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Anticipating Operational Workforce Readiness for Capital-Asset Integration: A Tri++ and Kepner-Tregoe Approach

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ABSTRACT
The success of integrating new capital assets and automated technologies depends not only on the technology itself but also on the readiness of the operational workforce. However, workforce readiness is often assessed only after technology adoption and through narrowly individual or technical perspectives. This study developed an anticipatory pre-commissioning framework that extended the Technology Readiness Index (TRI 2.0) into TRI++ by incorporating organizational dimensions, including role clarity and organizational capability, and integrating them with Kepner–Tregoe Potential Problem Analysis (KT-PPA) to transform identified readiness gaps into actionable mitigation measures. Specifically, the framework was developed using a mixed-methods design and demonstrated through the integration of a new shiploader at a large Indonesian mining port prior to commissioning. Data from 157 operational personnel were analyzed using a one-sample test and Pareto analysis, and the findings were triangulated with 25 semi-structured interviews analyzed through thematic analysis. The results indicated that the workforce demonstrated willingness but lacked sufficient organizational capability, with attitudinal readiness emerging as the strongest dimension and organizational constraints identified as the primary barriers. KT-PPA translated these findings into seven potential problems and five proposed solutions. This study offers a transferable approach for anticipatory workforce readiness evaluation by integrating psychometric measurement with structured, forward-looking risk analysis.

INTRODUCTION

The integration of new capital assets and automated technologies serves as a strategic lever for industrial productivity; however, successful implementation is often determined by human and organizational factors rather than technology alone. New systems typically fail not because the equipment is inadequate, but because the workforce responsible for operating and maintaining the assets is not prepared for the changes in skills, roles, and work practices required. As operations become increasingly automated and capital-intensive, assessing and developing workforce readiness before asset commissioning becomes a critical managerial task (Alshuwayer, 2025; Ananth et al., 2021; Beckwith, 2026; Chikurumilli, 2026; Mears, 2019).

One established approach for evaluating technology adoption preparedness is the Technology Readiness Index (TRI), which measures individuals' predispositions toward adopting and using new technologies through two motivators—optimism and innovativeness—and two inhibitors—discomfort and insecurity (Parasuraman, 2000; Parasuraman & Colby, 2015). TRI and its streamlined revision, TRI 2.0, have been widely applied; however, their applications have predominantly focused on consumer and service technology contexts and individual-level attitudes (Blut & Wang, 2020).

Three research gaps motivated this study. First, from a theoretical perspective, TRI has rarely been extended to examine operational workforce readiness for the integration of heavy industrial capital assets or to incorporate organizational-level conditions, such as role clarity and organizational capability, that determine whether individual willingness can be translated into operational readiness. Second, most technology-readiness studies have employed quantitative approaches, often using structural equation modeling (e.g., Blut & Wang, 2020); comparatively few studies have combined psychometric measurement with qualitative insights and structured, forward-looking risk analysis. Third, from a practical perspective, readiness is frequently measured after technology implementation, whereas anticipatory pre-commissioning workforce readiness for assets that are not yet operational, particularly in mining and port operations, remains insufficiently explored.

This study addressed these gaps by extending TRI into an integrated framework, TRI++, which augmented the four TRI 2.0 dimensions with two organizational dimensions—role clarity and organizational capability—and combined this measurement approach with Kepner–Tregoe Potential Problem Analysis (KT-PPA), a structured method for anticipating potential problems associated with planned changes (Kepner & Tregoe, 1997). The integrated framework was demonstrated through a single, information-rich case involving the planned integration of a new shiploader at the Dewatering Plant of a large mining-port operation prior to asset commissioning. The extension of TRI to include organizational dimensions was theoretically grounded in the understanding that individual readiness alone is insufficient to ensure operational preparedness; even highly motivated and optimistic employees may be unable to perform effectively without clear role expectations or adequate organizational support, including training, staffing, and operational systems. The integration of KT-PPA provided a forward-looking complement to the diagnostic function of TRI++, transforming identified readiness gaps into prioritized potential problems and actionable mitigation strategies (Ansari et al., 2025; Goniewicz et al., 2025; Hochrainer-Stigler et al., 2023; Wang et al., 2026; Xames & Topcu, 2026).

The primary contribution of this study was not the specific readiness scores obtained from a single site but the development of a transferable framework for anticipatory workforce readiness assessment that integrates psychometric measurement with structured risk analysis. The study was guided by three research questions: (RQ1) what factors determine the readiness of the operational workforce for the new asset? (RQ2) what potential problems may arise during the integration process, and how can they be mitigated? and (RQ3) what solutions can be recommended to address identified readiness gaps?

METHOD

Research Design

This study employed a convergent (concurrent triangulation) mixed-methods design (Creswell & Plano Clark, 2018), in which quantitative and qualitative data were collected during the same research period, analyzed separately, and integrated during the interpretation stage. The two approaches addressed complementary research questions: the survey identified the extent and magnitude of readiness gaps, while interviews explored their underlying causes and potential future risks. The integrated findings were subsequently analyzed using KT-PPA as the synthesis framework.

Case Setting

The framework is demonstrated in a single case, an information-rich case that is strategic in nature: the integration of a new shiploader (a capital asset of about US$300 million (2024 estimate) scheduled to be commissioned towards the end of the decade) into a large mining-

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port operation at the Dewatering Plant. The plant currently has a single ageing shiploader, making it a single point of failure, and the readiness of the workforce for the new asset is also a matter of operational continuity as well as productivity.

Quantitative Method

To assess the six TRI++ dimensions, a 30-item Likert questionnaire was used, and for the 11 negatively worded inhibitor items: they were then reverse-scored to indicate that higher values consistently denote greater readiness. From a population of 241 individuals, the Slovin formula at a 5 per cent margin of error suggested there was a minimum sample of 151 (157 valid responses were obtained satisfying the Roscoe (1975) guideline for sample size). Internal consistency was evaluated by Cronbach's alpha at a 0.70 threshold (Nunnally, 1978), interpreted through the descriptive reliability bands of George and Mallery (2003). Mean scores were compared to a three-level readiness scale where 4.00 is the threshold of the 'High/Ready' category and a one-sample t-test with 95 per cent confidence intervals, was used to test whether each mean differed significantly from the threshold. A non-parametric Kruskal-Wallis test was conducted to determine the differences between functional sections and a Pareto analysis was performed to find the deficits of each sub-variable below 4.00 in order to identify the "vital few".

Qualitative Method

Twenty-five semi-structured interviews were conducted with informants from all roles and seniority levels, from operators and foremen to engineers, superintendents, and managers. The transcripts were thematically analyzed (Braun & Clarke, 2006) in the form of deductive coding to the framework dimensions and inductive coding of emerging themes. Trustworthiness was established through methodological and data-source triangulation (Morse et al., 2002) and the recurrence and saturation of codes supported the credibility of the themes (Guest, Bunce & Johnson, 2006).

Integration

The triangulated findings were synthesized using KT-PPA to develop prioritized potential problems and solutions. Every potential problem was scored by combining its probability and seriousness, the likely causes were identified using a five-why analysis, and preventative and contingent measures were detailed, resulting in the prioritized problems and the solution packages reported below.

RESULT AND DISCUSSION

Quantitative Results

All six dimensions were over the 0.70 reliability level (Cronbach's α: TRI 2.0 = 0.879, Role Clarity = 0.716, Organizational Capability = 0.879, entire instrument = 0.901). The overall Employee Readiness Index score was 3.91 which was substantially below the criterion of 4.00 ($t = -2.02$, $p = 0.045$) as supported by the one-sample test, suggesting the workforce is not yet at a high level of readiness. However, the overall average masks an important pattern. Attitudinal readiness (TRI 2.0) mean was 4.07 and was not significantly different from the threshold ($t=1.32$, $p=0.189$), with strong optimism (4.59) and innovativeness (4.47). The two organizational variables were below the cut-off threshold; Role Clarity (3.68, $t = -4.93$, $p < 0.001$), Organizational Capability (3.76, $t = -3.42$, $p < 0.001$). The full table of scores, intervals and one-sample tests is shown in Table 1 below.

Table 1. Mean, 95% Confidence Interval, and One-Sample Test against the 4.00 Readiness Threshold, by Dimension and Sub-variable.

Level	Variable	Mean	95% CI	t vs 4	p-value	Category
Sub-variable	Optimism	4.59	4.50–4.69	12.21	$p < 0.001$	High
Sub-variable	Innovativeness	4.47	4.37–4.57	9.44	$p < 0.001$	High
Sub-variable	Discomfort (R)	3.79	3.63–3.94	−2.68	$p < 0.01$	Moderate (PROBLEM)
Sub-variable	Insecurity (R)	3.41	3.24–3.58	−6.70	$p < 0.001$	Moderate (PROBLEM)
Sub-variable	Blurred Boundary	3.62	3.46–3.77	−4.85	$p < 0.001$	Moderate (PROBLEM)
Sub-variable	Reporting Hierarchy	3.87	3.72–4.02	−1.74	$p = 0.085$ (n.s.)	Moderate (PROBLEM)
Sub-variable	Decision Authority	3.57	3.42–3.72	−5.65	$p < 0.001$	Moderate (PROBLEM)
Sub-variable	Manpower Quantity	3.03	2.82–3.24	−9.11	$p < 0.001$	Moderate (PROBLEM)
Sub-variable	Skill Quality	3.78	3.61–3.96	−2.49	$p < 0.05$	Moderate (PROBLEM)
Sub-variable	Interdepartmental Coordination	4.23	4.09–4.37	3.21	$p = 0.002$	High
Sub-variable	Knowledge Management	3.99	3.84–4.14	−0.17	$p = 0.866$ (n.s.)	Moderate (PROBLEM)
Main Variable	TRI 2.0	4.07	3.97–4.16	1.32	$p = 0.189$ (n.s.)	High
Main Variable	Role Clarity	3.68	3.56–3.81	−4.93	$p < 0.001$	Moderate (PROBLEM)
Main Variable	Organizational Capability	3.76	3.62–3.90	−3.42	$p < 0.001$	Moderate (PROBLEM)
Overall	Employee Readiness Index	3.91	3.82–4.00	−2.02	$p = 0.045$	Moderate (PROBLEM)

Note. One-sample t-test of each mean against the test value 4.00 (the High/Ready boundary); $n = 157$, $df = 156$. A positive t means the mean is above 4.00, a negative t below it; p is the two-tailed significance. (R) = reverse-scored, so a higher value still means better readiness. Three results are not significant (n.s., $p \geq 0.05$): TRI 2.0 ($p = 0.189$), Reporting Hierarchy ($p = 0.085$), and Knowledge Management ($p = 0.866$); in each the 95% CI straddles 4.00. Construct reliability (Cronbach's α): TRI 2.0 = 0.879, Role Clarity = 0.716, Organizational Capability = 0.879, full instrument = 0.901.

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A Pareto analysis of the readiness deficit showed four "vital few" sub-variables that collectively account for around four-fifths of the total deficit. These are: Manpower Quantity (3.03, the most severe deficiency), Insecurity (3.41), Decision Authority (3.57), and Blurred Boundary (3.62), as illustrated in Figure 2. The total of the attitudinal dimension was on the threshold. But the insecurity inhibitor in the attitudinal dimension is much below 4.00 and is maintained as a priority gap and not making up the favorable average.

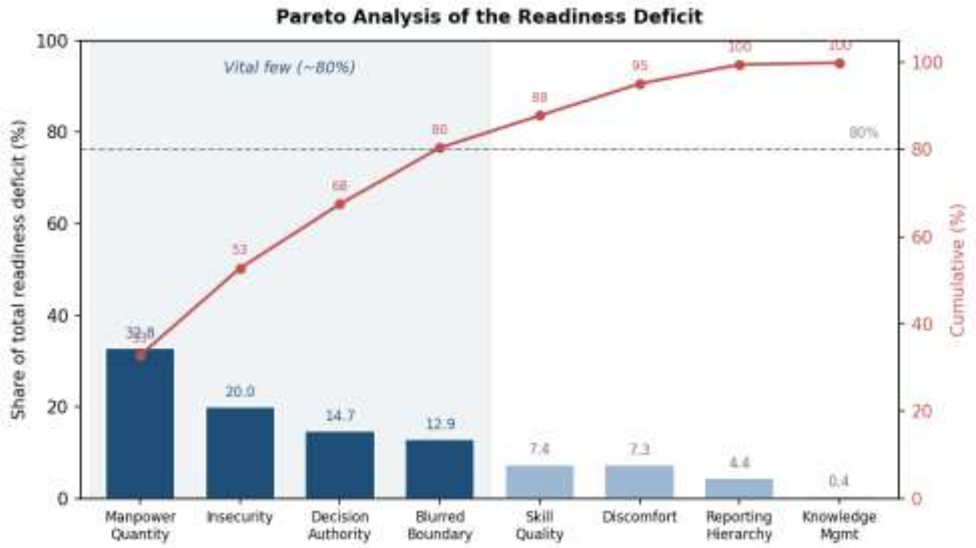

Figure 1 Pareto Analysis

Qualitative Results

Six themes emerged from the interviews. The first was an all-around enthusiasm for the new asset that was rooted not in techno-philia but in the lived fragility of depending on a single aging shiploader. Other themes were the real gaps in terms of manpower-quantity gap; role ambiguity which is present in cross-boundary tasks rather than between sections; lack of competency and training for new automated sub-systems; no proper operational-readiness institute to prepare the system before commissioning and risks of asset stewardship and corrosion defense under production pressure. The themes both confirmed the survey results and outlined the causes of the issues.

Integration and Potential Problems

Through methodological triangulation, the quantitative evidence on where and how large the gaps are is distilled, and the qualitative evidence on why they exist is distilled to form eight key readiness factors (two confirmed strengths and six gaps). KT-PPA on these six gaps resulted in seven prioritized potential problems, each with preventive and contingent actions so that mitigation should be planned, and not just improvised after commissioning. Based on the Probability×Seriousness rating, the problems are divided into three levels: a Tier 1 "people-system" triad (PP1–PP3, High×High), a Tier 2 asset-protection band (PP4–PP5, Moderate×High) and a Tier 3 operating discipline safeguards (PP6-PP7, Moderate×Moderate). The potential problems, their probability-by-seriousness ratings and their main mitigations are summarized in Table 2.

Table 2. Potential problems and their mitigation (KT-PPA summary).

No.	Potential Problem	P×S	Key Preventive Action	Key Contingent Action
PP1	Manpower shortfall compounded by fatigue	High×High	Workload-based staffing study (task	Pre-agreed cross-section borrowing

No.	Potential Problem	P×S	Key Preventive Action	Key Contingent Action
	(operating and maintaining the whole DWP complex plus the new shiploader)		breakdown; NASA-TLX + FTE/WISN); HR-accountable headcount	matrix; single-shiploader mode until coverage is restored
PP2	Cross-boundary role ambiguity (clean-up, pre-op checks, mooring/berthing, on-call signing, combined control room)	High×High	RACI/RARA matrix validated in a berthing simulation; explicit area ownership; staff-level KPI/KRA cascade	Single-incident-commander rule; published escalation line for any unowned safety/quality task
PP3	Competency-and-standards gap for the automated/combined control room and new sub-systems (Takraf control, AMS 6000/6500, hydraulics, banana spout)	High×High	Vendor-embedded training; control-room competency standard; hydraulics make-or-buy decision; management-of-change over the fixed design	Vendor remote-support retainer; vendor-supervised operation during retraining
PP4	Accelerated corrosion from spillage and housekeeping lapses over the larger footprint (with SL-1 retained as a maintained standby)	Moderate×High	Scheduled clean-up–sandblast–paint program (C5-M coating); routine corrosion inspection; SL-1 duty/standby alternation	Corrosion-finding SLA; surge contractor crew when backlog exceeds threshold
PP5	Incomplete operational readiness at commissioning (BOM/master data, strategies, SOPs, RACI/RARA, spares)	Moderate×High	Chartered, backfilled Operational-Readiness team; dated deliverables; witnessed go/no-go gates	Pre-commissioning readiness audit with named punch-list owners; vendor-operated interim with paired trainees
PP6	Loading-discipline override under production pressure (wet concentrate, speed-up) causing plug chutes	Moderate×Moderate	Binding moisture-to-rate SOP (Phase 1, rule-based) with operator stop/slow authority	Deviation log auto-escalation; pre-defined clearing crew and isolation on a plug chute
PP7	Distrust of remote/automated operation leading to manual workarounds	Moderate×Moderate	Staged-autonomy trust ladder with operator co-validation of cameras/sensors	Rehearsed manual-mode fallback; freeze the autonomy level on repeated anomalies

Note. P×S = probability × seriousness, appraised qualitatively with equal weight following the Kepner-Tregoe method. Tier 1 (High×High): PP1–PP3; Tier 2 (Moderate×High): PP4–PP5; Tier 3 (Moderate×Moderate): PP6–PP7. Abbreviations: DWP = Dewatering Plant; SL-1/SL-2 = Shiploader-1/Shiploader-2; NASA-TLX = NASA Task Load Index; FTE = full-time equivalent; WISN = Workload Indicators of Staffing Need; HR = human resources; RACI/RARA = responsibility-assignment matrices (Responsible–Accountable–Consulted–Informed / Role–Accountability–Responsibility–Authority); KPI/KRA = key performance indicator / key result area; AMS 6000/6500 = condition-monitoring system series; BOM = bill of materials; SOP = standard operating procedure; C5-M = ISO 12944 marine (high) corrosivity class; SLA = service-level agreement. Takraf denotes the original equipment manufacturer.

Recommended Interventions

The seven potential problems are identified by five solution packages (the recommended interventions), which are linked to common root causes instead of one-to-one to problems: a chartered operational-readiness program which finishes master data, stocking the spare parts and maintenance strategy within formal readiness gates (PP5), a workload and manpower-provisioning study based on workload measurement methods and human resources in place to assess the work (PP1 and removing a driver of PP2), a competency and training approach based on vendor embedding and a staged autonomy "trust ladder" where operators are responsible for the automation (PP3 and PP7) and a role-clarity governance package with responsibility matrices, explicit area ownership and a performance measurement cascade (PP2, and the accountability spine for PP4 and PP6), and an asset stewardship and loading discipline package for the shiploader existing as a standby and binding loading rate control (PP4 and PP6). The packages are linked in a tiered way based on the date of commissioning.

The key insight, where the personnel is ready but not yet organizationally prepared, redefines what "readiness" implies for capital asset integration: organizational, not attitudinal, binding restriction. Optimism and creativity are high but manpower, role clarity at task boundaries, competency for automation, and operational readiness processes, are not. This is an excellent outcome obtained with the extension of TRI++. A traditional TRI assessment would have provided an attitudinal score at the threshold, and declared the workforce generally ready, failing to identify the organizational limitations that actually constrain preparedness, operationally speaking.

From a data standpoint, psychometric measurement, qualitative depth and a structured anticipatory risk methodology allowed the study to move from diagnosis to prioritized action. KT-PPA layer has offered the forward-looking, actionable contribution that measurement cannot provide (i.e., it makes a static readiness profile into a set of prioritized pre-commissioning interventions).

CONCLUSION

This study developed and demonstrated an anticipatory framework for assessing operational workforce readiness for the integration of a new capital asset by extending the Technology Readiness Index into TRI++ and integrating it with Kepner–Tregoe Potential Problem Analysis (KT-PPA) within a mixed-methods design. In the pre-commissioning phase of a new shiploader integration, the framework identified a workforce that was willing but organizationally under-enabled, and it translated readiness gaps into seven prioritized potential problems and five solution packages. This research made three contributions. Theoretically, it extended technology-readiness measurement beyond individual attitudes and consumer contexts by incorporating organizational determinants of operational workforce preparedness for industrial capital assets. Methodologically, it combined psychometric assessment with qualitative insights and structured, forward-looking risk analysis. Practically, it provided managers with a pre-commissioning toolset to identify and address workforce-readiness challenges before new assets became operational. However, these contributions should be considered alongside several limitations. The study involved a single anticipatory case conducted before asset commissioning; the quantitative analysis was descriptive and did not examine causal relationships among constructs; and the research was conducted by a single researcher. Future longitudinal studies evaluating readiness after commissioning could reveal the predictive value of the anticipatory assessment, while replication across other capital-asset integration projects could further examine the framework's transferability.

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