



OCCUPATIONAL RISK ANALYSIS AND DEVELOPMENT OF THE SPECIFIC HEALTH AND SAFETY PLAN FOR THE CONSTRUCTION OF A DOUBLE-TRACK TUNNEL USING A TUNNEL BORING MACHINE

Monica Crinela BURDEA¹, Roland Iosif MORARU^{2*}

¹University of Petroșani, Petroșani, Romania, crina_bendea@yahoo.com

²University of Petroșani, Petroșani, Romania, roland_moraru@yahoo.com

DOI: 10.2478/minrv-2026-0052

received – 10.07.2026 / revised – 21.07.2026

accepted – 10.09.2026 / published – 25.09.2026

Abstract: *The research summarized in this article highlights that tunnelling operations represent some of the most complex activities in the construction sector, regarding both technology and occupational health and safety. The underground environment, confined working space, use of high-power equipment, mechanized transport, hyperbaric conditions, and the need for interventions within the excavation chamber give rise to specific occupational risks. The study analysed the responsibilities of the parties involved in the project, site organization, and the key technological processes that can impact worker safety. Furthermore, risks associated with each execution phase were identified and evaluated, and technical, organizational, and procedural measures were established to reduce risk levels and protect personnel. The results demonstrate that the use of TBM technology significantly contributes to mitigating risks specific to conventional excavation methods by limiting workers' direct exposure to the excavation face, reducing ground instability, and increasing process automation. However, this technology introduces new challenges regarding risk management related to working in confined spaces, ventilation, atmospheric monitoring, hyperbaric operations, and emergency management.*

Keywords: Tunnel Boring Machine (TBM), Occupational Health and Safety (OHS), risk analysis, Kinney method, company-specific OHS plan.

1. Introduction

Compliance with occupational health and safety legislation is an essential component of conducting economic activities safely and efficiently [1], [2]. In this context, Government Decision no. 300/2006 [3] regarding minimum health and safety requirements for temporary or mobile construction sites plays a fundamental role in regulating the responsibilities of all parties involved in construction work—from investors and designers to contractors and workers. This decision establishes a clear framework for mandatory occupational risk prevention measures, site organization requirements, and the conditions for cooperation and coordination among the various entities carrying out simultaneous activities on the same site. Failure to comply with legal provisions can lead not only to the imposition of sanctions but also to serious workplace accidents, with consequences for the health and lives of workers as well as for the execution of construction projects.

In the construction sector, characterized by a high level of occupational risk, the development and implementation of the Specific Health and Safety Plan (PSS) constitute both a legal obligation and an essential measure for preventing workplace accidents and occupational illnesses. In accordance with the provisions of Government Decision no. 300/2006, this document must be prepared by every contractor carrying out activities on the construction site and continuously adapted to the specific nature of the work, the identified risks, and the actual conditions under which the activity takes place. The importance of the PSS lies in the fact that it serves as the primary operational tool for planning, coordinating, and controlling health and safety measures throughout the execution of the works [3]. The plan includes an analysis of risks specific to each work phase,

* Corresponding author: Roland Iosif Moraru, Prof. PhD. Eng., University of Petroșani, Petroșani, Romania, contact details (University st. no. 20, Petroșani, Romania roland_moraru@yahoo.com)

prevention and protection measures, the responsibilities of the individuals involved, emergency response procedures, and the coordination mechanisms among all participants in the execution process [4].

The subject of this research is the substantiation and development of the specific Health and Safety Plan for the construction of the Poiana Tunnel, part of the A1 Sibiu–Pitești Motorway project (Section 3: Cornetu–Tigveni). This project represents one of Romania's most significant road infrastructure investments, forming an integral part of Pan-European Corridor IV, which ensures connectivity between Central and Western Europe and the Port of Constanța.

Site organization is a fundamental component of occupational health and safety management in tunnel construction. When TBM (Tunnel Boring Machine) technology is employed, site organization takes on particular importance due to the complexity of the technological process, the specific conditions of the underground environment, and the interdependence between surface operations and activities carried out inside the tunnel [5].

Unlike conventional construction sites, where activities take place in open areas allowing for great flexibility in workspace organization, tunnel construction involves confined spaces with limited evacuation options and a constant reliance on the operation of auxiliary systems [6]. Consequently, the site layout must be designed to allow excavation, transport, installation, and supply operations to proceed simultaneously without creating additional risks for personnel [7].

As excavation progresses, site organization must be continuously adapted to changing working conditions. The advancement of the tunnel necessitates the progressive relocation of temporary facilities, the updating of access routes, and the reconfiguration of operational areas. This dynamic requires periodic inspections and the continuous reassessment of risks associated with underground activities [8].

The ventilation system is a defining element of TBM tunnelling operations. Unlike surface-level works, where natural air exchange aids in the dispersion of pollutants, air quality in the underground environment depends entirely on the efficiency of the ventilation systems [9]. These systems must ensure a supply of fresh air, the removal of dust particles and gases generated by operational activities, and the maintenance of environmental conditions suitable for work activities. From this perspective, ventilation is not merely a technical utility but an essential measure for preventing occupational risks [10].

These specific features necessitate the rigorous identification and management of occupational risks as early as the work planning stage. In this context, developing a specific Health and Safety Plan tailored to the project's characteristics is essential for conducting operations safely and for protecting the lives and health of the workers involved in the tunnel's construction [11].

Failure to properly prepare and implement the PSS plan can lead to serious incidents resulting in human, material, and financial losses, as well as the imposition of sanctions by competent authorities. At the same time, a well-developed security plan fosters a prevention-oriented organizational culture by raising awareness and instilling a sense of responsibility among all those involved in the work process [12].

The Site-Specific Health and Safety Plan should certainly not be viewed merely as an administrative document, but rather as a risk management tool tailored to the dynamics of the construction site and the specific characteristics of each project. Its proper implementation aims to reduce occupational risks, prevent workplace accidents, and ensure a safe working environment for everyone involved in the project [13].

2. Analysis of technological execution processes in relation to worker health and safety

2.1. Brief project description

The Sibiu–Pitești Motorway is an integral part of Pan-European Corridor IV, which traverses Romania from west to east along the Nădlac–Arad–Timișoara–Lugoj–Deva–Sibiu–Pitești–Bucharest–Constanța route. The route of Section 3 of the Sibiu–Pitești Motorway runs between the localities of Cornetu and Tigveni—spanning from km 44+500 to km 81+900—with a length of approximately 37.40 km. This section lies within the administrative territory of two counties:

- Argeș County;
- Vâlcea County.

The Poiana Tunnel is located between km 60+021 and km 61+721, and has a length of 1.7 km, double track, which means a total length of 3.4 km, of which:

- natural tunnel length 1.7 km;
- artificial tunnel length of approximately 116 m for both ways (approximately 70 m for Sibiu Portal and approximately 46 m for Pitești Portal).

The average elevation of the tunnel is 775 meters above sea level. Within this motorway section, the Poiana Tunnel represents one of the most complex infrastructure projects undertaken in Romania, both technologically and from the perspective of occupational health and safety management. Constructing the tunnel using TBM (Tunnel Boring Machine) technology involves carrying out operations in a complex underground environment characterized by specific risks associated with working in confined spaces, mechanized transport, high-power equipment, artificial ventilation, hyperbaric conditions, and interventions within the excavation chamber.

The Poiana Tunnel (Fig. 1) will be constructed by excavating two galleries—one for each track—with the following main characteristics, in accordance with the Technical Requirements:

- carriageway width: 8.5 m;
- sidewalk width: ≥ 1.0 m;
- tunnel clearance: ≥ 5.0 m.

For each gallery, the total length will exceed 1,700 m. In detail:

- tunnel 1 (Sibiu → Pitești): 1780.00 m
- tunnel 2 (Pitești → Sibiu): 1778.11 m

The project beneficiary is the National Company for Road Infrastructure Administration S.A.; the number of workers on site is 500, and the estimated duration of the works is 16 months.



Fig. 1. The tunnel subject to construction: relevant sections

2.2. Technical characteristics of the TBM excavation method

Adopting a circular cross-section (Fig. 2.a) maximizes the load-bearing capacity of the final lining, minimizing the risk of damage from asymmetrical thrusts (Fig. 2.b).

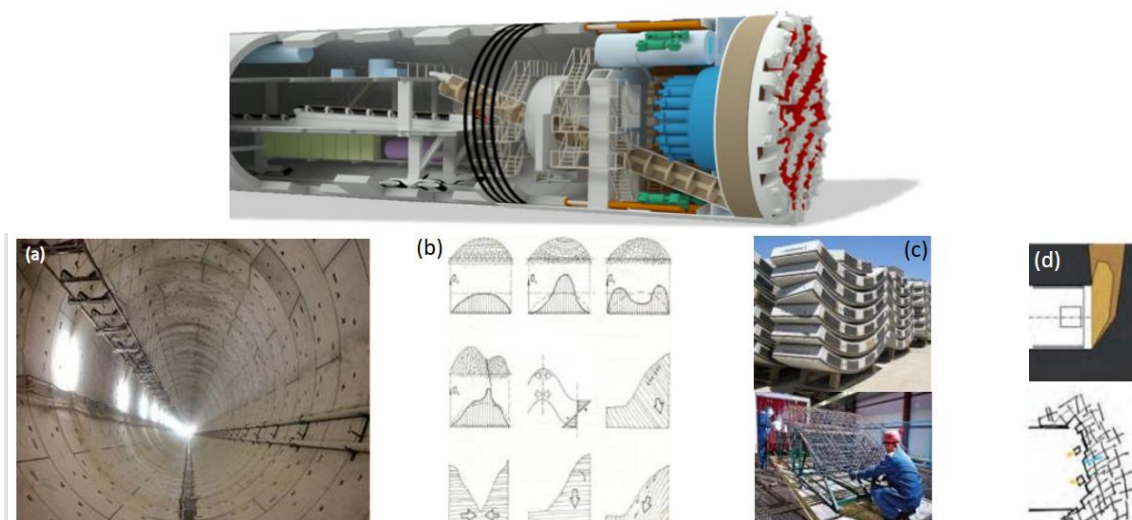


Fig. 2. Technical features of the TBM excavation method: a) circular cross-section maximizes the load-bearing capacity of the final lining; b) minimization of damage risk in the event of asymmetric thrusts; c) precast final linings; d) superior mechanical properties and strength class.

Mechanized excavation minimizes stress relief in the rock mass, the degradation of geotechnical properties, and associated risks. Prefabricated final linings offer superior mechanical characteristics (Fig. 2.c) (regarding strength class and quality control). The concrete segments, sealing system, and annular gap grout prevent seepage through the lined tunnel, thereby protecting existing aquifers from drying out or partial subsidence. Mechanized excavation minimizes the risk of face instability (Fig. 2.d) through a closed

excavation process with adequate face pressure, while also minimizing changes to the initial ground stress state and, consequently, the interaction with any potential landslide masses. Furthermore, mechanized excavation minimizes ground deformations and the impact on pre-existing structures [14].

2.3. OSH specifics: risks reduced a priori

Mechanized excavation with TBM, compared to traditional excavation, allows for a further **reduction in risks for workers**, by:

- further risk reduction due to the absence of machinery and personnel at the working face during excavation;
- further reduction of the risk of falling objects, as personnel work in a protected environment;
- reduced health risks for workers associated with dust, fumes, and noise generated by the movement of conventional excavation machinery;
- outdoor air is supplied to the TBM via a fan and dedicated ducting; machine-mounted sensors constantly monitor concentrations of oxygen, CO, CO₂, and H₂S;
- pressure sensors at the excavation face and methane concentration sensors significantly reduce the risk of serious accidents; all sensors are continuously monitored by experienced operators;
- guaranteed tunnel stability in the event of abandoning the excavation face: with traditional excavation methods, abandoning the face often leads to sloughing, rockfalls, or even collapses in complex ground conditions;
- resuming operations therefore entails risk profiles that are completely eliminated by mechanized excavation;
- the presence of an emergency refuge chamber and evacuation equipment on the TBM prevents casualties in the event of an accident;
- safe transport of excavated material using (electrically powered) conveyor belts—material is transported directly to the primary storage area;
- minimal human involvement in excavation operations: personnel come into direct contact with the active excavation face (cutterhead) only during maintenance operations performed under hyperbaric conditions; during normal operation, the work environment is confined to the interior of the TBM.

2.4. Action in Emergency Situations

Given the complexity of the tunnelling operations and the risks inherent to underground work, emergency management is a crucial component of the project's occupational health and safety system. To mitigate the consequences of potential accidents and ensure a rapid, effective response, organizational, technical, and medical measures have been established to protect personnel in the event of emergencies—such as workplace accidents, fires, flooding, gas releases, technical failures, hyperbaric incidents, or other events that could compromise worker health and safety [15].

a. Organization of emergency response

As part of the project, specific procedures for managing emergency situations are being developed, establishing staff responsibilities, communication flows, and protocols for alerting, evacuation, and intervention. All workers receive periodic training on:

- recognizing emergency situations;
- alarm and evacuation procedures;
- administering first aid;
- using emergency response equipment;
- response measures for fires, floods, gas releases, and hyperbaric incidents.

The training of the personnel is verified through periodic simulation exercises and practical applications carried out on the construction site and inside the tunnel. To ensure a rapid response in the event of accidents or medical incidents, a medical intervention team is permanently available within the project, 24 hours a day. The team consists of:

- physician;
- nurse;
- ambulance driver.

Medical personnel are trained to provide emergency medical care and to manage accidents specific to tunneling operations and hyperbaric interventions. Depending on the severity of the incident, injured individuals may be transported to medical facilities designated in the project's Emergency Plan.

b. First aid equipment

For rapid intervention in the event of accidents, the construction site and tunnel are equipped with:

- first aid kits, one for every 25 persons;
- automated external defibrillators (AEDs): 3 units (1 – Gate 1; 1 – Gate 2; 1 – TBM);
- eyewash stations;
- stretchers for evacuating injured persons;
- emergency communication equipment;
- first aid stations located in areas designated in the site layout plan.

The exact location of these facilities is marked and communicated to all workers during OHS training and emergency procedures.

c. Hyperbaric intervention chamber

Given that operations are conducted under hyperbaric conditions, the project includes a hyperbaric chamber in addition to the one integrated into the TBM. Located at the surface and operated by qualified personnel, this chamber is designed to provide medical treatment and monitoring for incidents associated with high-pressure exposure. It enables the application of specific therapeutic procedures and serves as an essential component of the emergency response system for activities carried out within the TBM's excavation chamber.

d. Refuge and survival chambers

To protect personnel working underground, the tunnel is equipped with refuge chambers located at intervals of approximately 500 meters. These spaces are designed to ensure the survival of personnel in the event that immediate evacuation is not possible due to fire, flooding, major equipment failure, or other emergencies. Each refuge chamber:

- is sized for approximately 24 people;
- ensures autonomy for a minimum period of 48 hours;
- has breathable air reserves;
- is stocked with drinking water and emergency supplies;
- is equipped with external communication systems;
- features emergency lighting and environmental parameter monitoring;
- is equipped with first aid gear and materials necessary for temporary survival.

e. Intervention and evacuation equipment

The project provides:

- signposted escape routes;
- emergency and escape lighting;
- emergency communication systems;
- fire-extinguishing equipment;
- tunnel atmosphere monitoring systems;
- equipment for personnel evacuation and rescue.

All equipment is periodically inspected and maintained in proper working order. The implementation of these measures aims to ensure an efficient emergency response capability, reduce intervention time, and limit the consequences for workers, equipment, and the environment.

3. Conduct of site operations: work phases, equipment used and personnel involved

3.1. Organization of the TBM excavation process and identification of hazard sources

An overview of the TBM technology used for tunnel construction, its operating principles, and the key activities performed during excavation highlights the specific nature of underground works, the factors influencing occupational health and safety, and the sources of potential hazards. The following section presents an analysis of the technological stages involved in tunnel excavation and identifies the main categories of risk arising from TBM operation, the interaction between personnel and equipment, and the specific conditions of the underground environment:

Excavation of the working face

- operation of the cutterhead;
- interaction with the ground;
- mechanical risks;
- risks arising from local collapses and inflows.

Installation of precast segments

- handling of segments;
- use of the erector;
- risks of impact, crushing, and falling loads.

Annular space injection

- use of pumping systems;
- exposure to high pressures;
- contact with the products used.

Transport of excavated material

- conveyor belts;
- MSVs (Multi-Service Vehicles);
- entanglement and collision risks.

Transport of segments and materials

- loading and unloading operations;
- mechanized handling;
- interference with personnel movement.

Personnel movement in the tunnel

- access routes;
- crossing areas;
- emergency evacuation.

Mechanical and electrical maintenance work

- hazardous energies;
- Lock-Out/Tag-Out procedures;
- interventions on installations.

Work in confined spaces

- access to restricted areas;
- potentially hazardous atmosphere;
- work environment monitoring.

Interventions in the excavation chamber and hyperbaric works

- access to the cutterhead;
- compression and decompression;
- decompression sickness;
- specific control measures.

Factors that exacerbate the severity of accidents

- limited space;
- restricted escape routes;
- long distances to the outside;
- ventilation dependent on mechanical systems;
- simultaneous operations.

Table 1 summarizes the work phases, the means/equipment used, and the exposed personnel.

Table 1. Work phases, means and equipment used, and exposed personnel

Tunneling works			
No.	Work stages	Means / equipment used	Personnel involved
1.	Portals Pile drilling (hole excavation, reinforcement installation, concreting, pile head preparation, anchor ties)	- Drilling rigs - Concrete mixer trucks - Dump trucks - Crane - Excavators - Front-end loaders - Dump trucks.	- Work supervisors - Drilling rig operators - Machine and equipment operators - Load slingers - Laboratory technicians - Mechanical fitters - Surveying workers.
2.	<i>Mechanized TBM excavation</i> Maintenance and intervention works in the excavation chamber	- Air compressors - Pneumatic tools - Mechanical tools - MSV (Multi-Service Vehicles) - Hyperbaric chamber - Rescue chamber.	- Work Supervisors - Machine and Equipment Operators - Team of Mechanical Fitters - Doctor - Nurse.

Tunneling works			
No.	Work stages	Means / equipment used	Personnel involved
3.	Prefabrication plants for tunnel lining segments - Reinforcement of segments - Concreting of segments - Watertightness gaskets.	- MSV – Multi-Service Vehicles - Cranes - Concrete mixer trucks - Concrete pumps - Formwork systems - Concrete injection systems - Air compressors - Pneumatic tools.	- Work Supervisors - Riggers / Slingers - Machine and Equipment Operators - Mechanical Fitter Team - Carpenter Team - Steel Fixer Team.
4.	Transport and assembly of the segments	- MSV – Multi-Service Vehicles - Cranes - TBM – Tunnel Boring Machine.	- Work supervisors - Load slingers/riggers - Lifting equipment operators - Mechanical fitter team - TBM operator team - Machine and heavy equipment operators.

3.2. Applicable minimum occupational health and safety requirements

In the construction sector, site operations must be conducted in compliance with occupational health and safety (OHS) requirements to prevent workplace accidents and occupational illnesses. Collaboration between the client and the contractor plays a crucial role in ensuring a safe working environment for everyone involved in the execution of the works.

The beneficiary's responsibilities regarding occupational health and safety

The beneficiary is obliged to create the necessary framework for carrying out the work in conditions of occupational health and safety, by:

- designating health and safety coordinators;
- ensuring the preparation and updating of the Health and Safety Plan for the construction site;
- providing the contractor with information regarding risks present at the site;
- verifying the existence of documents and authorizations required for carrying out activities;
- monitoring compliance with prevention and protection measures throughout the duration of the works;
- facilitating cooperation among all participants in the construction process.

The contractor's responsibilities regarding occupational health and safety

The contractor is responsible for organizing and carrying out activities in safe conditions and has the obligation to:

- implement the measures set out in the Health and Safety Plan;
- conduct health and safety training for workers prior to the start of work and on a periodic basis, in accordance with legal requirements;
- provide personal protective equipment appropriate to the existing risks;
- use work equipment that is compliant and technically inspected;
- identify and assess the risks specific to the activities being performed;
- monitor compliance with safety measures by own personnel and subcontractors;
- immediately report incidents, accidents, and hazardous situations.

Cooperation between the client and the contractor

To prevent occupational risks, the collaboration between the beneficiary and the entrepreneur must be based on:

- continuous exchange of information regarding risks and preventive measures;
- coordination of activities carried out simultaneously by multiple contractors;
- participation in periodic health and safety meetings;
- establishing responsibilities and communication protocols for emergencies;
- verifying the implementation of protective measures defined in the OHS documentation.

All measures and decisions regarding occupational health and safety must be recorded in specific documents and brought to the attention of all persons involved.

Organization of OHS activities on the construction site

The following measures shall be observed during the works.:

- access to the construction site is permitted only for authorized and trained personnel;
- hazardous work areas will be appropriately marked and cordoned off;
- access and evacuation routes will be kept clear and in good condition;
- work at heights will be performed only using collective and individual protection systems;
- temporary electrical installations will be inspected and operated safely;
- fire prevention and extinguishing measures will be ensured;
- periodic inspections regarding compliance with OHS requirements will be conducted.

Emergency management

The beneficiary and the contractor must collaborate to:

- developing and implementing emergency response procedures;
- training workers in first aid and evacuation;
- ensuring the necessary equipment for emergency interventions;
- organizing periodic evacuation and response drills.

From an occupational health and safety perspective, collaboration between the client and the contractor is essential for carrying out site activities safely. Through constant communication, effective coordination, and compliance with legal obligations regarding occupational health and safety, worker protection and accident prevention are ensured, and the work is carried out under optimal safety conditions.

4. Tools of the applied semi-quantitative assessment method

Risk assessment is carried out in three distinct stages, corresponding to the progression of activities on the construction site [16]:

i. During the work design and planning stage—specifically when determining execution methods and developing operational plans (e.g., the site organization plan), designing technical and logistical areas required for operations (installations, storage areas, workshops, offices, etc.), and determining the means of execution, including contracting, subcontracting, or outsourcing activities;

ii. Before the commencement of operational activities—a stage intended to validate the assessment conducted during the design phase and, where appropriate, to supplement it by accounting for operational details that could not be identified earlier, such as the specific type of lifting equipment used, safety data sheets for substances and materials, or actual on-site working conditions;

iii. During the execution of the work, whenever significant changes to execution processes occur—such as changes in work technology, the introduction of new installations or machinery, the opening of new work fronts, the use of new materials or substances, the emergence of interfering activities (e.g., additional subcontractors), or following accidents, incidents, or hazardous situations.

The analysis must take into account the actual conditions under which activities are carried out, as well as the level of compliance with the minimum requirements established by applicable legislation—requirements that must be strictly observed regardless of the nature of the work performed (e.g., the equipping of machinery and work equipment, compliance with regulations regarding electrical installations, requirements applicable to temporary works etc.) [17].

The assessment method applicable to the three stages previously identified is based on the recommendations of the European Agency for Safety and Health at Work, which provide guidelines for conducting a proper and effective occupational risk assessment. The main stages of the assessment process are as follows [18]:

- *hazard and at-risk person identification* – identifying workplace factors that could cause accidents or occupational illnesses, as well as the workers potentially exposed to these hazards;
- *risk assessment and prioritization* – analyzing identified risks by estimating the severity of consequences and the likelihood of occurrence, followed by classifying risks based on their level of importance;
- *determining preventive measures* – identifying the technical, organizational, and protective measures required to eliminate or control residual risks;
- *implementing established measures* – applying prevention and protection measures by developing and executing a priority-based action plan;
- *documenting the assessment* – preparing the necessary documentation to ensure the traceability of activities performed and measures implemented;

- *monitoring and reviewing the assessment* – verifying the effectiveness of implemented measures and periodically re-evaluating risks to ensure the assessment remains up-to-date with evolving activities and working conditions.

The risk assessment covering all three previously identified stages (the design stage, the stage prior to the commencement of works, and the stage involving significant modifications or the occurrence of accidents / incidents) is carried out by the site's OHS officer and approved by the Contractor's Representative [19]. The heads of the Design, Construction, and Work Area Management departments have the following responsibilities:

- to make available to the OHS officer all information and documents necessary for conducting a comprehensive assessment of the risks and hazards specific to the activities being carried out (execution methods, preliminary design documentation, plans, models, work schedules, etc.);
- to ensure that the risk assessment results and the established measures are integrated into and applied within the final documents and the operational activities carried out on the construction site.

For an accurate risk assessment, it is necessary to identify—based on the project or working conditions—potential sources of danger and the individuals exposed to the risk of a harmful event arising from these sources [20]. The assessment can be carried out using various methods: semi-qualitative mathematical models, best practice guidelines, logical reasoning, standardized checklists, and statistical techniques [21]. The chosen method must always be documented in the Risk Assessment Document or the specific Occupational Health and Safety Plan. Presented below is the Kinney-Wiruth semi-quantitative method, which was applied in the present study and is extensively substantiated and described in the specialized literature [22], [23], [24]. The formula adopted for calculating the risk level is as follows: [25]:

$$R = P \times G \times E$$

where:

P = the probability of the event occurring (table 2);

G = the severity of the consequence (table 3);

E = exposure factor depending on the number of exposed workers (table 4).

Table 2. Probability rating scale for identified risks

Classification of the probability of OHS events		Value	Level
Very likely	- There is a direct link between the identified deficiency and the occurrence of potential harm to workers - Such harm has already occurred due to the same deficiency—whether within the same company, in similar companies, or in similar operational situations - The occurrence of harm resulting from the identified deficiency would come as no surprise to the Organization.	4	C
Likely	- The identified deficiency could cause harm, even if not automatically or directly. - There are known instances where the deficiency was followed by harm. - The occurrence of the hypothetical harm would elicit moderate surprise within the Organization.	3	B
Low likelihood	- The identified deficiency could cause harm only under an unfortunate combination of circumstances - Only very rare past occurrences are known - The occurrence of the hypothetical harm would come as a major/moderate surprise to the Organization.	2	A
Unlikely	- The identified deficiency could cause harm as a result of the simultaneous occurrence of several independent and unlikely events - No such episodes are known to have occurred - The occurrence of such harm would be met with skepticism within the Organization.	1	0

Table 3. Severity rating scale for consequences

Classification of OHS incident severity		Value	Level
Very serious	Events resulting in: ▪ Fatal accident ▪ Permanent injuries, regardless of the actual number of days off work, involving permanent disability > 15 points.	1000	D
Serious	Events resulting in: ▪ Permanent injuries, regardless of the actual number of days off work, involving permanent disability of < 15 points. ▪ Accidents with a prognosis of > 40 days (serious or very serious accidents).	100	C
Relevant	Events causing: ▪ Accident with a prognosis of > 3 and ≤ 40 days	25	B
Modest	Events causing: ▪ Accident with a prognosis of ≤ 3 days	5	A
Low	An event that does not result in the injured worker refraining from work and can be addressed through: medical treatment; temporary reassignment of duties.	1	0

Table 4. Classification of exposure classes regarding the risk associated with identified hazards

Classification of OHS event exposure		Value	Level
High	▪ Over 20 exposed workers, even if not at the same time.	20	C
Significant	▪ Between 11 and 20 exposed subjects, even if not simultaneously.	10	C
Average	▪ Between 6 and 10 exposed subjects, even if not simultaneously	5	A
Limited	▪ Up to 5 exposed subjects, even if not simultaneously	1	0

The risk level classification matrix is presented in Table 5. The resulting R-value is compared against the matrix in Table 6. If the numerical value falls within the green zone, the risk may be considered acceptable; in all other cases (yellow, orange, and red zones), preventive and/or protective measures must be implemented to bring the risk value back to an acceptable level (green zone). The numerical risk value (R) and the identified preventive and protective measures must be recorded in the risk assessment form.

Specific risk assessments—such as those for exposure to noise, vibrations, electromagnetic fields, chemical hazards, fire, etc.—must be conducted using mathematical models proposed or established by nationally or internationally recognized bodies [26]. Based on this analysis, the technical, organizational, and procedural measures required to prevent risks and protect workers exposed to hazards must be identified, alongside precautionary measures aimed at continuous improvement [27].

Table 5. Risk level classification grid

		Exposure			
		1	5	10	20
P x G	1	1	5	10	20
	2	2	10	20	40
	3	3	15	30	60
	4	4	20	40	80
	5	5	25	50	100
	10	10	50	100	200
	15	15	75	150	300
	20	20	100	200	400
	25	25	125	250	500
	50	50	250	500	1000
	75	75	375	750	1500
	100	100	500	1000	2000
	200	200	1000	2000	4000
	300	300	1500	3000	6000
	400	400	2000	4000	8000
	1000	1000	5000	10000	20000
	2000	2000	10000	20000	40000
	3000	3000	15000	30000	60000
	4000	4000	20000	40000	80000

Table 6. Risk interpretation tool for prioritization

Risk value	Risk level	Recommended action
1- 20	Acceptable	Continuous monitoring
21-99	Low	To be scheduled for the short/medium term
100-999	Acceptable	To be scheduled urgently
> 1000	Inacceptable	Immediate actions

In situations where the residual risk level is considered unacceptable (according to the criteria set out in Table 6), the OHS department establishes additional prevention and protection measures that must be implemented to reduce the risk to an acceptable level.

Following the implementation of the established preventive and protective measures, a risk re-evaluation is conducted to determine the residual risk level and verify the effectiveness of the adopted measures. Conditions identified as presenting residual risk must be continuously monitored, and the risk assessment must be reviewed and updated whenever changes occur in working conditions, technological processes, or risk factors present on the site [28].

5. Assessment of foreseeable risks and development of the specific safety plan

Occupational risk assessment

By systematically applying the previously described method, a risk assessment was conducted for the two work phases: **Phase I – Execution of piles for the portals**, involving pile drilling, cleaning the borehole base, pile reinforcement, concreting, casing extraction, base grouting, pile head preparation, shotcreting of portal walls, and drilling for tensioning anchors (identified hazards are listed in lowercase in the risk assessment sheet in Table 7); **Phase II – Mechanized TBM operations** (maintenance and intervention work in the excavation chamber—identified hazards are listed in uppercase in Table 7). The characteristics considered during the identification and quantification of risks regarding occupational accidents and illnesses are summarized below:

- ✓ **Activity:** tunnelling operations;
- ✓ **Personnel involved:** 20 individuals: work supervisors, machine and heavy equipment operators, tunnel boring machine operators, steel fixers/concreters, carpenters, unskilled laborers, survey workers, laboratory technicians, crane operators, load slingers, lifting equipment operators, welders, mechanics/fitters, sandblasters, painters, asphalt workers;
- ✓ **Means/Equipment used:** chainsaws, excavators, bulldozers, dump trucks, motor graders, road rollers, hydraulic binder transport trucks, hydraulic binder spreading equipment, motor scrapers, water tankers, drilling rigs, conveyor belts, shotcreting equipment, formwork systems, concrete transport trucks, concrete pumps, concrete injection equipment, cranes, front-end loaders, aerial work platforms, self-elevating platforms, scaffolding and falsework, concrete vibrators, hand tools and work devices, welding equipment, pressure vessels, electric generators, sandblasting equipment, air compressors, asphalt pavers, asphalt dump trucks, sweeper trucks, TBM (Tunnel Boring Machine), hyperbaric chamber, refuge chamber, MSV (Multi-Service Vehicles);
- ✓ **Hazardous materials/substances used:** industrial gases, bituminous emulsion, paint, thinner;
- ✓ **Personal Protective Equipment (PPE):** Safety helmet, safety footwear, reflective vest, safety glasses, protective gloves, ear muffs/earplugs, safety harness for working at heights, dust masks.

Table 7. Results of the occupational risk assessment for tunnel construction using a TBM

Hazards	Initial risk				Prevention and protection measures	Residual risk			
	P	G	E	R = PxGxE		P	G	E	R = PxGxE
Entanglement or being pulled towards moving parts (at the drilling rig)	2	25	10	500 R.M. (C)	- Unauthorized access to the drilling rig is prohibited, as is workers climbing onto or off the rig while it is in operation; - The drilling rig must be operated only by authorized and specially trained personnel; - Manual intervention to change components is prohibited; - Maintenance and cleaning of the rig must be performed by authorized personnel only when the rig is shut down and the drive motors are stopped and secured against accidental startup; - If maintenance work must be performed while one or more machine functions are active, it must be carried out in accordance with precise, approved, and mandatory	1	5	10	50 R.S. (B)

Hazards	Initial risk				Prevention and protection measures	Residual risk			
	P	G	E	R = PxGxE		P	G	E	R = PxGxE
					instructions, as well as the manufacturer's technical recommendations and safety rules; - Starting the rig without the protective guards for moving parts in place is prohibited; - Wearing loose-fitting clothing or garments with loose sleeves that do not fit snugly against the body is prohibited.				
Falling into unmarked drilled holes	3	100	10	3000 R.I. (D)	- Signage indicating the risk of falling – access restriction; - Fencing off work areas and mandatory installation of a metal safety barrier around the borehole (minimum height of 1.5 m); - Prohibition of access to the work area for persons without official duties.	2	25	10	500 R.M. (C)
Fall from a height	3	100	10	3000 R.I. (D)	- Use of standardized ladders; - Use of PPE specific to working at heights; - Use of collective protective equipment (guardrails); - Proper training of workers regarding the safe performance of work at heights, work methods, and the correct use of safety harnesses; - Personnel performing work at heights must hold medical clearance from an occupational health physician stating "FIT FOR WORK AT HEIGHTS."	2	25	10	500 R.M. (C)
Handling heavy reinforcement elements with a crane – failure of binding elements – crushing of workers	2	100	10	2000 R.I. (D)	- Use of certified, authorized, and properly marked load-rigging and securing components that are in good condition, in accordance with PT ISCIR regulations; - Inspection of load-rigging and securing components prior to use; - Prohibition of manually guiding or positioning loads suspended from the lifting equipment hook; guidance must be performed remotely, using only guide ropes; - Passing underneath a load suspended from the lifting equipment hook is prohibited; - Load-lifting operations must be continuously supervised by the person in charge of the work; - Operating loads with the crane is prohibited when wind speeds exceed the limits specified by regulations.	1	25	10	250 R.M. (C)
Snagging, tripping – same-level fall	2	25	10	500 R.M. (C)	- Leveling the surface in the work area; - Maintaining order and cleanliness on work platforms; - Mandatory use of: safety helmet, safety footwear, and protective gloves; - Ensuring the safe movement of workers; - Marking excavations, pits, and obstacles; - Removing obstacles from the work area or marking them if removal is not possible; - Cables must be suspended and properly marked.	1	5	10	50 R.S. (B)
Gas emissions resulting from the welding process	2	25	10	500 R.M. (C)	- Ensuring ventilation in enclosed spaces where welding takes place; - Providing appropriate training for workers; - Restricting worker access to the work area.	1	1	10	10 R.A. (A)
Thermal radiation during welding – contact with molten metal particles propelled into the atmosphere and with hot surfaces.	2	25	10	500 R.M. (C)	- Use of welding masks or protective screens; - Use of protective equipment (heat-resistant gloves, leather apron, leggings, etc.); - Adherence to the specific instruction "Metal Cutting and Welding"	1	1	10	10 R.A. (A)
Contact with sharp or pointed surfaces	3	5	10	150 R.M. (C)	- Use of protective equipment specific to the work; - Maintaining order and cleanliness at the workplace.	2	1	10	20 R.A. (A)
Working with handheld power tools – electric shock	3	100	10	3000 R.I. (D)	- Handheld power tools must be inspected before use; - Power cables must be suspended on wooden supports; - The use of safety goggles is mandatory; - The use of power tools not equipped with an automatic shut-off mechanism (dead-man switch) is prohibited; - The use of power tools without protective guards for moving parts is prohibited.	2	25	10	500 R.M. (C)

Hazards	Initial risk				Prevention and protection measures	Residual risk			
	P	G	E	R = PxGxE		P	G	E	R = PxGxE
Conditions caused by the manual handling and transport of loads by carrying them directly	2	25	10	500 R.M. (C)	- Individual handling of heavy and bulky materials is prohibited; - Personnel shall be trained in accordance with occupational health and safety instructions regarding manual load handling; - The route taken by the worker while carrying loads must be free of obstacles and must not be unstable or slippery; - Material transport shall be mechanized whenever possible; - Only workers who are physically fit for the task shall be assigned.	1	5	10	50 R.S. (B)
Moving mobile equipment: striking, trapping, snagging, dragging under wheels, being struck by drilling material.	2	25	10	500 R.M. (C)	- Issuing audible and visual signals during maneuvering operations; - Use of reflective personal protective equipment (PPE); - Movement of workers within the area shall take place only along designated and properly marked access routes; - Proper signaling of hazards;	1	5	10	50 R.S. (B)
Shotcreting	3	1	10	30 R.S. (B)	- Use: protective gloves, safety goggles, rubber boots; - The pouring pump shall be positioned so that the pouring point is within the pump operator's line of sight; - Starting the pump shall be signaled audibly and shall take place only after receiving a confirmation signal to begin pouring from the worker responsible for handling the concrete distribution hose.	2	1	10	20 R.A. (A)
Skin conditions caused by contact with concrete	3	1	10	30 R.S. (B)	- Protective gloves must be worn; - Waterproof rubber protective boots must be worn. - In the event of skin contact, wash immediately with water.	2	1	10	20 R.A. (A)
Working with handheld pneumatic tools – noise, vibration	2	5	10	100 R.M. (C)	- The use of hearing protection and safety goggles is mandatory; - Pressure hoses must be connected to tools using only metal clamps; - The use of pneumatic tools not equipped with a self-locking device is prohibited; - Monitoring of the work environment and comparison with legal limits.	1	1	10	10 R.A. (A)
Natural gas seepage	3	1000	10	3000 R.I. (D)	- Continuous monitoring of flammable gas concentrations using multi-gas detectors; - Prohibition of open flames and smoking inside the tunnel, unless specifically authorized for such activities; - Avoidance of welding, grinding, cutting, and metal-on-metal mechanical impacts within the tunnel.	1	1	10	10 R.A. (A)
Unexploded ordnance (ammo)	1	1000	10	10000 R.I. (D)	- Carrying out demining operations prior to the commencement of excavation work; - Properly instructing workers on the measures to be taken in the event that unexploded ordnance is discovered; - Prohibiting the touching, moving, or displacing of discovered ordnance, whether manually or using machinery; - Notifying authorized companies to clear the discovered ordnance.	1	1	10	10 R.A. (A)
IMPACT FROM SPECIFIC TOOLS, IMPLEMENTS, AND WORK DEVICES – PUNCTURE, SCRATCHING, CUTTING, INJURY TO HANDS OR FEET.	3	25	10	750 R.M. (C)	- Daily safety briefing; - Use of personal protective equipment (protective gloves, safety goggles, overalls, etc.); - Pre-use inspection of work equipment; - Use of improvised or defective tools, hand tools, and work devices is prohibited; - Removal or bypassing of safety devices and protective elements on work equipment is prohibited; - Training workers on the safe use of tools and work devices; - Proper storage of reinforcement mesh; - Storage of material scraps in designated areas immediately after they are generated.	1	1	10	10 R.A. (A)
WORKING WITH HAND-HELD POWER TOOLS – ELECTROCUTION	3	100	10	3000 R.I. (D)	- Handheld power tools must be inspected before use; - Power cables must be suspended on wooden supports; - The use of safety goggles is mandatory; - The use of power tools not equipped with an automatic shut-off mechanism (dead-man switch) is prohibited; - The use of power tools without protective guards for moving parts is prohibited.	1	1	10	10 R.A. (A)

Hazards	Initial risk				Prevention and protection measures	Residual risk			
	P	G	E	R = PxGxE		P	G	E	R = PxGxE
WORKING WITH HAND-HELD PNEUMATIC TOOLS – NOISE, VIBRATION	2	5	10	100 R.M. (C)	- Mandatory use of hearing protection and safety goggles; - Pressure hoses must be connected to tools using only metal clamps; - Use of pneumatic tools not equipped with an automatic shut-off device (dead-man switch) is prohibited; - Worker training regarding the risks; - Monitoring of the work environment and comparison with legal limits; - Action plan to mitigate exceedances of legal limits; - Provision of tunnel lighting in accordance with applicable standards.	1	1	10	10 R.A. (A)
CONDITIONS CAUSED BY THE MANUAL HANDLING AND CARRYING OF LOADS	2	25	10	500 R.M. (C)	- Individual handling of heavy and bulky materials is prohibited; - Personnel shall be trained in the manual handling of loads in accordance with occupational health and safety instructions (IPSSM); - The route taken by the worker while carrying loads must be free of obstacles and must not be unstable or slippery; - Material transport shall be mechanized whenever possible; - Only workers who meet the necessary physical requirements shall be assigned to the task; - Tunnel lighting must be provided in accordance with applicable standards.	1	1	10	10 R.A. (A)
ATMOSPHERIC PRESSURE DIFFERENCES – GAS EMBOLISM	3	100	10	3000 R.I. (D)	- Worker training - Only specially qualified workers with relevant experience and the necessary competence to perform the task shall be assigned; - Workers without experience shall be continuously supervised by a competent person; - It is strictly prohibited to assign workers who do not hold medical clearance for working in compressed air. - All workers must be instructed and trained for fire response; - All persons involved in the lockout/tagout procedure must undergo a medical examination and be declared medically fit to perform this procedure;	1	1	10	10 R.A. (A)
Lack of GENERAL OHS/FIRE SAFETY/ENVIRONMENTAL TRAINING UPON SITE ENTRY	3	100	10	3000 R.I. (D)	- Before commencing work, all personnel must undergo OHS, fire safety, and environmental training for site access.	1	1	10	10 R.A. (A)
ACTIVITY-SPECIFIC TRAINING AND MEDICAL TESTING: The worker themselves is considered a hazard if they do not comply with health and safety standards or are unfit for the task.	3	100	10	3000 R.I. (D)	- All personnel must participate in workplace training and instruction. - Qualified and competent personnel shall be used for activities corresponding to the assigned work tasks. - No one shall be permitted to work in compressed air unless medically authorized.	1	1	10	10 R.A. (A)
MANUAL HANDLING OF LOADS: Back injury, injuries, cuts, and abrasions during the handling of hazardous materials.	3	100	10	3000 R.I. (D)	- Use personnel experienced in manual load handling; - Limit manual lifting to a maximum of 50 kg. - Follow safe manual lifting procedures to prevent injury. - If the load exceeds one person's capacity, arrange for a second person to assist; - When a load is lifted by more than two people, designate one person to communicate information and control the movement of the load. - Ensure appropriate equipment is used for lifting heavy loads.	1	1	10	10 R.A. (A)

Hazards	Initial risk				Prevention and protection measures	Residual risk			
	P	G	E	R = PxGxE		P	G	E	R = PxGxE
ENTRANCE AND EXIT (TUNNEL): Unauthorized access. Tripping hazards. Asphyxiation. Personnel struck by moving equipment.	3	100	10	3000 R.I. (D)	- Access to the tunnel shall be conducted in accordance with a Standard Operating Procedure, which must be strictly adhered to; - Only designated pedestrian access paths and walkways shall be used; - Adequate ventilation within the tunnel shall be ensured; - Gas concentrations within the tunnel shall be monitored regularly; - Work Permits shall be issued for personnel maintaining the traffic routes; - Mobile, temporary safety barriers shall be installed in work areas and at the safety perimeter of moving equipment; - Scaffold towers with access ladders or lifts shall be provided for access from the surface into the tunnel; - The continuous use of high-visibility protective equipment is mandatory; - The audible warning systems of MSVs (Multi-Service Vehicles) shall be checked daily;	1	1	10	10 R.A. (A)
WORK IN CONFINED SPACES: Untrained personnel. Inadequate ventilation. Suffocation due to oxygen deficiency. Presence of flammable and toxic gases. Fire and explosion.	3	100	10	3000 R.I. (D)	- The Standard Operating Procedure for tunnel access must be strictly followed; - A confined space entry permit must be obtained before entering the confined space; - Access to confined spaces shall be permitted only for persons trained and competent to perform tasks in restricted spaces; - Oxygen levels and the presence of flammable and toxic gases must be continuously monitored; - A portable gas detector must be provided for periodic use at 4-hour intervals; - Ensure space ventilation and guarantee that the minimum fresh air flow rate supplied to the confined space does not fall below 0.30 m³/min/person. - A portable fire extinguishing system must be provided in the fire-hazard zone. - Fire-fighting training must be conducted monthly. - Adequate lighting must be provided inside the tunnel, in accordance with specifications, to suit pedestrian needs.	1	1	10	10 R.A. (A)
HYPERBARIC CHAMBER PRE-CHECK (MAN LOCK): Air losses, Slips, Displacements, Falls	3	100	10	3000 R.I. (D)	- Before entry, the door seals and their closing and locking systems must be checked; - If the seals are dirty, clean them and apply a thin layer of silicone spray; - Check the seal and integrity of the viewing window; the viewing window must be clean and free of scratches; - Ensure that all door ball valves are in working order; - Do not place flammable materials inside the hyperbaric chamber; - Perform a visual inspection for issues such as mechanical damage, both inside and out; - Ensure that safety valves and pressure monitoring devices are in working order; - Check the air supply hoses; - Regularly check the operation of the telephone and emergency communication systems; - Ensure the fire suppression system is operational for chamber sessions; - The access area to the man-lock must be clear and free of obstructions.	1	1	10	10 R.A. (A)
PRE-CHECK OF THE AIR COMPRESSOR: Hose burst Injury	3	100	10	3000 R.I. (D)	- The air compressor must have a valid certificate of conformity; - Use hoses that are certified to relevant standards and of the appropriate size; - Check the compressor against the checklist before operation; - Periodically check the integrity and proper functioning of the valves, as well as the calibration of working pressure limits; - Periodically drain/purge condensate (water) from the air lines.	1	1	10	10 R.A. (A)

Hazards	Initial risk				Prevention and protection measures	Residual risk			
	P	G	E	R = PxGxE		P	G	E	R = PxGxE
AIR SUPPLY: - Air supply system malfunctions - CO2 poisoning - Air/oxygen leaks - Fire	3	100	10	3000 R.I. (D)	- Maintain the required working pressure (at the face) based on geological conditions. The maximum working pressure is 3.5 bar; - The compressed air used must be of breathable air quality; - Maintain a pressure of 6–8 bar for the compressed air supply and the breathable air in the control chamber; - Ensure an oxygen (O2) supply to the control cabin at a pressure of 10 bar; - All couplings must be sealed to prevent air/O2 leakage; - Verify that the set pressure remains constant; - If the oxygen (O2) pressure in the supply line exceeds the maximum limit, the safety valve must discharge; connect a discharge line to vent the O2 to a safe location; - Increase chamber ventilation to reduce the CO2 concentration inside the hyperbaric chamber.	1	1	10	10 R.A. (A)
HYPERBARIC CHAMBER SUPERVISION (MAN LOCK): - Unsuitable person - Lack of communication Miscommunication ; - Lack of control	3	100	10	3000 R.I. (D)	- The man-lock supervisor shall record all stages of the intervention (entry into and exit from the man-lock and the excavation chamber, as well as compression and decompression times); - Repeated or multiple exposures must be avoided; - No one shall work in compressed air exceeding 3.50 bar; - Persons without a cutterhead access permit shall not be allowed to enter the excavation chamber; - The man-lock supervisor must be a competent person; - The man-lock supervisor maintains continuous communication with person working inside the excavation chamber; - The man-lock supervisor and the workers inside the man-lock and the excavation chamber must communicate clearly; - The man-lock supervisor shall not allow more than 3 persons to enter the main man-lock; - The man-lock supervisor shall not leave the supervision post until the last person has exited the chamber.	1	1	10	10 R.A. (A)
LOCKING / UNLOCKING COMPRESSION / DECOMPRESSION MAN LOCK / HYPERBARIC CHAMBER; - High temperature - Toxic gases - Atmospheric pressure differences/ variations - Stress/Fatigue - Fire hazard	3	100	10	3000 R.I. (D)	- Compressed air operations must be performed by a competent, qualified, authorized, and trained person; - Working in compressed air is strictly prohibited for individuals not certified as medically fit; - A chart showing compression and decompression times must be displayed at the man lock entrance; - Do not allow individuals to remain in the man lock longer than the prescribed duration specified in the chart; - The LO-TO (Lockout/Tagout) procedure must be strictly followed; - Pay close attention to the compression and decompression stages; - Immediately identify and report any signs of decompression issues following lock-in; - Flammable materials are not permitted inside the man lock; - The man lock supervisor must maintain continuous communication with workers inside the excavation chamber; - Gas detection must be performed; work must be halted if concentrations exceed permissible limits; - A water-based fire suppression system must be provided at the personnel airlock and the excavation chamber.	1	1	10	10 R.A. (A)
PERSONS INSIDE THE HYPERBARIC CHAMBER (MAN LOCK): - Serious health hazard - Fire - Poisoning/suffocation - Loss of pressure - Noise	3	100	10	3000 R.I. (D)	- Maintain constant pressure (exhausted air must be replaced by an equal amount of fresh air). - If the O2 pressure in the supply line is excessive, the safety valve must open to reduce the risk of fire. The oxygen discharge line must be routed to a safe area. - All couplings must be sealed to prevent air/O2 leaks. - A permanent telephone link must be maintained between the intervention operator and the Man Lock Supervisor. - Optimal and efficient fresh air circulation must be ensured inside the Man Lock to prevent suffocation/intoxication and to reduce humidity. - Provide noise attenuation systems during Man Lock ventilation.	1	1	10	10 R.A. (A)

Hazards	Initial risk				Prevention and protection measures	Residual risk			
	P	G	E	R = PxGxE		P	G	E	R = PxGxE
ENTRY OF PERSONS INTO THE HYPERBARIC CHAMBER ANTECHAMBER (MAN LOCK); - Falling materials - Falls of persons - Fatigue - Dehydration - Injury/death	3	100	10	3000 R.I. (D)	-The TBM cutterhead/milling rotor must be stopped before entering the Man Lock antechamber. -Turn the key on the control cabin panel to the "Off" position, remove it, and hand it over to the intervention operator. -Open access to the cutterhead/milling rotor maintenance control panel. -Insert the key into the cutterhead maintenance control panel (external position). -Turn off the maintenance switch and secure it against restart using a personal LO-TO padlock. -Personnel are prohibited from being in the working chamber while the cutterhead position is being changed. -Rotating the cutterhead (clockwise and/or counter-clockwise) must be performed by the intervention operator using the remote control. -The temperature of the working chamber must be continuously monitored. -A sufficient supply of ORS (oral rehydration solution) packets must be kept in the lock chamber. A sufficient supply of drinking water must be ensured. -Reposition the cutterhead. -Before entering the antechamber, the TBM main key must be turned to the "OFF" position and kept outside the Man Lock (with the Man Lock Supervisor). -A permanent telephone connection must be maintained between the intervention operator and the Man Lock Supervisor.	1	1	10	10 R.A. (A)
WORKS IN THE EXCAVATION CHAMBER; - Falling materials - Falls of persons	3	100	10	3000 R.I. (D)	- Check the stability and permeability of the tunnel face. - Workers in the hyperbaric zone must immediately move from the excavation chamber to the main chamber if a loss of pressure occurs due to water ingress or a tunnel face collapse. - Before entering the excavation chamber, check for loose rocks that could fall. - Uncontrolled bentonite feed into the excavation pre-chamber must be avoided while personnel are working inside. - Never block escape routes with cables, ropes, or other materials. - Adequate lighting must be provided for the work area.	1	1	10	10 R.A. (A)
EXITING THE EXCAVATION CHAMBER; - Fatigue - Dehydration - Injuries - Physical disorders - Mental disorders	3	100	10	3000 R.I. (D)	- After completing the work, ensure that all personnel have left the excavation chamber. - Close the door. - Operate the access door locking system. - Turn the key on the cutterhead maintenance control panel to the " cabin control " position, remove it, and take it with you. - Insert the key into the control cabin panel: " cabin control " position. - Press the " cabin control release " button.	1	1	10	10 R.A. (A)
LIFTING AND HANDLING OPERATIONS FOR CUTTERHEAD WEAR PARTS; - Operations performed by unqualified or untrained persons. - Use of damaged or non-certified tools.	3	100	10	3000 R.I. (D)	- Only authorized, qualified, and competent personnel may perform lifting and handling operations. - All lifting tools, equipment, and devices must be inspected using a checklist prior to being put into service. - The use of damaged or non-certified lifting tools, equipment, or devices is strictly prohibited. - All lifting tools, equipment, and devices (manual hoists, chains, slings, etc.) must be in good condition. They must possess a valid certificate issued by a third party (ISCIR). - Standing, passing, or performing work beneath suspended loads is strictly prohibited.	1	1	10	10 R.A. (A)
MEANS AND MODES OF COMMUNICATION - Lack of communication or poor communication	3	100	10	3000 R.I. (D)	- Ensure and verify the audio communication system and equipment connecting the excavation chamber, the control cabin, and the man lock chamber before work begins. - Provide a dynamic telephone that operates independently of an external power supply. - The man lock supervisor must maintain continuous communication with workers inside the excavation chamber.	1	1	10	10 R.A. (A)

Hazards	Initial risk				Prevention and protection measures	Residual risk			
	P	G	E	R = PxGxE		P	G	E	R = PxGxE
- Loud howling / whistling sound-Communication malfunction					- The man lock supervisor and the workers must communicate clearly. - The volume control must be properly adjusted. Ensure that the microphone and speaker are functioning correctly. - Ensure that the cables are correctly connected.				
OPERATION OF INSTALLATIONS AND EQUIPMENT; - Malfunction of installations and equipment	3	100	10	3000 R.I. (D)	- The operator must hold a valid authorization and a valid physical/medical fitness qualification or certificate. - All installations, equipment, machinery, power tools, and hand tools must be in good condition, free from defects or makeshift modifications. - Safety, locking, and interlocking systems, as well as all components of the overall system, must be approved by a third party. - No part of the safety, locking, or interlocking systems may be replaced without approval.	1	1	10	10 R.A. (A)
HAND TOOLS/POWER TOOLS; - Electric shock - Numbness of the body - Noise pollution - Hearing loss	2	5	10	100 R.M. (C)	- Always use the right tool for the task. Makeshift solutions are not permitted. - Use appropriate tools powered by safe voltages (<110 V). - Ensure that all appropriate safety guards are installed and functional. - Never carry a tool by its cable or hose. - Never pull on the cable or hose to disconnect it from the power source. - Use both hands to operate the tool. - Follow the manufacturer's instructions for lubrication and accessory changes. - Maintain a stable stance and good balance while using a power tool. - Remove damaged portable power tools from service and label them "Do Not Use." - Ensure rotation of tasks and appropriate work intervals. - Keep cables and hoses away from heat sources, oil, and sharp edges.	1	1	10	10 R.A. (A)
LIGHTING SYSTEM; - Reduced visibility	2	5	10	100 R.M. (C)	- Provision of emergency power supply (battery backup) to maintain the electricity supply even in the event of a mains power failure. - Monitoring and ensuring light intensity appropriate for the work being performed is required.	1	1	10	10 R.A. (A)
ENVIRONMENTAL PROTECTION; - Pollution: accidental spills	2	5	5	50 R.M. (C)	- Any waste resulting from maintenance activities and spills must be removed and stored in appropriate containers. - Collection of contaminated wash water and disposal as hazardous waste.	1	1	10	10 R.A. (A)
SITUAȚII DE URGENȚĂ; - Riscuri pentru sănătate - Îmbolnăvire - Leziuni	2	5	5	50 R.M. (C)	- In the event of an emergency, appropriate medical kits and qualified/trained personnel capable of treating affected staff must be available on-site. - Refuge chambers (with a capacity of 20 persons) must be provided within the TBM. - First aid personnel must be present on-site. - All personnel must participate in fire-fighting training/briefings and be familiar with fire-fighting measures. - Emergency contact numbers must be displayed near the site. - An Emergency Rescue Team (ERT) must be present on-site. - All persons subject to the "Man Lock" procedure must be trained on the operation of the communication system, the alarm signaling system, and the fire suppression system. - Suitable pumps must be available. - A multi-service vehicle must be available near the TBM to transport an injured or affected person to the evacuation shaft area. - A transport basket must be available to bring the victim to the surface using a mobile or gantry crane.	1	1	10	10 R.A. (A)

The implementation of the measures is continuously ensured throughout the duration of the work by the site manager or work site supervisor.

Substantiating the specific health and safety plan

High-risk and specific zones

The Project Manager, together with the site coordination staff, is required to identify, assess, and continuously monitor areas of high and specific risk associated with the tunnel construction works. These areas will be appropriately demarcated and marked, and access to them will be restricted to authorized personnel who are properly trained and equipped. Given the specific nature of the operations performed using the TBM, the primary **areas of high and specific risk** are:

- the excavation face and cutterhead area;
- the excavation chamber and areas where hyperbaric work is performed;
- the TBM area and associated auxiliary installations;
- the area for transporting precast segments and handling suspended loads;
- the area containing conveyor belts and excavated material removal systems;
- vehicle and service train traffic routes within the tunnel;
- areas containing medium- and low-voltage electrical installations;
- storage and supply areas for fuels, lubricants, and other hazardous substances;
- areas at risk of fire and explosion;
- confined spaces and areas where hazardous gases may accumulate or oxygen levels may be depleted;
- areas for the assembly and maintenance of mechanical and hydraulic equipment.

Hazards associated with activities carried out in high-risk areas have been identified and assessed, and specific measures have been established to eliminate or reduce occupational risks. Specific procedures and work instructions have been developed for high-risk activities and communicated to workers prior to the commencement of work. To prevent accidents and protect workers' health, the following measures shall be applied, as appropriate:

- delineation and marking of work areas and hazardous zones;
- access control for high-risk areas;
- continuous monitoring of the tunnel atmosphere;
- verification of ventilation and communication system functionality;
- implementation of Lockout/Tagout procedures for equipment interventions;
- use of personal protective equipment appropriate to the identified risks;
- periodic inspection of equipment, machinery, and installations;
- compliance with procedures regarding hyperbaric work and access to the excavation chamber;
- provision of facilities for first aid and emergency response;
- keeping evacuation routes and access paths clear at all times;
- monitoring compliance with occupational health and safety measures by all personnel on site.

All persons carrying out activities within the project are required to comply with the provisions of the specific Health and Safety Plan, work instructions, and established prevention and protection measures, as well as the directives of the personnel designated to coordinate occupational health and safety activities.

Management of training, information, and instruction in the field of OHS

All workers involved in the execution of the work receive general introductory and periodic training tailored to the specific activities performed and the risks present on the construction site. The training process covers applicable legislation, general and specific risks, first aid measures, emergency procedures, and rules regarding the use of work equipment and personal protective equipment.

Workers are kept informed on an ongoing basis through "toolbox talk" meetings, posters, and informational materials, as well as through communication regarding any changes in the execution process. Training effectiveness is verified through periodic testing, field observations, inspections, and internal audits. For high-risk activities, workers must possess the qualifications, authorizations, and competencies required by applicable legislation. Furthermore, personnel with responsibilities regarding OHS, emergency situations, and first aid provision participate in specialized training programs designed to ensure the effective management of risks and emergencies on the site.

Management of worker health surveillance

Health surveillance management aims to ensure worker protection against occupational risks specific to TBM (Tunnel Boring Machine) tunneling operations and to maintain workers' fitness for work throughout the project's duration. Health monitoring is conducted in accordance with applicable national legislation and is tailored to the specific conditions of underground work.

The occupational health service assists in identifying and preventing occupational conditions associated with mechanized excavation and tunneling, continuously monitors personnel health, and provides recommendations on adapting work tasks to the workers' physical and psychological characteristics. Particular attention is paid to monitoring respiratory, musculoskeletal, and auditory conditions, as well as those linked to exposure to high pressures or specific underground working conditions. For interventions within the TBM excavation chamber or other activities performed under hyperbaric conditions, workers undergo additional medical evaluations and must meet specific medical fitness requirements. These activities are carried out according to approved procedures, under appropriate medical supervision, and in compliance with compression and decompression protocols.

Management of Personal Protective Equipment (PPE)

The process of managing personal protective equipment (PPE) encompasses identifying requirements, procurement, distribution, and worker training on proper use, as well as periodic inspection and maintenance. Equipment is selected based on the specific nature of the activities performed and the results of the occupational risk assessment.

Each worker receives the necessary equipment before commencing work and is required to use it correctly throughout the entire workday. Furthermore, workers receive training on how to use and maintain the equipment, as well as how to report any damage or non-conformities.

To ensure the continued effectiveness of protective measures, the equipment undergoes periodic inspections, and any items showing defects or wear are replaced immediately. Compliance with the rules regarding the use of personal protective equipment is continuously monitored.

Tunnel construction site setup and organization

For the tunnel project, site organization aims to ensure a continuous operational flow between the portal area and the excavation face, while maintaining an adequate level of safety for all personnel involved in the construction process. To this end, distinct zones are established for personnel access, equipment movement, material storage, machinery maintenance, and emergency management.

Access to the tunnel is controlled through specific procedures that allow for the continuous monitoring of personnel underground. The need for such a system arises from the specific nature of the working environment, where significant distances from the portal and the potential for unforeseen events necessitate constant knowledge of the number and location of individuals inside the tunnel.

Particular attention is paid to setting up the temporary infrastructure required for the TBM's operation. The machine's functioning relies on complex auxiliary systems, including power supply, industrial water networks, compressed air installations, drainage systems, and communication infrastructure. Without these, the excavation process cannot be carried out safely and efficiently. Consequently, the layout and organization of the tunnel worksite constitute not merely a logistical task but a complex risk management process that helps protect worker health and safety while ensuring the continuity of the execution process.

Traffic routes and danger zones

Unlike conventional construction sites, where access routes can be easily modified as work progresses, the transport infrastructure for TBM-excavated tunnels is constrained by the underground spatial configuration and the placement of technical installations. As excavation advances, a complex transport and supply system develops within the tunnel, comprising service trains, specialized vehicles, lifting equipment, utility pipelines, electrical cables, and conveyor belts for muck removal. The coexistence of these elements creates numerous points of potential interference that must be identified and managed as early as the work planning stage.

A key aspect of traffic organization is the delineation of pedestrian routes. Personnel movement to the tunnel face, assembly areas, or intervention points must take place along dedicated routes that are clearly marked and—to the extent possible—separated from areas used for transporting materials and equipment.

Particular attention must be paid to the movement of service trains used to supply the TBM and transport the precast segments required for the tunnel lining. This equipment operates in confined spaces with limited visibility and restricted room for manoeuvring around obstacles. Consequently, their movement must adhere to strict rules regarding travel speed, movement signalling, and communication between operators and personnel in the area. Transporting precast segments is another high-risk activity. The considerable weight and dimensions of these elements, combined with the need to handle them in confined spaces, can lead to serious accidents if the load loses stability or lifting systems fail. Therefore, transport

routes must be kept clear at all times, and handling operations must be coordinated to prevent personnel from entering the operating radius of suspended loads. In TBM-excavated tunnels, the removal of excavated material is frequently carried out using conveyor belts. While these improve process efficiency, they also introduce specific risks associated with entrapment, entanglement, or crushing points. For this reason, conveyor belts must be equipped with protective guards, emergency stop devices, and measures to prevent unauthorized access to hazardous areas. Crossing points for conveyor belt routes must be restricted to specially designated and clearly marked locations.

In addition to areas designated for transport, the tunnel contains other spaces characterized by a high level of risk. Notable among these are the excavation face, the cutterhead area, the excavation chamber, high-pressure hydraulic systems, electrical equipment, segment installation zones, and areas where maintenance work is performed. Access to these zones is restricted to personnel who are authorized, trained, and specifically designated to carry out the respective activities.

A particular risk associated with tunnelling operations is the interference between activities taking place simultaneously in the same work sector. Operations such as material transport, segment installation, maintenance, and electrical work may occur concurrently, creating situations where individual risks can mutually compound. For this reason, the layout of traffic routes must be continuously coordinated with the analysis of simultaneous operations (SIMOPS) so that conflicts between activities can be identified and eliminated before work begins.

Storage of materials on the construction site and inside the tunnel

Storage areas are organized to allow safe access for personnel and equipment without disrupting the technological process. Materials are arranged in an orderly and stable manner to prevent shifting, tipping, or damage during handling and use. Prefabricated segments, spare parts, consumables, and other materials required for TBM operations are stored in locations that facilitate efficient supply to the work face and minimize the risk of accidents. Hazardous or flammable materials, as well as those posing potential health or environmental risks, are stored separately in compliance with applicable safety requirements.

Proper organization of storage areas helps maintain order and cleanliness within the tunnel, reduces occupational risks, and ensures the continuity of the construction process.

Waste management

During TBM operations, the main categories of waste consist of excavated material, packaging, scrap metal, waste from equipment maintenance, and municipal waste generated by personnel.

To prevent accidents and maintain a safe working environment, waste is collected separately and periodically removed from work areas. Uncontrolled accumulation can impede the movement of personnel and equipment, hinder evacuation during emergencies, and create additional risks of tripping, slipping, or fire.

Excavated material is continuously removed via the technical systems integral to TBM operations, ensuring that work proceeds without disruption or operational bottlenecks. Other waste categories are temporarily stored in designated areas and disposed of through authorized operators, in compliance with applicable legal requirements.

Temporary installations and utilities

For tunnelling operations, artificial lighting is essential for ensuring safe working conditions, given the absence of natural light and the specific nature of the underground environment. Lighting systems are designed to provide the visibility required for carrying out work, personnel movement, and equipment operation.

In addition to general lighting, localized lighting systems are used in areas where tasks requiring a high degree of precision are performed. Safety and emergency lighting systems are also installed to facilitate personnel evacuation and rapid response in the event of a power outage or emergency situation.

The electrical systems used for TBM operations supply power to the technological equipment, lighting systems, and auxiliary installations required for the construction process. Given the specific underground conditions, these systems are designed and operated to minimize the risks of electric shock, fire, and accidental power interruption. All electrical installations are clearly identified, protected, and subject to periodic inspections by authorized personnel. Any faults detected are rectified before the systems are put back into operation, and the results of the inspections are recorded in the relevant documentation.

Ventilation is one of the most important auxiliary systems used in tunnel construction, serving to ensure environmental conditions suitable for underground operations. The ventilation system is sized to provide the necessary fresh air supply, exhaust dust and gases generated by technological processes, and maintain appropriate working environment parameters.

System operation is continuously monitored, and air quality parameters are periodically checked to identify any situations that could compromise worker health and safety. Should faults occur or permissible limits be exceeded, the necessary measures are taken to restore normal working conditions.

Simultaneous operations (SIMOPS) and interface documents

TBM tunnelling involves the simultaneous execution of numerous interdependent activities, carried out by different teams using equipment with distinct functions. Under these conditions, the management of simultaneous operations (SIMOPS) is an essential tool for accident prevention and the efficient coordination of activities within the underground workspace. In TBM tunnelling projects, the effective application of SIMOPS principles helps minimize interference between activities, optimize resource utilization, and prevent accidents arising from the simultaneous conduct of multiple operations in a confined space. Consequently, the management of simultaneous operations constitutes a key component of the occupational health and safety management system implemented at the worksite.

6. Conclusions

The research conducted highlighted that tunnelling operations represent some of the most complex activities in the construction sector, both from a technological standpoint and regarding occupational health and safety. The underground environment, confined working space, use of high-power equipment, mechanized transport, hyperbaric conditions, and the need for interventions within the excavation chamber give rise to specific occupational risks that necessitate rigorous prevention and control measures. The study analyzed the responsibilities of the parties involved in the project, site organization from an occupational health and safety perspective, and the key technological processes that can impact worker safety. Furthermore, risks associated with each execution phase were identified and evaluated, and technical, organizational, and procedural measures were established to reduce risk levels and protect personnel.

The analysis results demonstrate that the use of TBM technology contributes significantly to reducing risks specific to conventional excavation by limiting workers' direct exposure to the excavation face, reducing ground instability, and increasing process automation. However, the technology introduces new challenges regarding risk management related to working in confined spaces, ventilation, atmospheric monitoring, hyperbaric operations, and emergency management. The major risks identified within the project are associated with hyperbaric operations, cutterhead interventions, and potential tunnel fires (summary table 8).

Table 8. A summary of the major risks identified

Causes	Consequences	Measures
<i>Hyperbaric works</i>		
Incorrect decompression	Decompression sickness	Medical supervision
Medically unfit personnel	Barotrauma	Hyperbaric procedures
System malfunctions	Serious accident	Limiting exposure
<i>Cutterhead interventions</i>		
Accidental start-up	Crushing	Lockout-tagout
Hazardous atmosphere	Asphyxia	Work permit
Confined space	Fatal injury	Gas monitoring Rescue plan
<i>Fire in the tunnel</i>		
Electrical faults	Intoxications	Ventilation
Open-flame work	Burns	Fire extinguishers
Fuels and lubricants	Difficult evacuation	Evacuation drills
Equipment overheating	Suspension of work	Fire work permit

A key aspect highlighted in the paper is the importance of implementing an efficient occupational health and safety management system based on planning, continuous risk assessment, staff training, and ongoing monitoring of working conditions. Regarding risk assessment, occupational risks for exposed worker categories were identified and quantified using a semi-quantitative Kinney-type method. Applying the tools of this method during the risk assessment process enabled the formulation—for subsequent adoption and

implementation—of the most appropriate measures to minimize risks associated with specific hazards. The effectiveness of preventive measures depends directly on cooperation among the client, the contractor, OHS coordinators, and workers, as well as on adherence to established procedures for high-risk activities.

Furthermore, the analysis highlighted the pivotal role of emergency response measures. The availability of a dedicated medical team, hyperbaric chambers, refuge chambers, atmospheric monitoring systems, and first-aid equipment significantly enhances intervention capabilities and helps mitigate the consequences of adverse events.

Developing a specific Health and Safety Plan for the tunnel in question demonstrates that risk management must be approached as a continuous process, integrated into every stage of construction. This plan is not merely a legal requirement mandated by Government Decision no. 300/2006, but a practical management tool that enables hazard identification, the implementation of preventive measures, and the assurance of a safe working environment for everyone involved in the project.

In conclusion, the objectives of this study have been met: an applied analysis of the health and safety requirements specific to TBM tunnel construction was conducted, and a tailored Health and Safety Plan—adapted to actual site conditions—was established. Proper implementation of the measures outlined in this plan contributes to reducing occupational risks, preventing workplace accidents, protecting workers' health, and ensuring the safe execution of one of Romania's most important road infrastructure projects.

References

- [1] **Parlamentul României**, 2006
Legea securității și sănătății în muncă nr. 319/2006, Monitorul Oficial al României, Partea I, nr. 646/26.07.2006
- [2] **Guvernul României**, 2006
H.G. nr. 1425/2006 pentru aprobarea Normelor metodologice de aplicare a prevederilor Legii securității și sănătății în muncă nr. 319/2006, Monitorul Oficial al României, Partea I, nr. 882/30.10.2006
- [3] **Guvernul României**, 2006
H.G. nr. 300/2006 privind cerințele minime de securitate și sănătate pentru șantierele temporare sau mobile, Monitorul Oficial al României, Partea I, nr. 252 din 21 martie 2006
- [4] **Băbuț G.B., Moraru R.I.**, 2018
Evaluarea riscurilor profesionale: cerințe pentru eficientizarea procesului, Revista „Calitatea - acces la succes”, vol. 19, nr. 166, pag. 3-16.
- [5] **Koohathongsumrit N., Meethom W.**, 2024
Risk analysis in underground tunnel construction with tunnel boring machines using the Best–Worst method and data envelopment analysis, Heliyon, Vol. 10, Issue 1, e23486, ISSN 2405-8440, <https://doi.org/10.1016/j.heliyon.2023.e23486>
- [6] **Yazdani-Chamzini A., Yakhchali M., Mahmoodian S.H.**, 2013
Risk ranking of tunnel, construction projects by using the ELECTRE technique under a fuzzy environment, Int. J. Manag. Sci. Eng. Manag., 8 (1), pp. 1-14, 10.1080/17509653.2013.783185
- [7] **Chung H., Park J., Kim B.-K., Kwon K., Lee I.-M., Choi H.**, 2021
A causal network-based risk matrix model applicable to shield TBM tunneling projects, Sustainability, 13 (9) (2021), p. 4846, 10.3390/su13094846
- [8] **Kumar Agrawal A., Chattopadhyaya S., Murthy V.M.S.R., Kumar Adesh A.**, 2022
Assessment of reliability and maintainability of earth pressure balance tunnel boring machine (EPBTBM) – an approach, Tunn. Undergr. Space Technol., 121 (2022), Article 104337, 10.1016/j.tust.2021.104337
- [9] **Sharma A.K., Prasad Padhy T., Ahirwar Y.**, 2024
Tunnel ventilation in road tunnels, International Advanced Research Journal in Science, Engineering and Technology (IARJSET), DOI: 10.17148/IARJSET.2024.11215
- [10] **Hayati A., Mattsson M., Sandberg M.**, 2019
A wind tunnel study of wind-driven airing through open doors, International Journal of Ventilation, 18:2, 113-135, DOI: 10.1080/14733315.2018.1435027

- [11] **Kuricová A., Hudáková M., Kočár S., Hollá K.**, 2025
An Innovative Approach to Occupational Risk Assessment in OHS: A Case Study on the Verification of the ALrisk Model in Manufacturing Enterprises in Slovakia, International Journal of Environmental Research and Public Health, 22(5), 757. <https://doi.org/10.3390/ijerph22050757>
- [12] **Yrjo T.T., Keren N., Cena L., Simpson S.A., Stone R.T.**, 2024
Enhancing risk assessment skills in hazardous environments: Priming with a serious game approach, Safety Science, Volume 172, 106402, ISSN 0925-7535, <https://doi.org/10.1016/j.ssci.2023.106402>
- [13] **Saurin, T.A., Costella, M.F., Guimares, L.B.**, 2009
A method for assessing health and safety management systems from the resilience engineering perspective, Saf. Sci. ; 47(8):1056–1067. doi: 10.1016/j.ssci.2008.11.006
- [14] **Pecillo M.**, 2016
The concept of resilience in OSH management: a review of approaches, International Journal of Occupational Safety and Ergonomics, Volume 22, Issue 2, pp. 291-300, <https://doi.org/10.1080/10803548.2015.1126142>
- [15] **Darabont D.C., Moraru R.I., Antonov A.E., Bejinariu C.**, 2017
Managing new and emerging risks in the context of ISO 45001 standard, Quality - Access to Success, Volume 18, Supplement 1, pp. 11
- [16] **Tremblay A., Badri A.**, 2018
Assessment of occupational health and safety performance evaluation tools: State of the art and challenges for small and medium-sized enterprises, Safety Science, Volume 101, pp. 260-267, <https://doi.org/10.1016/j.ssci.2017.09.016>
- [17] **Băbuț G.B., Moraru R.I.**, 2013
Critical analysis and ways to improve the I.N.C.D.P.M. Bucharest risk assessment method for occupational accidents and diseases, Quality- access la success", vol 14, nr. 137/December 2013, pp. 55-66 (Romanian); pp. 113-120 (English)
- [18] **Bollier M., Meyer F.**, 2002
The Suva method for the risk assessment of technical devices and equipment, Swiss national accident insurance fund, 16th edition – July 2002, Lucern, Switzerland
- [19] **Paques J.J., Gauthier F., Pérez A., Charpentier F.**, 2006
Bilan raisonné des outils d'appréciation des risques associés aux machines industrielles, R-459, IRSST, Canada, www.irsst.qc.ca
- [20] **Pasman H.J.**, 2009
Learning from the past and knowledge management: Are we making progress?, Journal of Loss Prevention in the Process Industries, Vol 22, pp 672-679
- [21] **Bedford T., Cooke R.**, 2001
Probabilistic risk analysis - Foundation and methods, Cambridge University Press
- [22] **Băbuț G.B., Moraru R.I., Cioca L.I.**, 2011
„Kinney methods”: useful or harmful tools in risk assessment and management process?, Proceedings of the 5th International Conference on Manufacturing Science and Educations - MSE 2011, vol. II, pp. 315-318, Sibiu, Romania, 02-05.06.2011
- [23] **Ghahramani A., Amirbahmani A.**, 2022
A qualitative investigation to discover causes of occupational injuries and preventive countermeasures in manufacturing companies, Heliyon, Vol. 8, Issue 9, e10501, ISSN 2405-8440, <https://doi.org/10.1016/j.heliyon.2022.e10501>
- [24] **Rantala M., Lindholm M., Kivistö-Rahnasto J., Nenonen N., Tappura S.**, 2024
A tool for self-evaluation of a successful occupational health and safety risk assessment, Safety Science, Volume 173, 106441, ISSN 0925-7535, <https://doi.org/10.1016/j.ssci.2024.106441>
- [25] **Ayvaz B., Tatar V., Sağır Z., Pamucar D.**, 2024
An integrated Fine-Kinney risk assessment model utilizing Fermatean fuzzy AHP-WASPAS for occupational hazards in the aquaculture sector, Process Safety and Environmental Protection, Vol. 186, 232-251, ISSN 0957-5820, <https://doi.org/10.1016/j.psep.2024.04.025>

[26] **Searle D.**, 2023

The effect of formalising worker involvement in the risk assessment process on the accident rate within UK higher education, Social Sciences & Humanities Open, Volume 8, Issue 1, 100572, ISSN 2590-2911, <https://doi.org/10.1016/j.ssaho.2023.100572>

[27] **Bahn S.**, 2013

Workplace hazard identification and management: The case of an underground mining operation, Safety Science, Volume 57, Pages 129-137, ISSN 0925-7535, <https://doi.org/10.1016/j.ssci.2013.01.010>

[28] **Glevitzky, M., Popa, M., Mucea-Ştef, P.**, 2025

Popa, D.M., A Risk Management Approach in Occupational Health and Safety Based on the Integration of a Weighted Composite Score. Safety., 11(4):103. <https://doi.org/10.3390/safety11040103>



This article is an open access article distributed under the Creative Commons BY SA 4.0 license. Authors retain all copyrights and agree to the terms of the above-mentioned CC BY SA 4.0 license.