Journal of Corporate Governance, Insurance, and Risk Management
https://www.acadlore.com/journals/JCGIRM

Enhancing the Golden Triangle (Cost, Time, Quality) in Infrastructure Projects through Risk Management: A Case Study of the Algiers Metro Project

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Received: 10-09-2024 **Revised:** 12-07-2024 **Accepted:** 12-19-2024

Citation: Mohammedi, I., Belimane, W., & Bouchetara, M. (2024). Enhancing the Golden Triangle (cost, time, quality) in infrastructure projects through risk management: A case study of the Algiers Metro project. *J. Corp. Gov. Insur. Risk Manag.*, *11*(4), 227-245. https://doi.org/10.56578/jcgirm110403.

Abstract: The Golden Triangle consisting of cost, time and quality serves as a fundamental framework for assessing the success of infrastructure projects. Effective risk management is critical for optimising these interconnected dimensions by proactively identifying potential threats implementing risk mitigation strategies and ensuring project control. This study investigates the application of the international standard ISO 31000:2018 in enhancing the Golden Triangle's dimensions—time management, cost optimization and quality assurance—within the context of large-scale infrastructure projects. A qualitative research methodology was employed incorporating semi-structured interviews, document analysis and site observations to collect comprehensive data. Analytical techniques such as Failure Modes and Effects Analysis (FMEA), Bow-Tie analysis and Fishbone diagrams were utilised to prioritise risks, examine preventive measures and identify underlying causes. A total of forty-three (43) critical risks were identified as having significant impacts on the performance of the Algiers Metro project. The findings revealed that the implementation of a structured risk management approach improved adherence to project timelines, optimised cost control and ensured the delivery of quality outcomes. The integration of ISO 31000:2018 principles in conjunction with tailored analytical tools was found to add considerable value providing practical insights for improving infrastructure project performance. This work underscores the importance of systematic risk management and its role in enhancing the efficiency and success of large infrastructure projects.

Keywords: Risk management; ISO 31000:2018; Golden Triangle; Cost; Time; Quality; Infrastructure projects; Algiers Metro project

1. Introduction

Infrastructure development plays a pivotal role in societal and economic growth. serving as the backbone of modernization and progress. Within this context, underground construction including metro systems is crucial for enhancing urban connectivity and addressing challenges associated with urbanization (Szymański, 2017). However, the construction industry, particularly in Algeria, faces a highly competitive and risk-prone environment compounded by economic fluctuations and the complexity of large-scale projects.

One of the most persistent challenges in construction projects is managing the interplay between cost, quality, and time often referred to as the "Golden Triangle" of project management. These three factors are deeply interconnected and failure to balance them can lead to project delays budget overruns and compromised quality (Esmaeilipour et al., 2011). Inadequate risk assessment and management practices are frequently cited as primary contributors to these issues with the burden of risk often borne by project stakeholders (Mahamid, 2011).

In this context, risk management emerges as a critical tool for navigating uncertainties and improving project outcomes. By systematically identifying, analyzing and mitigating risks, project managers can enhance the likelihood of achieving project objectives. The international standard ISO 31000:2018 provides a comprehensive framework for risk management emphasizing a structured and consistent approach that aligns with international best practices (Khairullah et al., 2022).

This study focuses on the Algiers Metro Project, a high-profile infrastructure initiative undertaken by Cosider, an Algerian construction and public works company. The project exemplifies the complexities and risks inherent in large-scale underground construction. By evaluating the application of risk management practices guided by ISO 31000:2018, this research seeks to determine their contribution to improving the Golden Triangle parameters of cost, quality and time.

The central question driving this research is: How can risk management, based on ISO 31000:2018, address the challenges posed by project risks to the Golden Triangle thereby enhancing the success of infrastructure projects? To answer this, the study combines theoretical insights with a practical analysis of the Algiers Metro Project offering recommendations for improving risk management practices in similar contexts.

2. Literature Review

Risk management is a fundamental component of project management particularly in infrastructure projects where complexity and uncertainties pose significant challenges. The existing body of literature on risk management in infrastructure projects emphasizes not only the avoidance of risks but also the transformation of risks into competitive advantages (Osei-Kyei et al., 2022). These strategies are particularly crucial in the context of large-scale projects such as metro systems where risks related to time, cost and quality collectively known as the Golden Triangle must be carefully managed. The following review explores the role of ISO 31000:2018 in enhancing risk management practices within infrastructure projects with a particular focus on the Algiers Metro Project developed by Cosider Company.

The ISO 31000:2018 standard provides a comprehensive framework for managing risks across various sectors. It emphasizes the integration of risk management into an organization's overall governance and decision-making processes ensuring alignment with strategic objectives (ISO, 2018). The international standard facilitates the identification, assessment and management of risks in a proactive manner moving away from reactive strategies. For infrastructure projects. ISO 31000:2018 offers tools that help in identifying risks early, allowing for mitigation measures to be implemented before risks evolve into major issues.

Metro projects, particularly those involving complex systems such as Tunnel Boring Machines (TBMs), are inherently risky due to the technical challenges they present. Ding et al. (2012) and Sharafat et al. (2021) provided insights into risk identification methods in metro construction with a focus on the use of Bow-Tie analysis. This method combines fault tree and event tree analysis to create a visual model of how specific risks can lead to undesirable outcomes. It is particularly useful for understanding and mitigating risks related to TBM operations including equipment failure delays and unforeseen geological conditions. Zhang & Guan (2018) demonstrated the relevance of Bow-Tie analysis in TBM tunneling projects offering a model directly applicable to metro construction. Bow-Tie analysis is a visual method for identifying and analysing risks that combines qualitative and quantitative evaluations to map risk pathways showing causes, critical events and consequences (Liu. et al., 2022; Rajgor & Mamata. 2024).

In addition to Bow-Tie analysis, studies have explored various risk management strategies such as preventive measures (e.g., accurate project scheduling) and remedial actions (e.g., close supervision) that are vital for the successful execution of metro projects. Failure Modes and Effects Analysis (FMEA) is a systematic proactive tool for identifying potential failure points, their causes and the effects of these failures on a system process or project. It is widely employed across industries for risk identification and assessment purposes. The Fishbone Diagram visually identifies risks by categorizing them into six main areas: man, machine, method, material, measurement and environment (Varsha et al., 2015). It supports brainstorming to uncover root causes of delays and safety issues. Iqbal et al. (2015) highlighted the importance of these strategies in minimizing risks and ensuring timely and cost-effective delivery of metro systems. Furthermore, strategic risk management within the Golden Triangle of time, cost and quality is crucial for mitigating delays budget overruns and maintaining quality standards throughout the project lifecycle (Khalid, 2017; Zidane & Andersen, 2018).

The Golden Triangle of time, cost and quality serves as a critical framework for evaluating the success of infrastructure projects. Effective management of these three elements requires a combination of risk management strategies and tools. Among the most widely used techniques is Earned Value Management (EVM). which allows project managers to track project performance against planned objectives providing an early indication of potential risks related to time and cost. EVM is a valuable tool for integrating risk management practices into the project lifecycle, ensuring that risks associated with time, cost and quality are identified and mitigated promptly (Amini et al., 2023; Hussein & Moradinia, 2023). Applying EVM within the context of ISO 31000:2018 helps managers better understand the interdependencies between time, cost and quality enabling them to make informed decisions that optimize resources and minimize risks.

Metro construction projects face unique risks due to the complexities of underground infrastructure, the need for coordination among multiple stakeholders and the technical challenges of tunneling. The Algiers Metro Project, being developed by Cosider Company, presents an important case study for understanding how risk management practices can be applied in such complex settings. The project has faced significant challenges including delays and budget overruns which have underscored the need for robust risk management strategies. The application of ISO 31000:2018 can help address these challenges by providing a structured approach to risk management that is adaptable to the specific conditions of the Algiers Metro Project. This includes proactive risk identification, stakeholder engagement and the use of risk mitigation strategies such as HAZOP (Hazard and Operability Study) and FMEA (Failure Mode and Effect Analysis) to minimize risks related to safety scheduling. and budget.

This research contributes through the integration of multiple risk assessment methods. While previous studies have applied the ISO 31000:2018 standard to infrastructure projects, this study proposes a unique combination of FMEA, Bow-Tie and Fishbone methodologies to systematically analyze risk factors. This multi-method approach is expected to provide a more comprehensive risk assessment.

3. Context and Contribution of the Research

The case study of the present research focuses on the Algiers M28 Metro extension project, a vital infrastructure initiative aimed at extending the metro line from El Harrach Centre to Algiers International Airport (New Terminal). Spanning 10 kilometres, the project is notable for its complexity and significance as it includes the construction of 9 metro stations and 10 ventilation shafts designed to enhance urban connectivity and mobility in Algiers (Figure 1):

Figure 1. Ground plan- Algiers M28 Metro extension project
Source: Internal company document

The present research aims to bridge the gap in the existing literature by examining the application of ISO 31000:2018 to the Algiers Metro Project. Unlike many studies that provide general insights into risk management, this study examines the real-world challenges faced by the Cosider company in managing risks related to time, cost and the technical complexities of metro construction. By employing a case study approach, this research will offer practical insights into how risk management methodologies such as Bow-Tie analysis, EVM and others can be applied to large-scale infrastructure projects. The Algiers Metro Project offers a unique opportunity to examine how ISO 31000:2018 can be used to improve risk management practices in the context of Algerian infrastructure development.

The integration of ISO 31000:2018 into the management of risks within metro projects provides a structured and adaptable framework that enhances decision-making and project outcomes. By addressing the risks associated with time, cost and quality, ISO 31000:2018 ensures that projects are delivered efficiently and effectively. The Algiers Metro Project serves as a pertinent case study for the application of these methodologies, offering valuable insights that can inform future metro projects in Algeria and similar infrastructure developments worldwide. This research contributes to the growing body of literature on risk management in large-scale infrastructure projects, providing both theoretical insights and practical solutions to the challenges faced by project managers.

4. Methodology

This study adopts a qualitative approach to analyze risk management practices in the Algiers Metro Project. The methodology is designed to ensure a comprehensive understanding of the risks encountered during project execution and how they were managed.

4.1 Data Collection Methods- Risk Identification

Various data collection methods were employed, including document analysis, direct observations, interviews with key project personnel and brainstorming sessions. These methods provided a holistic view of risk identification, assessment, and mitigation strategies, ensuring a robust and well-founded analysis of risk management practices in line with ISO 31000:2018.

4.1.1 Document analysis

We reviewed the company's documents in accordance with its internal regulations and confidentiality policies. The SWOT analysis highlighted internal strengths and weaknesses, as well as external opportunities and threats, providing insights into risk factors. The internal audit report was also consulted to assess internal controls and compliance, revealing potential gaps in risk management practices. These two documents were provided to us by the project manager, as they contain essential information for identifying and addressing risks and play a crucial role in developing effective risk management strategies for the project.

4.1.2 Observation

The observations focused on the implementation of risk management practices according to the ISO 31000:2018 standard. Note-taking and audio recordings were used to document risk management strategies. The main risks identified concerned time, cost and quality, with proactive mitigation measures in place. Communication between stakeholders ensured effective risk management. Data was collected over a 26-day period, from April 15. 2024. to May 11. 2024.

4.1.3 Interview

Semi-structured interviews were conducted with seven (07) key personnel in the project (Table 1). The selection of this sample was based on the expertise of the respondents: project managers and senior risk specialists with more than ten years of experience.

The interviews were audiotaped, notes were taken, and relevant documents were consulted on-site. Data collection was conducted over a 26-day period, from April 15. 2024. to May 11. 2024. During this time. a comprehensive risk identification process was carried out (See interview guide in Appendix A).

Table 1. Interview methodology and sample description

Interviewees	Project Implementation Engineer Project Topographer Head of the Quality Management Department Assistant to Head of Quality Management Project Cost Control Officer Planning Officer HSE (Health. Safety. and Environment) Officer
Interview Type	Semi-structured interviews
Duration	Approximately 40 minutes per interview
Language	Conducted in French to ensure clear communication
Interview Description	An exploration of roles, responsibilities, project objectives, risk identification, management practices, and lessons learned from the Algiers Metro project, with a focus on strategies, challenges, and opportunities for improvement in risk management.

4.1.4 Document analysis

During the brainstorming session, seven (07) key stakeholders were gathered, including Engineers, Quality Department Members, the Procurement and Planning Manager and the HSE Manager. The session lasted three (03) hours during which participants collaboratively identified the root causes of the primary risks affecting the project.

This multi-method approach to data collection was adopted to triangulate the results and draw valid conclusions with minimal biases. Additionally, it allowed for a deeper understanding of the challenges associated with risk management in this complex construction project. The results highlighted the importance of a collaborative process in identifying critical risks and contributed to the development of strategies to effectively address these challenges.

4.2 Risk Management/ ISO 31000:2018 Methodology

The effective implementation of ISO 31000:2018 requires a structured approach that begins with defining the project context to ensure a comprehensive understanding of risk factors.

4.2.1 Document analysis

The context provides an understanding of the organization's objectives, the internal and external environment in which it operates to achieve these objectives and the role of stakeholders involved.

The external context includes factors outside the organization that can impact the project either directly or indirectly. These factors encompass political conditions, economic trends. social and cultural influences, technological advancements, environmental concerns, legal frameworks and the influence of stakeholders within the specific project environment.

The internal context refers to factors within the organization that influence the project's entire life cycle. These include the organizational structure, strategic priorities, financial and technical capabilities, decision-making processes and information systems. Additionally, relationships with internal stakeholders and organizational culture should also be considered.

4.2.2 Risk analysis

Risk analysis was carried out using Bow-Tie Analysis and the Fishbone Diagram. At the end of this phase, the causes of the identified risks were defined.

4.2.3 Risk evaluation

The evaluation was carried out in two stages: evaluating the risks based on their severity and occurrence to establish the Risk Assessment Grid using the Failure Modes and Effects Analysis (FMEA) method, then assessing the impact of risks on the three factors: Quality, Cost and Time, then:

First, for risk assessment, two key factors were considered. Occurrence refers to the likelihood of a risk happening during the project. Evaluating occurrence helps determine the probability of the risk and enables early preventive action. Severity of Potential Damage assesses the possible consequences or harm if the risk materializes. Understanding severity helps prioritize risks and allocate resources for mitigation.

These two factors are combined through multiplication to determine the criticality of each risk or Risk Priority Number (RPN) providing a clear understanding of both its likelihood and potential impact (Table 2 and Table 3). This approach supports informed decision-making and effective risk management throughout the project.

$$\mathrm{RNP} = \mathrm{SEVERITY} \times \mathrm{OCCURRENCE}$$

Table 2. Risk assessment Grid/FMEA

Very high 64	64	128	256	512
High 16	16	32	64	128
Medium 4	4	8	16	32
Low 1	1	2	4	8
SEVERITY↑				
OCCURRENCE→	**1** Very low Less than once a year	**2** Low From once every 6 months to once a year	**4** High From once a month to once every 6 months	**8** Very high From every day to once a month

Source: Internal company document

Table 3. Evaluation Scale/FMEA

R>256	High risk/to be controlled	Priority I
32 < R ≤256	Medium risk/to be controlled	Priority II
8 < R ≤ 32	Moderate/to Watch	Priority III
R ≤8	Minor/acceptable	Priority VI

Source: Internal company document

- SEV (Severity): Rated on a scale from 1 to 64. Higher values indicate risks with a more severe impact if they occur;
- OCC (Occurrence): Rated on a scale from 1 to 16. Higher values indicate risks that are more likely to occur;

- RPN (Risk Priority Number): Calculated by multiplying severity by occurrence for each risk. The RPN helps prioritize risks for mitigation or management efforts. Higher RPN values indicate risks that require higher priority for mitigation.

Second, risks are prioritized by calculating the average of their impacts and associated probabilities with scores categorized into low, moderate or high priority using specific methods and visual indicators such as colors. The analysis highlights which risks require immediate action based on their severity and likelihood while lower-priority risks may instead be monitored. To achieve this, we used the matrix proposed by PMI (2013) (Table 4 and Table 5).

Table 4. Probability and impact matrix

Very high **0.8**	0.080	0.240	0.400	0.560	0.720
High **0.4**	0.040	0.120	0.200	0.280	0.360
Moderate **0.2**	0.020	0.060	0.100	0.140	0.180
Low **0.1**	0.010	0.030	0.050	0.070	0.090
Very Low **0.05**	0.005	0.015	0.025	0.035	0.045
IMPACT↑					
PROBABILITY→	**0.1** Very low	**0.3** Low	**0.5** Moderato	**0.7** High	**0.9** Very high

Source: (PMI, 2013)

Table 5. Impact scales of a risk on major project objectives

Defined Conditions for Impact Scales of a Risk on Major Project Objectives (Examples are shown for negative impacts only)					
Project Objective	**Relative or Numerical Scales are Shown**				
	Very Low/.05	**Low/.10**	**Moderate/.20**	**High/.40**	**Very high/.80**
Cost	Insignificant	<10% cost increase	10-20% cost increase	20-40% cost increase	≥40% cost increase
Time	Project end item is effectively useless	<5% time increase	5-10% time increase	10-20% cost increase	≥20% Time increase
Quality	Project end item is effectively useless	Only very demanding applications are affected	Quality reduction requires sponsor approval	Quality reduction unacceptable to sponsor	Project end item is effective useless

Source: (PMI, 2013)

- Probability: This represents the likelihood of a risk occurring, usually on a scale from 0 to 1.
- Impact: This indicates the potential severity or consequence of the risk if it occurs, also on a scale from 0 to 1.
- Matrix Value: This is the product of probability and impact, showing the overall risk score. It helps prioritize risks.

RStudio (Integrated Development Environment (IDE)) was used for data visualization. This tool enabled the creation of graphs illustrating the relationship between risk impact and probability over time, providing valuable insights into the risks that significantly affect time, cost and quality.

4.2.4 Risk treatment

An action plan was developed specifying the actions, the responsible party and the implementation timeline.

5. Results

5.1 Risk Identification

Based on interviews, direct observations and brainstorming sessions, a list of 43 potential risks was developed. These risks were classified into five categories: operational, technical/design/planning, material management, execution and human resources (Table 6).

According to Table 6, key risks included compliance challenges, design constraints, supply chain disruptions, safety hazards and workforce issues. By leveraging team expertise and past experiences, this process enhances risk control, preparedness and project success.

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Table 6. Identified risks

Categories	Risk ID	Risks
Laws and regulations	R1	Restrictive legislation (site safety. new regulations. laws. standards. taxes).
	R2	Lack of flexibility in current markets and contracts with customers.
	R3	Pre-selection of unsuitable suppliers.
	R4	Subjective evaluation of external providers.
	R5	Non-compliance with contractual clauses and inadequate calls for tenders.
	R6	Failure to meet delivery deadlines.
	R7	Non-conforming product.
	R8	Shortage of raw materials.
	R9	Raw material prices are rising and contract prices established in 2013 are depreciating. Continued depreciation of the Algerian dinar. Austerity plans since 2014. Difficult budgetary situation. Finance law and halt to imports of several products (concrete blocks and others. etc.). Quality of local products.
Technical design and planning	R10	Inherently limited technical expertise. Limited pre-project study. Incomplete geotechnical survey.
	R11	The complex geological nature of the site (risk of collapse. landslides. subsidence. etc.). The proximity of the sites to red-listed buildings or high-rise buildings and the almost immediate proximity to a disadvantaged population (risk of theft. physical aggression and trespassing).
	R12	Dynamic systems are strongly influenced by the environment (soil. meteorology. geology. hydrogeology. etc.).
	R13	The duration of the project increases the likelihood of events having a significant impact on performance dispersion (change in standards. evolution of objectives. etc.). economic. political and social constraints. etc.
	R14	Human errors may result from inappropriate decisions. insufficient.
	R15	Tracking of changes (deadlines. tasks. budget) absent or ineffective.
	R16	Contractual conflict with the owner and the contractor.
	R17	Incorrect assessment or estimate by the project owner during the feasibility phase (delayed approval of plans. failure to approve technically feasible plans).
	R18	Force majeure.
	R19	The location of the project in a city with a very congested and narrow traffic network. Poor quality and degradation of the roads.
Material management	R20	Maintenance team unfamiliar with new TBM technology.
	R21	Failure to properly use equipment.
	R22	Insufficient experience. lack of knowledge and/or.
	R23	Skills.
	R24	Lack and restocking of spare parts.
HSE	R25	Non-compliant equipment (no certificate of conformity. technical safety inspection).
	R26	Poor expression or understanding of the need.
	R27	Inspections not carried out.
	R28	Failure to carry out awareness and induction sessions for new recruits.
	R29	Missed target (Severity & Frequency).
	R30	Failure to control risks at the project level.
	R31	Failure to monitor the various non-conformities recorded.
	R32	Failure to transmit information on time.
	R33	Failure to achieve PM objectives.
	R34	Lack of staff following sick leave (Covid-19).
	R35	Non-compliance with HSE regulations by external service providers (service providers. partners. subcontractors).
Works	R36	Deviation of the TBM from its route. Emergence of the TBM in groundwater: the need for huge quantities of water for the TBM.
	R37	Non-conformity poorly dealt with and unresolved stop points.
	R38	Appearance of competition. Overlap of work with other companies. Bureaucracy on the part of certain interested parties (expropriation problems. issuing of permits. etc.). Political and socio-economic context in turmoil.
	R39	Penalties for non-compliance with regulations. Delay in work completion. Material and human damage. Company image.
HRM	R40	Unsatisfied recruitment requests.
	R41	Judiciable monitoring.
	R42	Conflicts/strikes Employee complaints.
	R43	Escape of brains and skills.

5.2 Risk Analysis

For risk analysis, we combined the Fishbone Diagram method and the Bow-Tie method. Fishbone Diagrams were developed to analyze the causes associated with the lack of equipment and resources within material management. The analysis was structured around five main categories: People, Methods, Materials, Environment, and Equipment. Special attention was given to the equipment category. In addition, Bow-Tie diagrams were established (see risk causes in Appendix B).

We present below the diagrams related to the risk associated with TBM (Figure 2 and Figure 3):

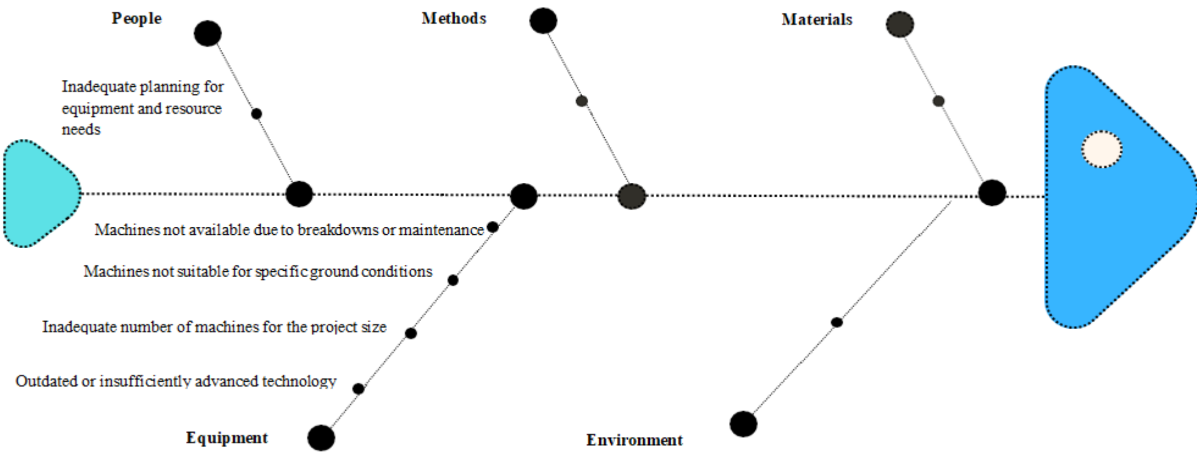

Figure 2. Fishbone diagram of material risks

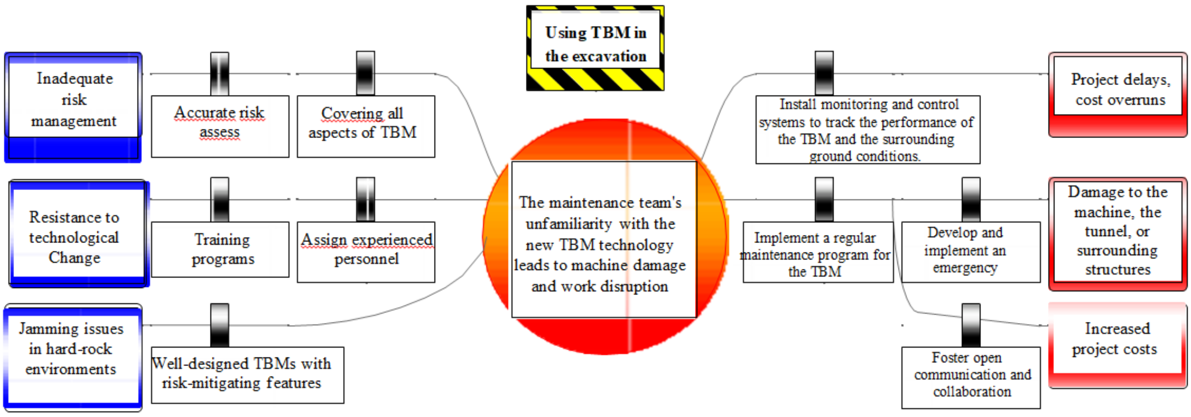

Figure 3. Bow-tie diagram

5.3 Risks Evaluation

5.3.1 Evaluation FMEA

The risk assessment results. based on their Severity and Occurrence. (are presented in Appendix C.) Based on this evaluation. the risks have been positioned in the risk assessment grid (Table 7).

Table 7. Risk assessment Grid

64	**R18 R39**	**R6**	**R11 R29 R36**	**R20 R13**
16	**R38**	**R3 R8 R9**	**R4 R12 R21**	**R17 R30**
4	**R14 R15 R16 R31 R32 R33 R34 R37 R40 R41 R42**		**R5 R23 R25 R27 R28**	**R10 R19**
1			**R2 R22 R24 R26 R35 R43**	**R7 R1**
SEV↑				
OCC→	**1**	**2**	**4**	**8**

Based on the risk assessment grid, the company must address three (3) priority I risks, followed by seven (7) priority II risks, fifteen (15) priority III risks and eighteen (18) priority IV risks.

5.3.2 Evaluation of the impact on time. cost and quality

Using the matrix proposed by PMI (2013) (see Table 4), the impact of the identified risks on the three factors time, cost and quality was evaluated (see Appendix D for evaluation details).

Based on the results, we developed RStudio visualizations illustrating the impact of risks on time, cost and quality (Figure 4, Figure 5, and Figure 6 respectively).

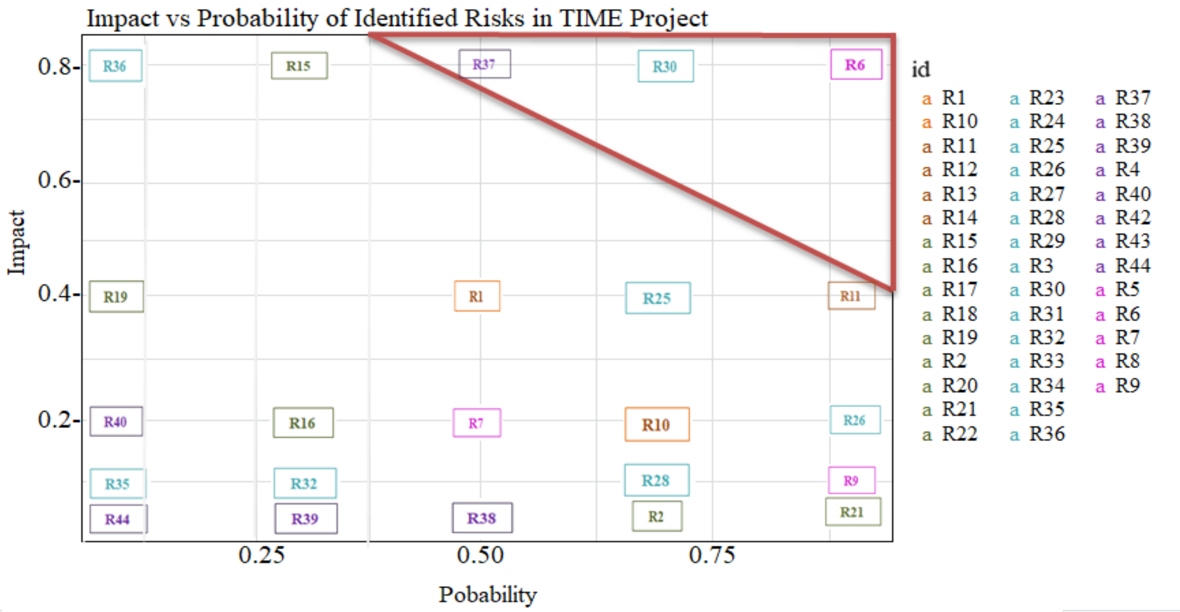

Figure 4. Time matrix

Note: Figure generated by RStudio

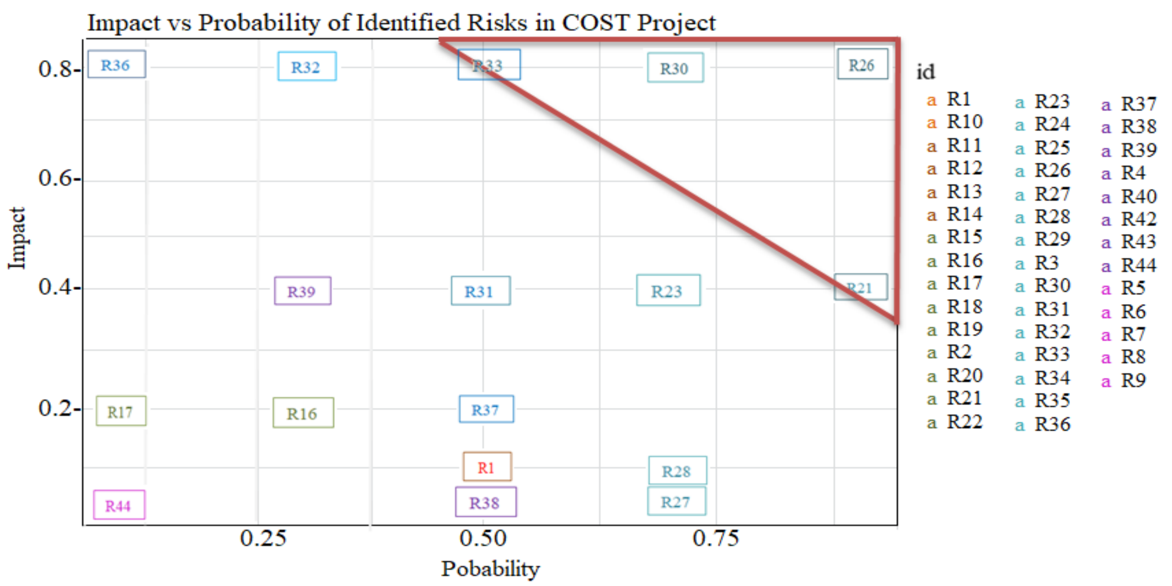

Figure 5. Cost matrix

Note: Figure generated by RStudio

Failure to meet delivery deadlines failure to control risks at the project level and poorly addressed non-conformities with unresolved stop points were evaluated as high-risk issues that could cause schedule delays. Once these risks are controlled, time delays can be prevented. One major benefit of conducting such a risk assessment is that it highlights critical areas to focus on ensuring the project runs smoothly and remains under control.

Critical risks affecting the cost aspect include improper equipment utilization, inadequate articulation or understanding of project requirements, failure to manage risks at the project level and inability to achieve project management objectives. Neglecting these risks could result in additional project costs.

The risks that may challenge the project's quality include for example failure to properly use equipment. These mentioned risks are significant and can greatly impact the project. For instance, if equipment is not used correctly, it can negatively affect the quality potentially leading to the project not being delivered to the client according to their requirements and expectations. Therefore, it is crucial to address these risks while they are still manageable to deliver what the client desires and meet the project objectives.

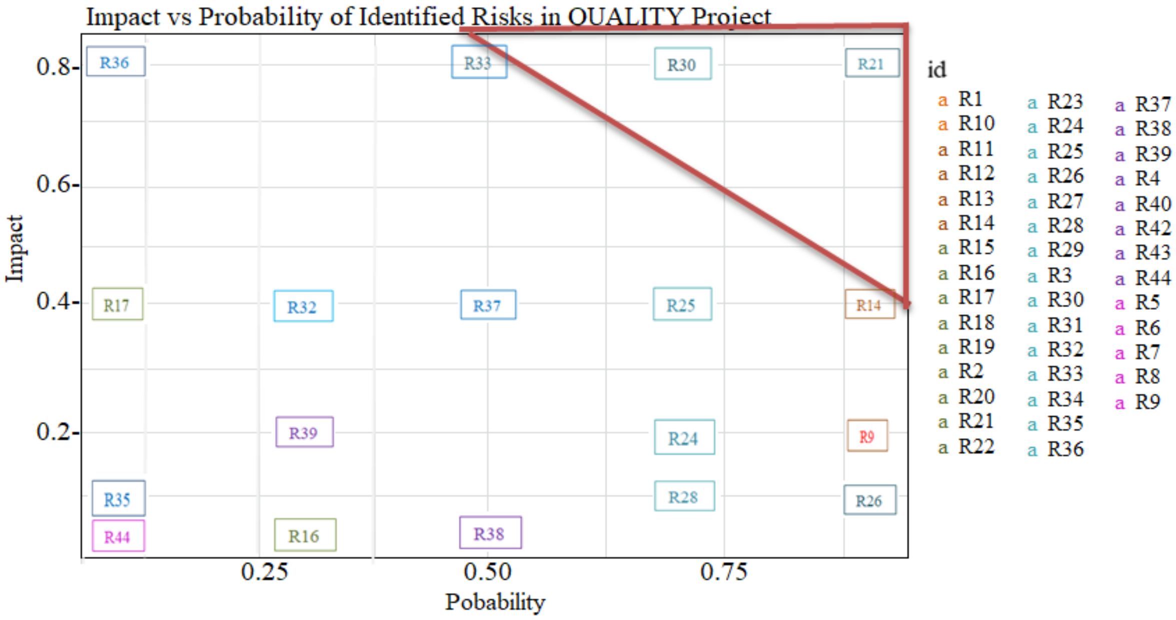

Figure 6. Quality matrix

Note: Figure generated by RStudio

5.4 Risks Treatment

Actions for assessing and managing risks within Cosider Company were defined. Specific measures were outlined to address various risks detailing the individuals or teams responsible for each action and the frequency of implementation (see action plan in Appendix E).

The risk management action plan presented demonstrates a comprehensive and multifaceted approach to addressing the identified risks. It highlights the following points:

- Comprehensive Approach: The plan covers a wide range of risks and outlines a diverse set of actions to address them. This comprehensive approach is commendable as it demonstrates a thorough risk assessment and a commitment to proactive mitigation.
- Stakeholder Involvement: The plan emphasizes the importance of collaboration, coordination and engagement with various stakeholders including regulatory bodies, suppliers, customers and project team members. This collaborative approach can help build buy-in enhance information sharing and improve the effectiveness of the risk management efforts.
- Continuous Monitoring and Improvement: The plan includes actions related to ongoing monitoring. such as regulatory watch, supplier performance measurement and strategic environmental scanning. This reflects a recognition of the dynamic nature of risks and the need for continuous adaptation and improvement.
- Training and Competency Development: The plan prioritizes training and competency development for various roles, from storekeepers to project team members. This focus on building internal capabilities is crucial for ensuring effective implementation and sustainable risk management practices.
- Proactive Measures: Several actions such as anticipating and defining the choice of methods introducing new suppliers and diversifying supply sources, demonstrate a proactive approach to risk management. This forward-looking mindset can help the project anticipate and adapt to emerging risks.
- Operational-level Details: The plan provides a good level of detail in terms of specific actions, responsible parties and deadlines. This granularity can facilitate clear accountability and effective execution of the risk management strategies.
- Potential Areas for Improvement: While the plan is comprehensive, it could be further strengthened by

incorporating more quantitative risk assessment techniques such as risk scoring or Monte Carlo simulations to prioritize and allocate resources more effectively. Additionally, the inclusion of contingency planning and escalation procedures could enhance the project's overall resilience.

Overall, the action plan presents a well-structured and multifaceted approach to risk management, reflecting a good understanding of the project's risk landscape and a commitment to proactive risk mitigation.

6. Discussion

The results illustrate the significant role of risk management. as guided by ISO 31000:2018, in improving the Golden Triangle—Time, Cost and Quality—in infrastructure projects as evidenced by the Algiers Metro Project. The findings were analyzed in alignment with the principles of ISO 31000:2018 and the specific risks identified during this study's qualitative investigation. The qualitative analysis, supported by interviews, internal documents and site observations, identified 43 key risks that directly impacted the execution of the Algiers Metro Project. These risks spanned technical, financial, environmental and operational categories. Risk mitigation strategies applied within the ISO 31000:2018 framework enabled the project team to anticipate, assess, and manage these risks systematically. The methods employed—FMEA analysis, Bowtie analysis and Fishbone diagrams—provided a structured approach to identifying root causes and potential consequences of risks fostering informed decision-making and proactive intervention.

The findings highlight that systematic risk management, in accordance with ISO 31000:2018 principles, enhanced the project's capacity to manage deviations in timelines, resource allocation and unforeseen challenges. Notably, mitigation strategies contributed to better control of delays and cost overruns. thereby aligning the project's outcomes with the expectations of the Golden Triangle. These findings are consistent with ISO 31000:2018 principles, which emphasize the iterative and integrated nature of risk management across all project stages. ISO 31000:2018 advocates continuous risk monitoring, stakeholder engagement and evidence-based decision-making practices that were evident in the Algiers Metro Project's management processes. The systematic application of risk identification and assessment tools enhanced foresight, ensuring that mitigation strategies were implemented in alignment with strategic objectives.

Furthermore. the study confirms ISO 31000:2018's emphasis on integrating risk management into organizational culture. The findings indicate that fostering a culture of risk awareness within the Cosider team strengthened collaboration, stakeholder engagement and accountability. These cultural shifts enhanced the project team's ability to navigate risks and ensure timely project delivery. These conclusions align with the findings of Mustaro & Rossi (2013), who highlighted that continuous monitoring, stakeholder engagement and the development of internal capabilities are key strengths of an effective action plan.

The Golden Triangle serves as a critical benchmark for infrastructure projects. The Algiers Metro Project's ability to maintain control over these three interrelated parameters can be attributed to systematic risk management practices. Risk strategies identified through FMEA and Bowtie analyses were instrumental in addressing risks that could lead to delays or resource inefficiencies. For example, financial risks related to labor shortages and equipment availability were mitigated through preemptive actions such as the reallocation of financial resources and supplier diversification.

The study demonstrates that risk management, guided by ISO 31000:2018 principles, effectively improved time performance by minimizing project delays, cost management by addressing financial risks at an early stage and quality assurance by implementing targeted interventions to mitigate technical uncertainties.

The findings align with existing literature emphasizing the importance of systematic risk management in achieving project success. Previous studies have shown that ISO 31000:2018 fosters a proactive rather than reactive approach to risk, aligning risk management practices with project objectives and strategic planning. However, this case study contributes to the literature by illustrating how these principles directly impact large-scale infrastructure projects such as the Algiers Metro Project and by demonstrating the effective application of qualitative methods such as FMEA, Bowtie and Fishbone diagrams for risk assessment.

Nonetheless, this study reveals unique insights, notably the critical role of cultural adaptation and stakeholder engagement, underscoring that risk management is not solely a technical or procedural exercise but also a social one requiring a commitment to shared learning and collaboration.

The findings provide important practical implications for infrastructure project managers and decision-makers. They suggest that integrating ISO 31000:2018 principles can enhance resource allocation, improve stakeholder alignment and foster a more adaptive approach to unforeseen risks. Moreover, the practical application of qualitative risk analysis methods such as FMEA and Bowtie supports better strategic foresight by offering a clearer visualization of risk pathways and consequences.

7. Conclusions

The study delves into the perceptions and practices of risk management within the construction industry, with a particular focus on the Algiers metro construction project. Despite the ubiquitous presence of risk in construction endeavors, the understanding and formal application of risk management processes often fall short of theoretical ideals. Through qualitative methods, the study uncovers insights into how risks are perceived, managed and the willingness of industry professionals to embrace structured risk management processes.

The findings suggest a gap between theoretical concepts and practical application, with an emphasis on the need for profitability and simplicity in risk management practices. Additionally, the study identifies key suggestions for enhancing risk management within construction projects, along with acknowledging inherent limitations and proposing avenues for future research and extension.

From our experience, we suggest that Cosider Company establish formal risk management processes, invest in training, allocate adequate resources, promote risk awareness, utilize technology and continuously improve by regularly reviewing past projects to identify areas for enhancement in risk management practices. These measures can strengthen its risk management practices and improve project outcomes.

Unlike previous studies, which focus on generic risk management approaches, this research provides a detailed analysis specifically tailored to the context of the Algiers Metro Project. The study identified 43 major risks and assessed their impact on the Golden Triangle (cost. time. and quality) offering practical insights particularly relevant to large-scale infrastructure projects. One of the main contributions of this study is the identification of equipment-related risks as a dominant factor in project delays and cost overruns. This aspect, which has been little explored in previous literature, highlights the need for better resource allocation and preventive maintenance strategies.

While the findings are promising, it is important to acknowledge certain limitations. This study focused on a single case study (the Algiers Metro Project with Cosider), which may limit the generalizability of the findings. Additionally, while the qualitative approach provided deep insights into risk processes. Future research could integrate quantitative risk modeling for a more comprehensive analysis. Moreover, the 26-day observation period may not account for long-term risks, such as seasonal delays. Therefore, it would be relevant to extend the monitoring period, potentially covering multiple project phases or seasonal cycles to enhance the comprehensiveness of the risk assessment.

Building on this study's insights, future research should explore comparative case studies across multiple infrastructure projects to identify common patterns and unique risk management practices. Further studies could also examine the long-term effects of ISO 31000:2018 adherence on project lifecycle outcomes and explore technological integration in risk management tools.

Data Availability

The data used to support the research findings are available from the corresponding author upon request.

Conflicts of Interest

The authors declare no conflict of interest.

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Appendix

Appendix A. Interview Guide

Interview Guide

Theme: Risk Management in Infrastructure Projects - Case Study: Cosider Company (Algiers Metro)

Interview Date: ———————————— **Position Held:**

The Simple:

Purpose:

The purpose of this interview is to explore the role of risk management in infrastructure projects. with a specific focus on the Algiers Metro project undertaken by Cosider Company. Your insights are invaluable to our research.

General information:

Can you please provide a brief overview of you and your role and responsibilities in the Algiers Metro project?

Information on the Algiers Metro project:

Could you tell us about the Algiers Metro project and its objectives?

Overview of the main risks:

Could you discuss potential risks that you are aware of and have encountered in this project?

Can you provide examples of how risk management practices have influenced the project's schedule and deadlines or cost overruns or quality-related? How often can we find them?

How does the utilization of Tunnel Boring Machines (TBMs) contribute to the overall risk management framework of the construction project?

Are there any best practices or strategies that you believe contributed to the effective management of risks in this project?

Are there any aspects of risk management that you believe could have been improved or implemented differently in the Algiers Metro project?

Do you have any comments or suggestions?

Appendix B. Risks causes

Risk ID	Causes
R1	Non-compliance with applicable laws and standards.
R2	Failure to take into accounts the strengths and technical and economic advantages of the methods).
R3	Poorly defined criteria for pre-selecting suppliers. Lack of periodic supplier files reviews. Lack of challenge between existing and new suppliers able to offer new solutions and pricing conditions.
R4	Loss of suppliers. subcontractors and partners. Poor quality of service from certain suppliers. subcontractors and partners. Lack of authorized service providers for recycling and taking care of DSD and other waste.
R5	Drafting of technical specifications so that only one supplier is selected. Absence of certain important elements in the tender documents (supplier's response time to the request. address of the place where the offer is to be submitted). Failure to select suppliers offering the best quality/price ratio
R6	Indebtedness to certain suppliers. Delay in delivery due to means of transport (sea. rail. road). due to congestion at the port of transition. due to weather conditions long delivery times. Poor choice of suppliers. Supply was made to suppliers who did not respect.
R7	Product poorly received. Poor understanding of specifications or expression of needs. Selection of suppliers offering poor quality.
R8	Exhaustion of existing safety stock before the next entry. Depletion of market stock. Insufficient stock management strategy. Poor stock management. Staff incompetence. Inadequate distribution of tasks in the process.
R9	Country's economic crisis.
R10	Partial mastery.
R11	Geological nature of the soil.
R12	The trace of the project is located in a mountainous area. Natural constraints.
R13	Absence of clauses in the contract to deal with this type of risk.
R14	Lack of relevant management training. Pressure and workload. Communication problem with MOE.
R15	The company's specific organization.
R16	Lack of communication and language problems with stakeholders. inherently limited technical expertise.
R17	Natural risk.
R18	Inherently limited technical expertise.
R19	Locating the project in the capital.
R20	Absence and lack of relevant training. Absence of clauses in purchase contracts on the technology owner's obligation to provide training and transfer know-how.
R21	Fault and lack of foresight in the long term. The Finance Act and the importation shutdown.
R22	Lack of relevant training.
R23	Lack of rigorous follow-up.
R24	Lack of rigorous follow-up.
R25	Unavailable on the national market (finance law). Lack of forward planning.
R26	Poor expression or understanding of the need.
R27	Lack of means to monitor and carry out HSE activities.
R28	Partial application of the procedure.
R29	Non-compliance with HSE regulations.
R30	Lack of effective corrective action. Partial application of the accident. Incident investigation procedure.
R31	Partial application of the procedure.
R32	Non-compliance with transmission deadlines. Absence of input elements to complete monthly tracking.
R33	Non-implementation of SST/AES actions. Lack of resources. Failure to allocate the necessary budget to OHS/HEA actions.
R34	Staff vaccination. Encourage staff to comply with barrier measures both inside and outside the company.
R35	Partial mastery of HSE.
R36	Geological nature of the terrain. System failure.
R37	Partial application of the procedure.
R38	Non-compliance with contractual requirements. Tough competition between companies.
R39	Failure to comply with applicable regulations. Failure to apply the emergency plan.
R40	Lack of some required positions in the job market Personnel list imposed by ANEM with inadequate skills Partial application of the Salary grid procedure.
R41	Partial application of the procedure.
R42	Ineffective Governance Arrangements. Personality Clashes and Disagreements. Substandard Products and Services. Substandard Products and Services.
R43	unmotivated human capital.

Appendix C. Risks evaluation results/ RPN

Risk ID	Risk Evaluation		
	SEV	OCC	RPN
R1	1	8	8
R2	1	4	4
R3	16	2	32
R4	16	4	64
R5	4	4	16
R6	64	2	128
R7	1	8	8
R8	16	2	32
R9	16	2	32
R10	4	8	32
R11	64	4	256
R12	16	4	64
R13	64	8	512
R14	4	1	4
R15	4	1	4
R16	4	1	4
R17	16	8	128
R18	64	1	64
R19	4	8	32
R20	64	8	512
R21	16	4	64
R22	1	4	4
R23	4	4	16
R24	1	4	4
R25	4	4	16
R26	1	4	4
R27	4	4	16
R28	4	4	16
R29	64	4	256
R30	16	8	128
R31	4	1	4
R32	4	1	4
R33	4	1	4
R34	4	1	4
R35	1	4	4
R36	64	4	256
R37	4	1	4
R38	16	1	16
R39	64	1	64
R40	4	1	4
R41	4	1	4
R42	4	1	4
R43	1	4	4

Appendix D. Evaluation Results/ Impact on Cost. Quality and Time

Risk ID	Project	Probability	Impact	Matrix
	Quality	0.5	0.05	0.025
R1	Cost	0.5	0.1	0.05
	Time	0.5	0.4	0.2
	Quality	8	0.4	0.2
R2	Cost	0.7	0.4	0.2
	Time	0.7	0.05	0.4
	Quality	0.5	0.05	0.035
R3	Cost	0.5	0.2	0.14
	Time	0.5	0.8	0.4
	Quality	0.7	0.4	0.2
R4	Cost	0.7	0.1	0.05
	Time	0.7	0.1	0.07
	Quality	0.1	0.05	0.035
R5	Cost	0.1	0.05	0.035
	Time	0.1	0.05	0.005

	Quality	0.9	0.1	0.01
R6	Cost	0.9	0.4	0.04
	Time	0.9	0.8	0.72
	Quality	0.5	0.8	0.72
R7	Cost	0.5	0.2	0.18
	Time	0.5	0.2	0.1
	Quality	0.5	0.05	0.025
R8	Cost	0.5	0.4	0.2
	Time	0.5	0.8	0.4
	Quality	0.9	0.2	0.1
R9	Cost	0.9	0.8	0.4
	Time	0.9	0.1	0.09
	Quality	0.7	0.8	0.72
R10	Cost	0.7	0.4	0.36
	Time	0.7	0.2	0.14
	Quality	0.9	0.4	0.28
R11	Cost	0.9	0.4	0.28
	Time	0.9	0.4	0.36
	Quality	0.7	0.4	0.36
R12	Cost	0.7	0.4	0.36
	Time	0.7	0.4	0.28
	Quality	0.5	0.8	0.56
R13	Cost	0.5	0.8	0.56
	Time	0.5	0.8	0.4
	Quality	0.9	0.4	0.2
R14	Cost	0.9	0.4	0.2
	Time	0.9	0.2	0.18
	Quality	0.3	0.05	0.045
R15	Cost	0.3	0.4	0.36
	Time	0.3	0.8	0.24
	Quality	0.3	0.05	0.015
R16	Cost	0.3	0.2	0.06
	Time	0.3	0.2	0.06
	Quality	0.1	0.4	0.12
R17	Cost	0.1	0.2	0.06
	Time	0.1	0.1	0.01
	Quality	0.7	0.8	0.08
R18	Cost	0.7	0.8	0.08
	Time	0.7	0.8	0.56
	Quality	0.1	0.8	0.56
R19	Cost	0.1	0.8	0.56
	Time	0.1	0.4	0.04
	Quality	0.9	0.8	0.08
R20	Cost	0.9	0.4	0.04
	Time	0.9	0.2	0.18
	Quality	0.9	0.8	0.72
R21	Cost	0.9	0.4	0.36
	Time	0.9	0.05	0.045
	Quality	0.7	0.8	0.72
R22	Cost	0.7	0.05	0.045
	Time	0.7	0.1	0.07
	Quality	0.7	0.2	0.14
R23	Cost	0.7	0.4	0.28
	Time	0.7	0.8	0.56
	Quality	0.7	0.8	0.56
R24	Cost	0.7	0.2	0.14
	Time	0.7	0.05	0.035
	Quality	0.7	0.4	0.28
R25	Cost	0.7	0.4	0.28
	Time	0.7	0.8	0.56
	Quality	0.9	0.2	0.14
R26	Cost	0.9	0.1	0.07
	Time	0.9	0.8	0.72
	Quality	0.7	0.1	0.09
R27	Cost	0.7	0.1	0.09
	Time	0.7	0.05	0.035
R28	Quality	0.7	0.1	0.07

	Cost	0.7	0.1	0.07
	Time	0.7	0.1	0.07
	Quality	0.1	0.8	0.56
R29	Cost	0.1	0.8	0.56
	Time	0.1	0.8	0.08
	Quality	0.7	0.8	0.08
R30	Cost	0.7	0.8	0.08
	Time	0.7	0.8	0.56
	Quality	0.5	0.8	0.56
R31	Cost	0.5	0.4	0.28
	Time	0.5	0.4	0.2
	Quality	0.3	0.1	0.05
R32	Cost	0.3	0.4	0.2
	Time	0.3	0.8	0.24
	Quality	0.5	0.8	0.24
R33	Cost	0.5	0.8	0.24
	Time	0.5	0.8	0.4
	Quality	0.1	0.8	0.4
R34	Cost	0.1	0.8	0.4
	Time	0.1	0.8	0.08
	Quality	0.1	0.1	0.01
R35	Cost	0.1	0.1	0.01
	Time	0.1	0.05	0.005
	Quality	0.1	0.8	0.08
R36	Cost	0.1	0.8	0.08
	Time	0.1	0.8	0.08
	Quality	0.5	0.8	0.08
R37	Cost	0.5	0.4	0.04
	Time	0.5	0.2	0.1
	Quality	0.5	0.05	0.025
R38	Cost	0.5	0.05	0.025
	Time	0.5	0.05	0.025
	Quality	0.3	0.05	0.025
R39	Cost	0.3	0.2	0.1
	Time	0.3	0.4	0.12
	Quality	0.1	0.2	0.06
R40	Cost	0.1	0.05	0.015
	Time	0.1	0.05	0.005
	Quality	0.1	0.05	0.005
R41	Cost	0.1	0.05	0.005
	Time	0.1	0.05	0.005
	Quality	0.1	0.05	0.005
R42	Cost	0.1	0.05	0.005
	Time	0.1	0.05	0.005
	Quality	0.1	0.05	0.005
R43	Cost	0.1	0.05	0.005
	Time	0.1	0.05	0.005

Appendix E. Action plan

Risk ID	Action /Means of Control	Responsible	Deadline/ Frequency
R1	Compliance with current regulations. regulatory watch. awareness-raising and collaboration with interested parties. with follow-up and processing of recorded complaints.	Project management team	Each complaint/ complaint
R2	Anticipate. define and give value to the choice of methods (creation of a communication unit dedicated exclusively to promoting the strong points and technical and economic advantages of the methods).	Project management team	Each month
R3	Establish a strategic monitoring process through which the project listens proactively to its socio-economic and political environment in order to open windows of opportunity and reduce the risks linked to uncertainty.	Project management team	Each month
R4	Measurement of supplier performance through comparative analysis. determination and rating of pre-selection criteria. Use of a pre-selection grid and transfer of criteria. allocation of status and ranking of selected suppliers' establishment of a panel of approved suppliers for each type of.	Process pilot	Each month

R5	Include at least one new supplier to allow access to new technologies and to evaluate the market from time to time. Measure the performance of suppliers. by carrying out a comparative analysis between them. Determine and rate pre-selection criteria.	Process pilot	Each month
R6	Avoiding the use of technical specifications so that only one supplier is selected. Gathering information. Objective recruitment of buyers.	General manager and head of the finance process and department	On each payment date
R7	Respect payment deadlines diversify sources of supply for each raw material favor the closest suppliers. Look for at least two nearest sources of supply for each raw material.	Purchasing manager stock manager and a competent person	Each delivery
R8	Expression of needs well established selection of suppliers offering good quality. receipt of products must be done by a competent person non-conforming product must be isolated to prevent its use.	Purchasing manager stock manager and a competent person	Each delivery
R9	Update inventory management strategy to avoid stock-outs. Manage raw material inventories properly. Specialized training for storekeepers to manage the store properly. All departments must accurately determine monthly raw material consumption and trends.	Purchasing manager Stock manager and a competent person	Monthly
R10	Reinforce and intensify coordination meetings with MOE. review preliminary design in sensitive areas.	Technical responsible. works responsible	Yearly
R11	Rigorous follow-up and monitoring. simulation tests on the various major risks. involving the relevant stakeholders.	Technical responsible. works responsible	Monthly
R12	Standardize procedures. techniques and working documents. Rigorous monitoring. carry out simulation tests on the various major risks. involving the parties concerned.	General manager and head of the finance process and department	Monthly
R13	Ensure a relevant training plan for everyone involved in the process.	All those involved in the project	Monthly
R14	Strengthen and intensify coordination meetings with customers and stakeholders.	Technical supervisor	Monthly
R15	Carry out simulation tests on the various major risks. with the integration of the various project stakeholders.	Purchasing manager stock manager and a competent person	Monthly
R16	A procedure for tracking changes. designation of a competent person to manage and track changes.	The heads of department concerned	Monthly
R17	Carry out simulation tests on the various major risks. with the integration of the various project stakeholders.	The heads of department concerned	Monthly
R18	A procedure for tracking changes. designation of a competent person to manage and track changes.	The heads of department concerned	Monthly
R19	Review and include a clause in the contract on the obligation of technology suppliers in terms of training and follow-up. Ensure a relevant training plan for everyone involved in the process.	The heads of department concerned	Monthly
R20	A detailed traffic plan for the various worksites. driver awareness of road risks and compliance with traffic regulations.	Stock manager	Monthly

R21	A detailed traffic plan for the various worksites. driver awareness of road risks and compliance with traffic regulations.	The heads of department concerned	Monthly
R22	Ensure a relevant training plan for everyone involved in the process.	The heads of department concerned	Monthly
R23	Detailed forecast planning. set up an interactive dashboard. Competent inventory management. Increase storage capacity.	The heads of department concerned	Daily
R24	Rigorous follow-up. designation of a competent person for follow-up.	The heads of department concerned	Monthly
R25	Reliable provisional schedules. develop partnership relations with suppliers.	General resources responsible	Daily
R26	Coordination between the various project players Raising staff awareness	General resources responsible	Daily
R27	Ensure the presence of an HSE officer at both sites. with daily visits by the engineers and HSE manager.	HSE responsible	Daily
R28	Establishment of an awareness program with daily briefings according to the work schedule.	Project management	Daily
R29	Analysis of workplace accident statistics CPHSU and management meeting OHS management program Staff	Project management	Daily/ weekly/ half-yearly/ yearly
R30	training. information and awareness HSE instructions and procedures.		
R31	Removal of reservations by taking corrective action in accordance with procedure.	HSE responsible	Each Audit
R32	THE communication.	Quality manager	Monthly
R33	Joint workplace visits. meetings and HSE inspections.	Project management	Yearly
R34	Staff vaccination. Encourage staff to comply with barrier measures both inside and outside the company.	HSE responsible	Yearly
R35	Make external service providers aware of HSE regulations and standards Make external service providers aware of HSE best practices.	HSE responsible	Yearly
R36	Coordination between the various parties involved in driving the TBM Drawing up a contract with SEAAL for the recovery of purified water.	HSE responsible	Yearly
R37	Internal management and works meetings and with the design office lifting of reservations and non-conformities.	Project management	Yearly
R38	Compliance with contract clauses (deadlines. quality. HSE) Reinforce and intensify coordination meetings with different stakeholders.	Works department	Yearly
R39	Implement regular compliance audits. enhance project management practices. conduct thorough risk assessments. improve communication. invest in technology and infrastructure. manage reputation. foster a culture of continuous improvement. and ensure legal compliance.	Project management	Yearly
R40	Preparation of a database see the possibility of COSIDER projects in the final phase for mutations.	HR manager	Yearly
R41	Preparation of a database see the possibility of COSIDER projects in the final phase for mutations.	HR manager	Yearly
R42	Awareness-raising and communication. Installation of worksite secretaries at all sites.	HR manager	Yearly
R43	Motivation and skills retention. Implementation of forward-looking employment and skills management.	HR manager	Yearly