Maintenance Criticality Frameworks: Beyond the 2×2 Matrix

Risk & Criticality Assessment - Fixed-Plant Mining and Minerals Processing

Abstract. *The 2×2 probability consequence matrix is ubiquitous in asset criticality assessment and is demonstrably insufficient for the environments in which it is most widely used. This Technical Note sets out a four-level criticality framework that evaluates consequence across four independent dimensions, distinguishes detectability from preventability in failure mode analysis, and provides the differentiation needed to allocate maintenance resources in a genuinely risk-informed manner. A worked example from a fixed plant mining environment and a comparison against common industry approaches are included.*

1. Why the 2×2 Matrix Falls Short

The canonical matrix maps probability against consequence to yield a single criticality score. In fixed-plant mining and minerals processing contexts, it fails on four counts:

- **Consequence is not one-dimensional.** A 200 L reagent release, an eight-hour mill stoppage, and an operator injury are not commensurable. Collapsing them into a single “high / low” rating forces the assessor to pick one dimension and silently discard the remainder.
- **Probability is rarely knowable.** For low-population or short-service assets, statistical probability is unavailable. Subjective scoring anchors on recent experience and systematically underweights rare high consequence events.
- **Two bands do not differentiate.** A four cell grid collapses the middle of the risk distribution into a single cell, producing large populations of “medium” assets that receive uniform treatment despite materially different underlying profiles.
- **Detectability is absent.** A failure that develops visible precursors over weeks is operationally very different from one that occurs without warning. The 2×2 matrix does not distinguish them, yet this distinction drives the entire maintenance tactic selection.

2. A Four-Level Criticality Framework

SEAMPAS applies a four level rating of **Critical, High, Medium, Low,** evaluated independently across four consequence dimensions. The asset’s overall rating is the **highest single dimension rating, never an average**. Decoupling matters because the controls each dimension drives are different: a Critical Safety rating drives hard barriers and permit regimes; Critical Production drives redundancy and planned windows; Critical Environmental drives containment design and regulatory engagement. Four bands also provide meaningful differentiation across the middle of the distribution, where binary approaches produce undifferentiated populations.

Dimension	Low	Medium	High	Critical
Safety	First aid; no lost time	Medical treatment; restricted duties	Serious injury; LTI	Fatality or permanent disabling injury
Environmental	Contained on-site; no reporting	Minor regulatory breach; on-site cleanup	Reportable release; community impact	Major release; licence or permit risk
Production	< 4 h loss, or buffered	4–24 h loss; partial throughput	24–72 h loss; bottleneck propagation	> 72 h loss or total plant shutdown
Cost (direct + lost production)	< A$25k	A$25k – A$250k	A$250k – A$1M	> A$1M

3. Detectability and Preventability as Separate Axes

Consequence tells us what matters; detectability and preventability tell us what can be done. SEAMPAS evaluates these as two independent questions:

- **Detectability -** can this failure mode be identified during the P–F interval by a realistic monitoring technique (vibration, thermography, oil analysis, inspection, process parameter trending)?
- **Preventability -** can the underlying cause be eliminated by design, operation, or scheduled restoration (lubrication, seal replacement, torque, alignment)?

The 2×2 collapse of these into a single "manageability" concept produces condition-monitoring recommendations for failures that cannot be detected, and restoration tasks for failures that cannot be restored. Separating the axes produces four distinct tactical responses:

Detectable?	Preventable?	Appropriate Tactic
Yes	**Yes**	Condition based restoration at P–F threshold
Yes	**No**	Condition monitoring with planned replacement trigger
No	**Yes**	Time or usage based scheduled restoration
No	**No**	Design review, redundancy, or failure finding task (not a PM problem)

4. Worked Example - Fixed-Plant Slurry Transfer

Consider a Warman MCR 450 centrifugal slurry pump transferring mill discharge to a cyclone cluster. The pump is a single train asset with no installed standby. Under a 2×2 matrix it would typically be rated "High/High" and assigned a generic planned maintenance package. The four level framework produces differentiated guidance:

Dimension	Rating	Driver
Safety	**High**	Pressurised slurry; potential hot work exposure during breakdown repair
Environmental	**Medium**	Bunded; contained leakage; reagent bearing slurry requires on site capture
Production	**Critical**	Single train; no installed bypass; > 72 h restoration from catastrophic volute failure
Cost	**High**	Replacement A$380k; typical unplanned repair A$120k plus downstream production loss

Overall rating: Critical (Production driven). Applied to the dominant failure modes:

- **Impeller / volute wear -** detectable (discharge pressure trending, motor amperage); preventable (slurry concentration control). Tactic: condition based replacement at P–F threshold, combined with process control verification.
- **Gland seal failure -** detectable (gland water flow, visual); preventable (packing replacement). Tactic: scheduled restoration at 2,000 operating hours.
- **Bearing-housing overheating -** detectable (thermography, oil analysis); partially preventable (contamination control). Tactic: condition based monitoring with oil change trigger.
- **Drive-end coupling fatigue -** not reliably detectable in service; not preventable in operation. Tactic: time based replacement at OEM interval with on-site spare, not a monitoring candidate.

The 2×2 approach would prescribe a uniform package. The four level approach differentiates three distinct tactics and flags the coupling as a failure mode for which monitoring is not a valid control, material differences in spare part strategy, inspection planning, and downtime budgeting.

5. Comparison with Common Industry Approaches

Approach	Consequence Dimensions	Rating Bands	Detectability Separated	Fit for Fixed-Plant Mining
2×2 probability consequence matrix	1 (aggregated)	4 cells	No	Inadequate - the primary concern of this Note
5×5 matrix (ISO 31000-style)	1 (usually aggregated)	25 cells	No	Better granularity, same dimensional collapse
API RP 580 RBI	3 (safety / environmental / financial)	5×5 per dimension	Partial (via POF modifiers)	Strong for pressure systems; heavy for rotating equipment
SAE JA1011 RCM	Categorical	Categorical	Yes (explicit in decision logic)	Methodologically aligned; resource-intensive at asset register scale
SEAMPAS four level framework	**4 (independent)**	**4 per dimension**	**Yes (independent axis)**	**Designed for this context**

The SEAMPAS framework is best understood as a practical synthesis - it borrows the categorical consequence treatment of RCM, the multi-dimensional approach of API RP 580, and the tactical clarity required at asset register scale (typically 500–5,000 registered items in a mid-sized fixed plant).

6. Key Takeaways

- A 2×2 matrix is a **screening tool, not a criticality framework**. It lacks the dimensional resolution needed to inform maintenance tactic selection.
- Consequence must be evaluated **independently across four dimensions** (safety, environmental, production, cost); the overall rating is the maximum, never the average.
- Detectability and preventability are **separate questions**; their combination - not consequence alone - drives tactic selection.
- Four bands are the **minimum resolution** required to differentiate the populations that collapse into “medium” under binary approaches.
- For Critical rated assets, combine with RCM style decision logic; for Low and Medium assets, streamlined PMO style reviews are proportionate.

References and Further Reading

ISO 31000:2018 Risk management - Guidelines. International Organization for Standardization.

ISO 55000:2024 Asset management - Vocabulary, overview and principles.

API RP 580 (4th ed.) Risk-Based Inspection. American Petroleum Institute.

SAE JA1011 / JA1012 Evaluation Criteria for Reliability-Centered Maintenance (RCM) Processes; A Guide to the Reliability-Centered Maintenance (RCM) Standard. SAE International.

Moubray, J. Reliability-centred Maintenance (2nd ed.), Industrial Press.

About this Technical Note

SEAMPAS Technical Notes are short, focused treatments of specific problems in physical asset management and reliability engineering, drawn from field application in mining, minerals processing, oil and gas, utilities, and heavy rail. They are intended for practising engineers, maintenance managers, and asset management leaders responsible for translating principle into practice.

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