante (I) Impact résultant (I)	2,5	MEDIO/MOYEN			
Livello di rischio (P x I) Niveau de risque (P x I)	5,0	Distacco di diedri Sicurezza del personale			
<b>Azioni Correttive / Actions Correctives</b>					
Descrizione azioni da implementare in caso di sopravvenienza del rischio Description des actions à mettre en oeuvre en cas de survenance du risque				Responsabile delle azioni Responsable des actions	
Modifica/adattamento della sezione tipo (bullonatura al fronte, maggiore spessore di calcestruzzo proiettato al fronte)				GPT CO3-4	
Modifica/adattamento della sezione tipo (bullonatura al fronte, maggiore spessore di calcestruzzo proiettato in calotta)				GPT CO3-4	
Modifica/adattamento della sezione tipo con maggiore spessore di calcestruzzo proiettato				GPT CO3-4	

Figure 4: Risk Assessment Sheet

**Risk Assessment:** Once identified, the risks are assessed using a **5-level scale for probability and severity (P×I)**. The likelihood of occurrence and the impact of events are classified separately into five classes. The product of these two dimensions provides an overall assessment that allows prioritization of risk management actions. Risks are then classified according to a risk matrix, which divides them into **very low, low, medium, high, and very high** severity, facilitating the decision on whether to mitigate or accept the risk.

Risk Level	Risk Level = P × I	Risk Level Description
Very Low	0-1	No action required; negligible criticality.
Low	1-4	No action required other than monitoring using appropriate procedures..
Medium	4-9	The activity related to the risk may be undertaken; specific procedures and project integration with predefined measures are required.
Hight	9-16	The activity related to the risk shall not start until the risk has been reduced or eliminated; however, no significant impacts on the project are expected.
Very Hight	>16	The activity related to the risk shall not start until the risk has been reduced or eliminated; in the absence of mitigation measures, significant impacts on the project are expected.

Figure 5: Risk Level Assessment Matrix

2. **Management of Corrective Measures:** For risks considered significant and not entirely avoidable through preventive measures, **corrective actions** are developed. These include actions such as modifications to the excavation plan, recalibration of the TBM, adoption of specific emergency plans, and strengthening of monitoring systems. Corrective actions are closely tied to the adaptive and dynamic approach of the construction site, as the progress of the works may reveal new risks or modify the assessment of already identified risks.

In line with ITA/AITES guidelines, and consistent with the recommendations of the AFTES Working Group GT32R2F1 (2012) on the characterization and management of geological, hydrogeological, and geotechnical uncertainties, preventive, corrective, and monitoring measures are integrated into a management plan that is continuously adjusted to operational and geological conditions. This adaptive approach ensures a rapid and effective response to potential emergencies and supports the progressive reduction of uncertainties during construction. The proposed methodology enables proactive risk management, optimizing the safety and efficiency of operations and contributing to the overall success of the Lyon–Turin project.

## 4. CASE STUDY

The construction of tunnels using TBMs in complex geological settings requires a structured risk management system that integrates progressive knowledge of the ground, continuous monitoring, and technological flexibility of the machine. The aim is to prevent the so-called “TBM blockage” and to reduce the impact of critical events on safety, schedule, and costs. The adopted strategy is based on three operational levels: early risk identification, preventive measures to reduce the probability of occurrence, and corrective measures to limit the effects if the event occurs.

### 4.1 WEAK ROCK IN COMPETENT ROCK MASSES

In very strong and poorly fractured rock masses, penetration of the cutterhead can be extremely low, with reduced production and high stress on the tools. High abrasivity also accelerates cutter wear. Prevention is based on proper cutterhead design, tool selection and spacing, limitation of rotational speed, preventive maintenance, and continuous adjustment of machine parameters.

- Identification: low penetration rates, abnormal increase in torque and thrust, rapid cutter wear detected during inspections.
- Preventive measures: optimal cutterhead design, appropriate tool selection and spacing, limitation of peripheral speed, preventive maintenance, and availability of spare parts.

- Corrective measures: adjustment of excavation parameters (thrust and cutterhead rpm), replacement and rotation of cutters, possible modification of cutterhead configuration.

## 4.2 FRONT STABILITY

The presence of faults altered zones, or poor-quality materials can cause collapses or uncontrolled flows of material against the cutterhead, with the risk of reaching torque limits or over-excavation. Measures include variable-geometry cutterheads, high available torque, probe drilling ahead, ground improvement, control of excavated volumes, block crushing, and belt cleaning.

- Identification: sudden variations in torque and thrust, increase of excavated volume compared to theoretical, geological observations at the face.
- Preventive measures: probe drilling ahead, geophysical investigations, preventive ground improvement, systematic control of excavated volumes, variable-geometry cutterhead.
- Corrective measures: targeted drainage and grouting, reduction of advance rate, removal of unstable blocks.

## 4.3 FAULT CROSSING

Faults are characterized by highly degraded and unstable ground, which can cause frequent blockages. Probe investigations and preventive “umbrella” treatments with overlapping drilling and grouting are required, and the TBM must be equipped for such operations.

- Identification: results of probe drilling and TSP, lithological and structural changes, increased permeability.
- Preventive measures: probe investigations ahead, umbrellas of overlapping drilling and grouting.
- Corrective measures: repetition of consolidation treatments, increase of over-cutting, reduction of stoppages.

## 4.4 KARST

If intercepted, cavities compromise excavation stability. They must be detected by drilling and geophysical methods and then filled with lightweight concrete to allow TBM passage and correct lining installation.

- Identification: drilling, geophysics, sudden pressure losses or abnormal volumes.
- Preventive measures: early detection and filling with lightweight concrete.
- Corrective measures: emergency filling and local stabilization.

## 4.5 SQUEEZING

Plastic materials such as clays, marls, and schists generate strong convergences that increase friction on the shields up to blockage. Mitigation includes over-cutting, high available thrust, short and conical shields, lubrication with bentonite, and continuous advance without long stops.

- Identification: increase in required thrust forces, convergence measurements, advance difficulties.
- Preventive measures: over-cutting, conical and short shields, bentonite lubrication, continuous advance.
- Corrective measures: increase of over-cutting, consolidation and drainage, possible by-pass.

## 4.6 WATER FLOW

Large inflows make the material muddy, hinder transport, and can induce face instability. Countermeasures include drainage, waterproofing and consolidation of the face, filling of the annular gap, pumping systems for high discharges, and in extreme cases switching to closed-mode TBM operation up to about 9 bars.

- Identification: probe drilling, sudden increase in inflow, changes in face pressure.

- Preventive measures: preventive drainage, waterproofing, TBM design for pressurized operation up to about 9 bars.
- Corrective measures: intensive pumping, additional consolidation, conversion to closed mode (slurry or EPB).

#### **4.7 SPALLING ROCKBURST**

In competent rock under high cover, sudden failures and violent energy release may occur. Prevention requires proper design of shields and lining, early identification of critical zones, and limitation of personnel presence at the face.

- Identification: structural surveys, acoustic signals, micro seismic monitoring.
- Preventive measures: design of resistant shields and segments, continuous monitoring, limitation of personnel at the face.
- Corrective measures: removal of unstable blocks, local stabilization, modification of excavation parameters.

#### **4.8 PERMEABLE SOIL AND SLURRY LOSSES**

In Quaternary deposits, excavation must be carried out under pressure with slurry due to the high permeability of the soil. Main risks include high tool wear, difficulty in handling coarse materials, slurry absorption by the ground, losses in the slurry circuit, and the complexity of hyperbaric maintenance.

- Identification: geological data, laboratory tests, pressure variations, material losses, volume drops in the slurry circuit, and increased bentonite consumption.
- Preventive measures: pressurized slurry excavation, cutterhead with a suitable opening ratio, wear-protected crushers, protection of exposed parts, optimized slurry mix design, maintenance of slurry reserves, and effective filter cake formation.
- Corrective measures: adjustment of slurry rheology and pressure, increase in density and viscosity, use of additives, targeted hyperbaric interventions, and localized sealing.

#### **4.9 ASBESTOS**

In ophiolitic “green rocks” the main hazard is dispersion of asbestos fibers. Required measures include area compartmentalization, dust suppression, continuous air monitoring, filtration, use of PPE, limitation of personnel, and management of muck and water as hazardous waste.

- Identification: mineralogical analyses, air monitoring with SEM.
- Preventive measures: excavation in closed slurry mode, area compartmentalization, HEPA filters, PPE.
- Corrective measures: negative-pressure ventilation, local remediation, controlled management of hazardous

#### **4.10 ALIGNMENT DEVIATION**

In difficult ground the TBM may deviate from the theoretical alignment. This is prevented with three-dimensional guidance systems that continuously control position and attitude on all three axes.

- Identification: continuous 3D guidance system.
- Preventive measures: sensor calibration and constant control.
- Corrective measures: correction of attitude and guidance parameters.

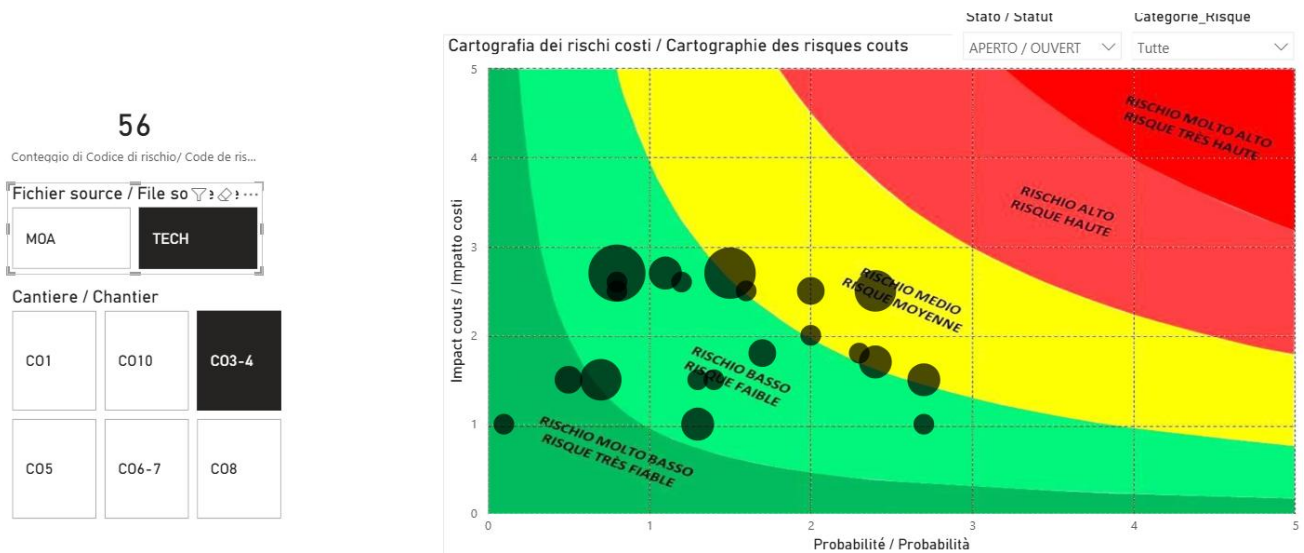


Figure 6: TBM C0034 Risk Synthesis Map

## 5. CONCLUSION

The case study of Lot C0034 of the Lyon–Turin Base Tunnel shows how mechanized tunnelling in extremely complex geological settings requires a structured, dynamic, and strongly integrated approach to risk management. The extraordinary lithological variability, the presence of tectonically disturbed zones, high overburden, and sections in loose and saturated materials require TBM design and operational strategies to be based not only on geological data, but on a risk-driven decision-making process.

The application of ISO 31000 principles and ITA/AITES guidelines made it possible to develop a management model structured on three levels—identification, prevention, and mitigation—capable of supporting all project phases, from the selection of TBM characteristics to on-site operational management. The P×G matrix classification system allowed the prioritization of actions, directing resources toward the most critical risks for safety, schedule, and cost.

The analysis of the main risk scenarios—from poor cuttability to squeezing, from water inflows to clogging, up to issues related to asbestos-bearing rocks and trajectory deviations—shows how prevention must be directly embedded in machine design, while corrective measures must already be planned before excavation begins, within an adaptive construction-site framework.

A key element of the entire system is continuous monitoring: geological data, TBM parameters, and site observations feed the risk plan in real time, making it a living rather than static tool. In this way, risk management is not a formal obligation but becomes real support for operational decision-making.

The C0034 experience shows how a risk-based approach makes mechanized excavation more reliable, reduces the likelihood of critical events, limits downtime, and contains extra costs. The proposed methodology, based on transparent and reproducible criteria, represents a reference that can also be applied to other major underground projects characterized by high geological uncertainty.

In conclusion, risk management should not be considered a secondary activity, but a structural component of the design and construction of modern tunnels. In the case of the Lyon–Turin project, it proves to be one of the fundamental tools for transforming a work of exceptional geological complexity into a technically controllable, safe, and long-term sustainable project.

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