EARLY CONSTRUCTION READINESS ASSESSMENT FOR RISK MANAGEMENT IN TUNNELLING: MULTI PROJECT VALIDATION

F. Mondaca, A. Adema & S. Gutiérrez
Skava Consulting, Santiago, Chile

ABSTRACT: Tunnelling projects are frequently located on or near the critical path of large, integrated developments such as mining and transportation infrastructure, creating strong pressure to begin construction early. As a result, they are particularly vulnerable to premature starts, in which mobilization occurs before true readiness is achieved, amplifying safety, schedule, cost, and quality risks.

This paper positions the Construction Readiness Assessment (CRA), developed by the Construction Industry Institute (CII), as an early-phase risk management tool for tunnelling projects, applied at the pre-investment Feasibility Study (FS) stage rather than solely as a late-stage construction gate. A phase-appropriate CRA evaluation was first applied to a fast-tracked mining tunnelling project, demonstrating immediate value in identifying high-impact readiness gaps not typically captured by conventional feasibility deliverables. This methodology was subsequently applied retrospectively to three additional tunnelling projects within the mining industry to validate cross-project consistency.

The results show that early CRA application consistently highlights a concentrated set of execution-related readiness gaps, even where engineering and planning maturity appear adequate, revealing that earlier implementation would have exposed additional risks and reinforced execution planning. These findings indicate that embedding CRA early and iteratively can improve readiness-related decision-making, strengthen study outputs, and provide a defensible pathway toward achieving Construction-Ready (CR) status in tunnelling projects.

1. INTRODUCTION

The Construction Industry Institute (CII) (CII, 2018) developed a comprehensive survey which collected data from 80 projects and categorized them as Construction-Ready (CR) and Construction-Not-Ready (CNR). The results demonstrated substantial differences between these two groups. It was found that CR projects achieved a 22% reduction in schedule duration, a 29% improvement in productivity, 20% cost savings, 7% less rework and 21% fewer changes compared to CNR projects. These findings highlight construction readiness as a strong determinant of execution performance.

In response to this, the CII (2018) developed the Construction Readiness Assessment (CRA), which offers a structured framework to evaluate a project preparedness to enter the construction phase. This methodology produces a Construction Readiness Score (CRS) and classifies projects as CNR, Borderline, or CR. This tool is generally applied in the later stages of projects as a tool to quantify readiness and greenlight execution start.

While the negative impacts of CNR conditions are evident across multiple sectors, their consequences are particularly severe in underground developments. Tunnelling projects are characterized by constrained logistics, complex interfaces, and the unpredictable nature of underground works. Subjected to CNR conditions, these characteristics tend to magnify safety risks, schedule disruption, cost growth, and quality issues.

Moreover, tunnelling works are frequently located on, or near, the critical path of large integrated projects such as mining developments and transportation infrastructure. As a result, strong pressure often exists to begin construction early to protect overall project schedules and business objectives. This pressure can lead to premature starts, where construction activities begin before the project has achieved sufficient levels of technical definition, maturity and execution readiness.

Although the CRA framework was developed from multiple industry sectors, including mining and infrastructure, its application to tunnelling projects at early stages has not been reported in the literature. This paper positions CRA as an early-phase diagnostic and risk-management tool for tunnelling projects, applied from pre-investment through front-end engineering rather than only immediately prior to construction. The tool was applied to four underground mining construction projects at development of the FEL-3 phases, in commonly used front-end loading (FEL) frameworks, hereafter referred to as Feasibility Study (FS). A phase-appropriate benchmark CRA evaluation was conducted while maintaining traceability to the full CRA taxonomy, enabling meaningful application at early stages. This allows the management team to address risks through targeted proactive actions across owner, designer, and contractor teams.

2. CRA FRAMEWORK

2.1 CRA FRAMEWORK OVERVIEW

The CRA framework evaluates 228 readiness factors, grouped into 15 categories: Project Team, Engineering, Planning, Health/Safety/Security/Environment (HSSE), Execution, Tools and Equipment, Quality Management, Change Management, Contract Management, Human Resource Management, Stakeholder Management, Risk Assessment and Management, Procurement and Material Management, Commissioning, and Project Controls.

Each readiness factor is assessed through binary responses: yes or no. Once all factors are computed, the sum of the answers (1 for yes, 0 for no) multiplied by their respective weights provides the CRS, which is expressed as a percentage. Factor weights were derived by CII (2018) through a data-driven analytical model, which highlights those factors that most strongly differentiates the CR from CNR projects.

The CRA framework establishes the general cutoff for a project to be CR as a CRS greater or equal to 80%. To avoid reliance on a strict cutoff, an intermediate “Borderline” category was defined for CRS values between 75% and 85%, indicating that construction start may be feasible but that additional preparatory actions are required.

2.1.1 Key and Fundamental Factors

Out of the 228 readiness factors, 210 are classified as key factors and 18 as fundamental factors. The distinction between these two groups lies in their ability to differentiate project performance. A key factor is one that is completed by a high percentage of CR projects and often missed by CNR projects, and therefore serve as strong indicators of readiness. For example, conducting a clash detection analysis is identified as a key factor.

Fundamental factors, however, are not less important. They represent essential tasks that are so critical that both CR and CNR projects consistently perform them. However, given that they are performed by all projects, they do not contribute to the CRS but rather should be taken as a list of actions that must be performed before project construction can begin. These factors tend to be mostly associated with HSSE and human resources, reflecting an industry-wide commitment to safety and workforce requirements that is maintained regardless of overall construction readiness.

3. APPLICATION TO TUNNELING PROJECTS

3.1 EARLY CRA ON A FAST-TRACKED PROJECT

3.1.1 Project Context and Objectives

The CRA was first applied to a fast-tracked tunnelling initiative developed within the Andes Mountain Range, in central Chile. The project, hereafter referred to as *P1* for confidentiality reasons, emerged near the close of a FS phase as an attempt to define a technically executable and economically viable path for early underground development of a mining project, to be developed within the context of an existing open-pit mining operation. Its objective was not full project sanction, but rather to enable early access and infrastructure works that could support future underground exploitation while preserving optionality in the overall development strategy.

P1 was therefore characterized by overlapping objectives: advancing engineering to a level sufficient to demonstrate constructability and cost viability, while deliberately deferring certain execution decisions, such as contractor selection and detailed mobilization planning, to subsequent phases. This created a typical fast-track condition in which pressure to "be ready" for early works despite acknowledged immaturity in several execution-related areas.

3.1.2 Timing and Scope of CRA

The CRA was conducted at the end of the FS engineering, prior to any commitment to construction commencement or contractor selection. At this stage, the project had an established set of engineering deliverables, consolidated cost estimates, and a defined baseline schedule. However, detailed execution planning, procurement strategies, and workforce arrangements had not yet been developed.

The assessment was carried out in person by the authors through a series of workshops, held alongside with multiple project representatives capable of answering for its state across the 15 different categories. The assessment was performed intentionally conservative, treating the absence of execution-phase deliverables not as exclusions but as explicit readiness gaps. This approach allowed the CRA to function as an early diagnostic of CNR conditions rather than as a pass–fail gate for construction start.

3.1.3 Key Readiness Gaps Identified

As expected for a FS, the overall CRS obtained was of 39.7%, clearly placing the project in a CNR condition. More important than the absolute score was the concentration and nature of high-impact readiness gaps, which were primarily associated with execution enablers rather than technical design maturity. Key gaps included incomplete definition of hold points and handoffs, absence of a site-specific safety plan and geotechnical verification near portal areas, lack of defined procurement and logistics control processes, incomplete project team resourcing and role clarity, and the absence of a defined construction-to-commissioning interface. The result of this CRA assessment can be observed in detail in Figure 1.

In contrast, "Engineering", "Planning", and "Risk Management" categories showed comparatively higher maturity, reflecting the project's study-phase focus. This pattern confirmed that readiness risks were not driven by flawed engineering concepts, but by missing integration between engineering outputs and future construction and commissioning requirements.

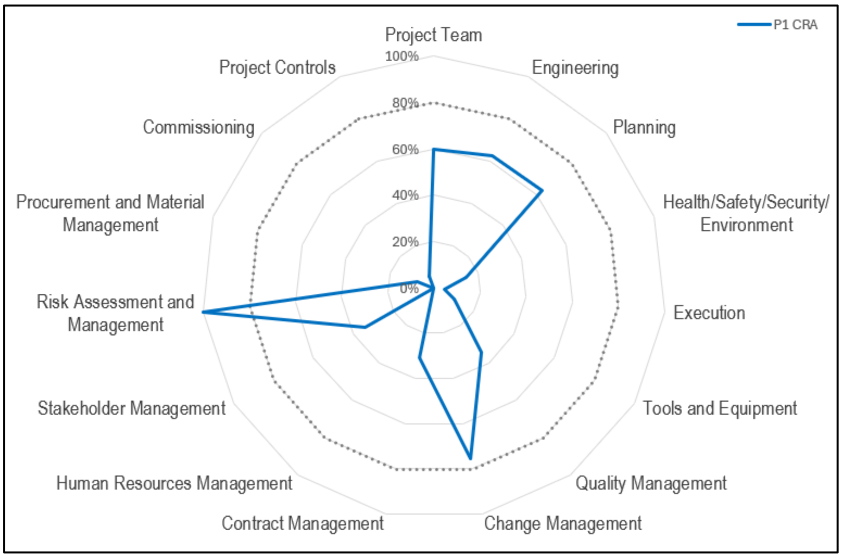

Figure 1. CRA assessment results displayed in a spyder chart for project P1.

3.1.4 Value Delivered

Although *P1* was no longer pursued under a fast-track construction strategy as part of broader project-level decisions, the CRA assessment was completed, formally documented, and its value was promptly recognized by the project team. The structured identification of readiness gaps provided a transparent and defensible basis for understanding why early construction would have carried disproportionate risk without further project maturity.

Beyond its immediate findings, the CRA strengthened the FS by exposing misalignment between engineering deliverables, execution assumptions and schedule logic. In this context, the CRA functioned less as a construction approval gate and more as an early risk-management instrument, converting latent readiness deficiencies into explicit risks that informed subsequent project decisions.

3.2 RESTROSPECTIVE APPLICATION ACROSS OTHER PROJECTS

As the value of early CRA application became evident in *P1*, it was decided to apply this tool retrospectively to three more tunnelling projects at similar study development stages. For confidentiality reasons, these projects will be described as *P2, P3* and *P4* from here onwards.

3.2.1 Projects Overview and Applicability

P2 consisted of the development of a large exploration tunnel within a greenfield mining project in northern Chile. The project objective aimed to execute underground exploration works under strong schedule pressure and evolving design maturity, with the objective of improving geological and geotechnical knowledge to support subsequent development decisions.

P3 consisted of the development of a key infrastructure component within a copper–molybdenum brownfield project in Argentina, designed to connect two valleys through an underground belt conveyor tunnel forming part of the mine's material handling system. The FS focused on engineering definition and execution planning for the tunnel, associated portals and ventilation works to enable future construction.

P4 was an underground development initiative within an operating underground mining complex in central Chile, aimed at replacing and upgrading the ventilation and heating system serving the underground division. This project was developed as a FS with a robust technical and economic basis to support investment decisions and subsequent detailed engineering and execution phases.

While these projects differ in scope and context, they all involve the development of underground infrastructure within larger mining projects and occupy an enabling position on the critical path. As mining projects, they are subject to comparable investment assurance requirements and risk-based standards used to support investment decisions, resulting in significant schedule pressure and an elevated risk of premature mobilization. This renders them optimal for the retrospective evaluation of the readiness gaps and associated risks that could have been identified from the pre-investment stage, had the CRA methodology been applied in a timely manner.

3.2.2 CRA Evaluation and Readiness Gap Identified

The retrospective assessments were carried out using the same methodology applied to *P1*, consisting of structured, in-person evaluations conducted by the authors with project representatives capable of providing authoritative responses. As expected, given the different context and scope of the projects, the CRA provided different results for the three projects. P2 and P3 achieved a CRS value of 21.73% and 16.33% respectively, consistent with their greenfield and brownfield contexts. In contrast, P4 achieved a significantly higher CRS value of 48.54%, reflecting its development within an operating underground mining complex where several execution-related factors were already in place.

It is hard to identify in the figure due to the overlap of the different projects, but the highest category across all four projects is the "Risk Assessment and Management" Category, which obtained a score of 100% for *P1* and *P4*, and 66% for *P2* and *P3*. This can be easily explained by the risk-oriented nature of FS, where risk identification and categorization are a core aspect. Also, among the categories with the highest overall scores are "Project Team", "Engineering", and "Planning", highlighting the factors that can be more effectively addressed during the study phase.

It is also possible to recognize considerable similarities in the gaps identified using this methodology. As can be seen in Table 1, substantial gaps were identified across multiple categories; "Execution", "Contract Management", "Human Resources Management", "Stakeholder Management", and "Project Controls" all averaged below 10%, while other categories, such as "Tools and Equipment", "Commissioning", "Procurement and Material Management", and "Project Controls" would have also scored below 10% had it not been for *P4*. It's important to recall that this project is to be developed within an operating underground mining complex, for a major global mining company. This means that the study starts from a base with multiple factors already solved, therefore explaining the sizable gap to other projects and the relatively higher development in categories not usually associated with FS development.

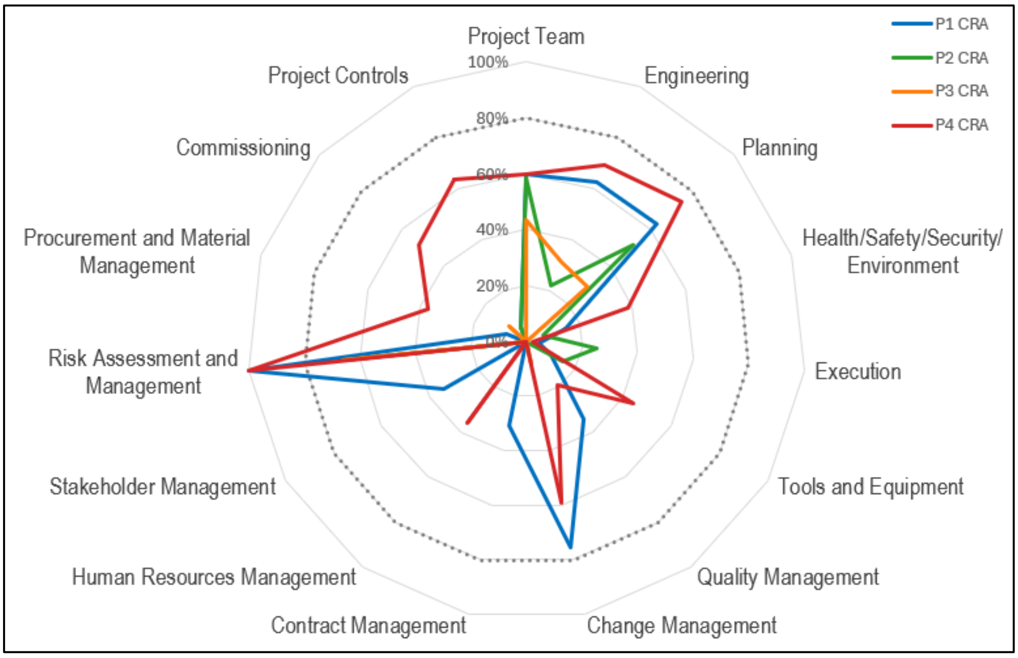

Figure 2. CRA assessment results displayed in a spyder chart for projects P1through P4.

Table 1: Average category scores per category for projects P1 through P4.

Category	Average Category Score
	%
Project Team	55
Engineering	46
Planning	55
Health/Safety/Security/Environment	15
Execution	8
Tools and Equipment	17
Quality Management	13
Change Management	37
Contract Management	8
Human Resources Management	9
Stakeholder Management	9
Risk Assessment and Management	83
Procurement and Material Management	11
Commissioning	15
Project Controls	9

3.2.3 Remarks From Retrospective Assessments

To ensure consistency and comparability across projects, a set of unified assessment criteria was therefore adopted:

- For factors regarding project team representation (e.g., Does the project team include representative(s) from the engineering team?), a response of "Yes" was assigned if the projected execution organizational chart explicitly included such roles.
- For factors regarding agreement and knowledge within the project team (e.g., Is the project team aligned on the site-specific safety plan?) were addressed as "No" as the FS cannot guarantee this if the team is not yet formed.
- For the factors that do not specify subject (e.g., Have the project drivers (cost/schedule) been agreed on by the team?), the study team was considered.
- Regarding the "Contract Management" category, all factors were addressed as "No", unless the study had access to owner framework contracts that could guarantee some of the factors (this was the case for *P1*).

- In cases of uncertainty regarding the status of the factor, this was conservatively assessed as “No” to avoid overestimation of project maturity.

Overall, a readiness factor was evaluated as “Yes” only if it could be reasonably assured based on the deliverables or the information available.

4. TARGET EVALUATION FOR FS AND DISCUSSION

To establish a development-stage–relevant benchmark against which the evaluated projects could be compared, an additional “Target” assessment was conducted by the authors, based on their personal experience and learnings from the workshops. This assessment sought to answer, for each CRA factor, the following question: Should a robust and complete pre-investment level study address this factor for a tunnelling project within the mining industry?

The assessment resulted in a CRS of 55.06%, with the distribution illustrated in Figure 3. The most prominent strengths of a FS are typically associated with risk identification and business evaluation. This is clearly reflected in the spyder chart, were the “Risk Assessment and Management” and “Stakeholder Management” categories, both closely linked with inherent project risks, achieved scores of 100% and 98%, respectively. This further highlighted by the high score attained by the “Planning” category (95%), which encompasses key factors related to budget definition and schedule development.

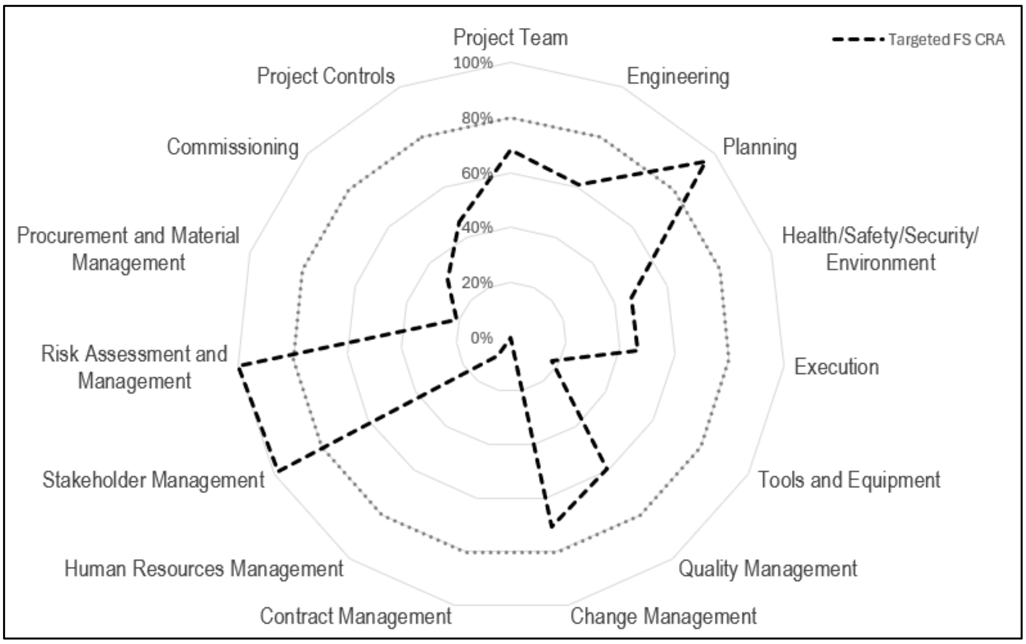

Figure 3. Targeted FS Construction Readiness Assessment.

Among the remaining categories, “Project Team” and “Engineering” also achieved relatively high scores, as these areas address fundamental issues that are expected to be resolved, even if not fully, during the pre-investment phase. “Quality Management” and “Change Management” were likewise categories that can be assessed at early development stages. Although they are not critical at FS level, it remains valuable to consider these factors early, as doing so contributes to overall project maturity.

Finally, execution-oriented categories exhibited the lowest readiness levels, consistent with the fact that feasibility studies are not intended to fully address detailed construction planning, control and execution.

4.1 COMPARISON WITH EVALUATED PROJECTS AND FINDINGS

Figure 4 compiles the results of all assessments performed. Overall, the targeted FS CRA defines a well-shaped envelope that consistently bounds the four assessed projects, with only a limited number of justified deviations. These include *P1* in Contract Management category, where availability of owner frameworks contract allowed verification of several contract-related factors despite the FS level development, and *P4*, whose location within an already operational underground mine enabled the assessment of aspects beyond what would typically be expected at this level, resulting in higher scores across several categories.

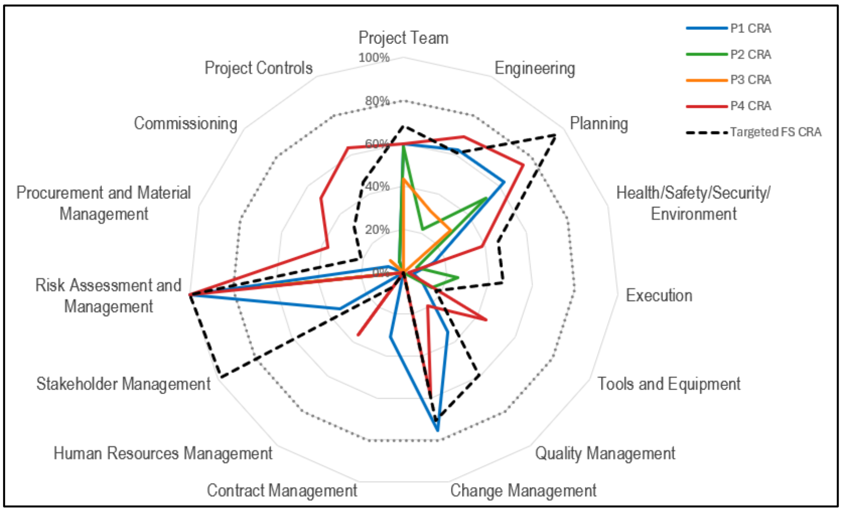

Figure 4. Compilation of all Construction Readiness Assessments.

"Stakeholder Management" emerged as one of the most significant areas of weakness across the projects. Insufficient maturity in this category can expose projects to substantial risks, including misaligned objectives, uncontrolled scope growth, and schedule and costs overruns driven by poorly communicated stakeholder expectations. "Quality Management" also exhibited notable gaps, increasing the likelihood of rework and escalating costs due to unclear quality requirements, insufficient acceptance criteria, and limited quality control mechanisms.

The gaps observed in the "Project Controls" and "Commissioning", in all projects except for *P4*, highlight weaknesses in performance monitoring and in managing the transition to operations. Such shortcomings may result in delayed issue identification, incomplete system testing, unclear roles and responsibilities, delayed start-up and operational or safety risks at handover.

Beyond the quantitative results, the evaluation process proved highly effective in identifying unforeseen risks. Workshops with project representatives facilitated the recognition of project-specific weaknesses and supported the definition of proactive mitigation measures to be incorporated in subsequent engineering phases.

The assessment also enabled the establishment of a benchmark CRS for FS. While a CRS of approximately 55% at this stage does not indicate construction readiness, it provides a validated reference point against which FS level projects can be compared. However, as outlined by *P4*, CRA outcomes at this development stage may exhibit significant variability depending on project context and industry. Accordingly, reliance on the overall CRS alone may be misleading, and a category-level review is therefore strongly recommended to ensure that progress, gaps, and associated risks are properly understood.

5. FUNDAMENTAL FACTORS ASSESSMENT

As fundamental factors do not effectively discriminate between CR and CNR projects, they were excluded from the comparative analysis presented previously. Nevertheless, these factors remain essential to overall project success and therefore cannot be disregarded when performing a CRA. Table 2 presents the assessment results for all projects with regards to the fundamental factors.

A pattern consistent with that observed for the key factors is evident, while the targeted FS assessment generally encompasses the assessed projects. Only a limited number of deviations is observed, primarily associated with Projects *P1* and *P4*, which can be reasonably explained by their specific project contexts.

The fundamental factors are predominantly associated with "HSSE" and "Human Resources" categories. These areas are closely linked to project execution and are therefore less central during the pre-investment phase. However, as essential enablers for any project, these factors should be identified early and progressively developed to ensure adequate maturity by the end of detailed engineering and prior to construction commencement.

Table 2: Fundamental factors assessment for all studied projects.

	P1	P2	P3	P4	Targeted
	(Y/N)	(Y/N)	(Y/N)	(Y/N)	(Y/N)
1.10 Is a support system in place to allocate resources?	No	No	Yes	No	Yes
4.1 Have safety goals been set?	Yes	Yes	No	Yes	Yes
4.3 Is there medical support defined for the project?	Yes	Yes	No	Yes	Yes
4.4 Is there an environmental management plan in place?	Yes	Yes	Yes	Yes	Yes
4.5 Is there a site-specific safety plan in place?	No	No	Yes	Yes	Yes
4.8 Are the site security control procedures in place?	Yes	No	Yes	Yes	No
4.16 Is there a safety induction/orientation plan in place?	Yes	No	Yes	Yes	No
5.9 Are there adequate communication tools in place (including tablets, Wi-Fi, radios, phones, etc.)?	No	No	No	No	No
5.18 Is there an adequate geotechnical investigation of the project site?	No	No	Yes	No	Yes
10.1 Has the project team completed a review and analysis of the labor market, including competing projects in the area?	No	No	No	Yes	No
10.3 Is there a plan in place to minimize craft absenteeism?	No	No	No	No	No
10.5 Have billable labor rates been established?	No	No	No	No	No
10.7 Is there a project-specific-traning program in place?	No	No	No	Yes	No
10.10 Are there on-boarding procedures in place to on-board new hires?	No	No	No	Yes	No
10.16 Are there termination procedures in place to on-board new hires?	No	No	No	No	No
10.17 Are there promotion procedures in place to on-board new hires?	No	No	No	No	No
11.4 Is there a public relations and outreach program in place?	No	No	Yes	Yes	Yes
13.10 Is there clear procurement process and supporting systems in place for delivery?	No	No	Yes	No	No

6. CONCLUSIONS

6.1 CONCLUSIONS

This paper demonstrates that the CRA can be effectively repositioned as an early, structured risk-management tool when applied at the pre-investment FS stage of tunnelling projects. Across both the fast-tracked case study and the retrospective multi-project application, early CRA implementation consistently exposed high-leverage readiness gaps that are not typically identified through conventional feasibility deliverables alone. The definition of a phase-appropriate FS target further showed that Construction-Not-Ready outcomes at this stage are expected and should be interpreted as guidance for execution preparation rather than as indicators of project failure. In this context, early CRA application transforms latent readiness deficiencies into explicit, manageable risks and provides a structured basis for prioritizing execution-oriented activities as projects transition into the execution phase.

In the case of Project P1, early CRA application directly informed how ongoing and subsequent engineering phases should be structured. Identified readiness gaps, particularly those related to execution planning, interfaces, contracting strategy, project controls, and commissioning readiness, were formally documented in the Project Execution Plan, establishing a clear roadmap for focusing engineering efforts on subsequent phases. More broadly, the comparative analyses indicate that formally closing the FS phase with a CRA-based assessment provides clear direction on how to focus detailed engineering and construction preparation. Embedding CRA as a minimum FS close-out activity would therefore strengthen continuity between project development stages and reduce the risk of premature mobilization driven by schedule pressure rather than project maturity.

6.2 STUDY LIMITATIONS

Several limitations of the study should also be acknowledged. Some of the analysed projects experienced strategic shifts or late decision changes near the close of the FS, postponing key determinations to detailed engineering and partially constraining the assessment (*P2* case). In other cases, the scale and complexity of the projects required integration across multiple consultants, resulting in fragmented information availability (*P3* case). Despite these constraints, representatives from both projects expressed strong interest in the methodology and indicated that it would have been highly valuable for identifying study gaps and associated risks earlier in the process.

It is also important to emphasise that achieving a high CRS alone does not guarantee project success. The CRA is effective in assessing the completeness of project preparation, but it does not evaluate the technical quality of the underlying deliverables. As such, it should be viewed as a complement to, rather than a substitute for rigorous quality assurance and technical review processes across all project stages.

7. ACKNOWLEDGEMENTS

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LITERATURE

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MSc, Fernando, Mondaca Fellenberg: Author1
Skava Consulting
fernando.mondaca@skava.cl

MSc, Andrés, Adema Yusta: Author2
Skava Consulting
andres.adema@skava.cl

MSc, Sergio, Gutiérrez Cofré: Author3
Skava Consulting
sergio.gutierrez@skava.cl