Find the report for your problem

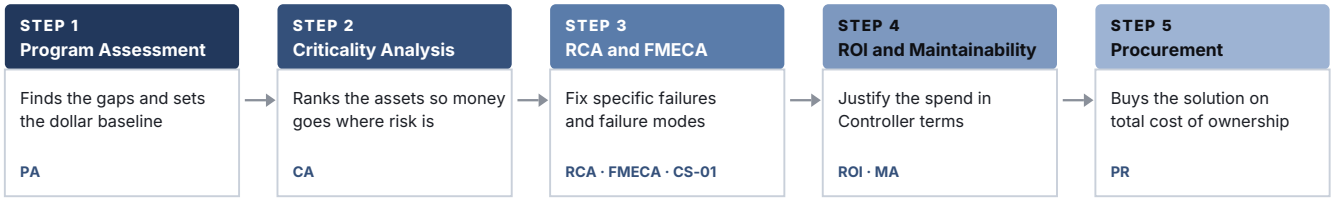
Each sample is a complete report, written for the plant manager and the controller as well as the maintenance team. Start with the problem you recognize.

THE PROBLEM YOU HAVE	REPORT AND WHAT IT ANSWERS	WHAT YOU GET	BEST FOR · SCOPE
"Downtime is killing us and I don't know where to start; my funding requests keep getting turned down"	**Maintenance & Reliability Program Assessment** **PA-2027-001** · 10 pages Where the program stands, what unreliability costs in dollars, and what to fund first	Maturity scores on 10 elements; cost-of-unreliability baseline; gated 18-month roadmap with NPV	**Plant manager, controller** **Typical duration:** 3–4 weeks **We need:** 12 months of CMMS, downtime log, and maintenance GL; 3 days on site; interviews
"Everything is a priority, so nothing is"	**Asset Criticality Analysis** **CA-2026-003** · 10 pages Which assets deserve PM, PdM, and spares money, and which don't	Ranked asset register with tiers; PM hours and spares reallocated; review gate	**Maintenance manager** **Typical duration:** 2–3 weeks **We need:** Asset list, failure history, production rates; one cross-functional workshop
"We keep fixing the same failure"	**Root Cause Analysis (RCA/RCFA)** **RCA-2026-014** · 11 pages Why it failed, the physical, human, and latent causes, and what stops it recurring	Evidence register; logic tree; corrective-action plan with owners; cost of the failure and NPV of the fix	**Maintenance manager, plant manager** **Typical duration:** 1–3 weeks **We need:** Failed parts (kept), work orders, operator accounts, access to the asset
"We've accepted failures as 'just how it is here'"	**Case Study: VFD-Induced Bearing EDM** **CS-01** · 8 pages What a real investigation looks like when the plant has normalized failures	Sanitized real RCA: teardown evidence, shaft-voltage measurements, red-flag screening, recommendations	**Maintenance manager** Real investigation, sanitized. Shows the method on a problem the plant had normalized.
"This line or machine is our worst performer"	**FMEA/FMECA** **FMECA-2026-007** · 11 pages Every way the system can fail, ranked by dollar risk, and which tasks address it	Failure-mode register ranked in $/yr; task package; break-even; food-safety and safety overrides	**Maintenance manager, reliability engineer** **Typical duration:** 3–5 weeks **We need:** Drawings, failure history, OEM manuals; 3–4 workshop sessions with crafts and operators
"Should we rebuild, monitor, or replace this asset?"	**Single-Asset Reliability ROI** **ROI-2026-005** · 10 pages Which option returns the most, and when replacement would become justified	Weibull analysis; option NPVs with scenarios; replace trigger; decision tree	**Controller, plant manager** **Typical duration:** 2–3 weeks **We need:** Failure and repair history, costs, OEM quotes
"Repairs take too long and eat into production"	**Maintainability Analysis** **MA-2026-006** · 10 pages Where repair time goes and which fixes pay back	Repair-time breakdown by element; levers ranked by return; design-for-maintainability standard	**Maintenance manager, engineering** **Typical duration:** 2–3 weeks **We need:** Observed repairs or video, work orders, sanitation and production windows
"We bought the cheapest option and paid for it later"	**Procurement Recommendation** **PR-2026-008** · 9 pages Which bid to award on total cost of ownership, not purchase price	Pass/fail gates; weighted scoring; 10-year TCO; contract terms and acceptance tests	**Controller, purchasing** **Typical duration:** 1–2 weeks **We need:** Bids, specifications, the approved business case

Durations are typical for one plant and one asset or system. Scope is confirmed with each client before work starts.

How the reports fit together

One method, applied in the order a plant usually needs it.



Most plants start at step 1 or step 3. Every report stands on its own, and each one feeds the next.

WHAT EVERY REPORT HAS IN COMMON

STANDARD	WHAT IT MEANS FOR YOU
Graded evidence	Every finding is marked Confirmed, Supported, or Inference, so you can see what the data supports and what is judgment.
Downtime in dollars	Downtime is valued at lost contribution margin, with recovered volume at its recovery cost, not at sales price.
Controller-ready finance	NPV, IRR, and payback at your hurdle rate, with CAPEX, OPEX, and inventory separated.
Ranges, not single numbers	Conservative, expected, and high-impact cases, plus stress tests and the break-even point.
No double counting	A benefit claimed in one report is excluded from every other, so the totals hold up to Finance review.
Standards cited	Methods reference the governing standards, such as ISO 55001, ISO 14224, IEC 60812, and IEC 61649.

ABOUT THESE SAMPLES

Seven reports describe one fictional cultured-dairy plant, so the numbers reconcile across them: the same downtime rates, and no benefit claimed twice. Names, people, and figures are fictional. CS-01 is a sanitized account of a real investigation, with no names or identifying details.

NEXT STEP

Start with the problem you recognize. Open the report on page 1 that matches it. If more than one fits, the Program Assessment is the usual starting point: it shows which of the others will pay back first.

MAINTENANCE AND RELIABILITY PROGRAM ASSESSMENT

From Firefighting to a Funded Reliability Program

A plant-wide maturity assessment, a dollar baseline of the cost of unreliability, and a gated 18-month roadmap with a funding request built to survive Finance review.

SAMPLE — FICTIONAL DAT

CLIENT	Larkspur Valley Foods, Inc. — Plant 2 (cultured dairy, three packaging lines)
SCOPE	Maintenance and reliability program, all production and utility assets; 12 months of CMMS, production, and finance data to December 2026
REPORT NO.	PA-2027-001 · Revision 0 · Issued February 2, 2027
METHOD	Apex Reliability Maturity Model (10 elements, mapped to ISO 55001:2024 and the SMRP Body of Knowledge pillars); SMRP metric definitions; 24 interviews, 3-day site walk, document and data review
BUILDS ON	Six pilot projects completed at Plant 2: RCA-2026-014, FMECA-2026-007, CA-2026-003, ROI-2026-005, MA-2026-006, PR-2026-008. Their benefits are excluded here.

Demonstration document. Sample report. All company names, people, data, and financial figures are fictional and shown for demonstration only. The structure, methods, and level of detail match Apex Reliability Engineering client deliverables.

Executive Summary

Decision brief for the Plant Manager, Plant Controller, and Operations Director. Sections 1–6 contain the supporting detail.

BOTTOM LINE

Plant 2 loses an estimated **$1,500K a year to unreliability** (range $1,230K–$1,800K), most of it as lost contribution margin during 427 hours of unplanned downtime. The six pilot projects fixed specific assets; the program that would stop new problems does not exist yet (maturity **2.1 of 5**). A gated 18-month program costing **$412K in year 1** and $236K/yr at run rate returns an expected **$289K NPV** over 5 years. The conservative case loses money, so funding is released in stages: **no more than $175K is at risk before the first proof point.**

COST OF UNRELIABILITY	PROGRAM MATURITY	YEAR-1 FUNDING	EXPECTED NPV, 5 YR	AT RISK BEFORE GATE 1
$1.50M	**2.1 → 3.4**	**$412K**	**$289K**	**$175K**
Per year; $1,233K addressable after pilot claims	Of 5; target at month 18	$322K OPEX, $90K CAPEX, 2 FTE	IRR 44%; payback 2.7 yr	Month 6; leading indicators

DECISIONS REQUESTED

1. **Approve phase 1**: a maintenance planner/scheduler, CMMS clean-up, and PdM tools ($46,000 CAPEX). Phase 1 spend is capped at $175,000 through month 6.
2. **Pre-approve phases 2 and 3**, released only if Gate 1 (month 6) and Gate 2 (month 12) are met (Section 6).
3. **Track the program in one P&L view** owned by the Controller. 85% of the benefit lands in production margin, not in the maintenance budget that pays for it (Section 3).

WHAT THE ASSESSMENT FOUND

- **No planner.** 46% of labor hours break the weekly schedule; jobs are kitted 9% of the time.
- **Data cannot support decisions.** 22% of corrective work orders carry a failure code, which is also why the cost range is wide.
- **Earlier funding requests stalled for fixable reasons**: one lump sum, no dollar baseline, and no exit point.
- **Strengths to build on:** criticality and RCA are now at level 3 after the pilots, and the craft team is experienced.

SAMPLE — FICTIONAL DATA

Sample report. All company names, people, data, and financial figures are fictional and shown for demonstration only.

1 Baseline: Where the Plant Stands

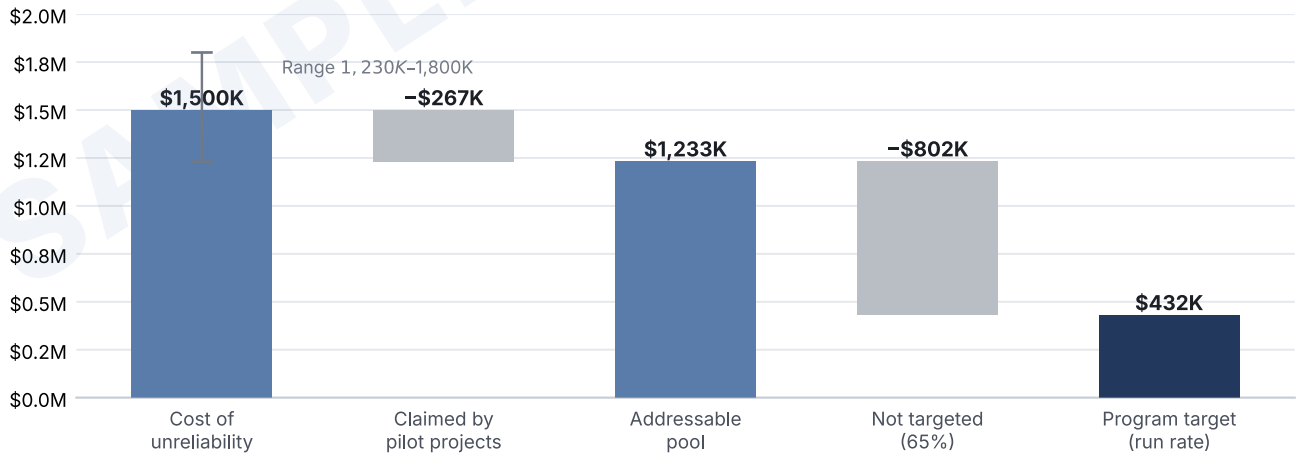
Work-management metrics show a reactive plant. The cost of that, in dollars, is the starting point for the business case.

TABLE 1.1 — PERFORMANCE BASELINE AND TARGETS

METRIC	SMRP REF.	BASELINE	GATE 1 (M6)	MONTH 18	COMMONLY CITED REFERENCE	EVIDENCE
Planned work	5.3.1	**38%**	55%	75%	80–90%	CONFIRMED
Reactive work	5.4.1	**46%**	35%	20%	below 10%	CONFIRMED
Schedule compliance	Work mgmt.	**52%**	70%	85%	above 90%	SUPPORTED
PM compliance (on time)	Work mgmt.	**71%**	90%	95%	above 95%	CONFIRMED
Failure-code completion on corrective WOs	—	**22%**	80%	90%	Plant standard	CONFIRMED
Tier A assets with PdM coverage	—	**35%**	60%	100%	100% of tier A	CONFIRMED
Total maintenance cost, % of RAV	1.5	**5.0%**	Monitor	Monitor	Not a target alone	CONFIRMED
Stocked MRO inventory, % of RAV	1.4	**2.3%**	—	2.1%	Industry-specific	CONFIRMED

Metric definitions follow SMRP Best Practices (6th ed.), using maintenance labor hours as the denominator. Reference values are commonly cited ranges, not SMRP-published targets; SMRP's own targets are in its copyrighted Best Practices document and should be checked there. Maintenance cost as a percent of RAV is monitored, not targeted: SMRP cautions that lower maintenance cost does not by itself mean better performance.

FIGURE 1.1 — FROM COST OF UNRELIABILITY TO THE PROGRAM TARGET (ANNUAL, EXPECTED)



The whisker on the first bar is the $1,230K–$1,800K range. Benefits already claimed by the pilot projects are removed before the program's target is set, so nothing is counted twice.

SAMPLE — FICTIONAL D

1 Baseline (continued)

What the cost is made of, how the downtime figure was built, and what the data does and does not support.

TABLE 1.2 — COST OF UNRELIABILITY, 12 MONTHS

COMPONENT	ANNUAL
Unplanned downtime, lost contribution	$1,175,425
Overtime premium on breakdown work	$106,600
Product loss and re-sanitation	$96,000
Expedited parts and freight	$64,000
Emergency contractor call-outs	$58,000
Total (expected)	**$1,500,025**

TABLE 1.3 — EXCLUDED: ALREADY CLAIMED BY PILOTS

PROJECT	ANNUAL
FMECA-2026-007 (Line 3 filler, includes RCA-2026-014)	$194,843
ROI-2026-005 (HG-1, option O2), year-1 savings	$56,264
MA-2026-006 (HG-1 window overrun)	$15,600
Addressable pool	**$1,233,318**

TABLE 1.4 — UNPLANNED DOWNTIME BY AREA

AREA	UNPLANNED HOURS	BLENDED $/H	ANNUAL COST	SOURCE OF HOURS
Line 1 (cups)	130	$2,305	$299,650	Production downtime log
Line 2 (bottles)	105	$2,005	$210,525	Production downtime log
Line 3 (cups, high speed)	150	$2,615	$392,250	Production downtime log
Process and utilities (stops all lines)	42	$6,500	$273,000	Production downtime log
Total	**427**		**$1,175,425**	

Line rates are lost contribution margin, with half the lost volume assumed recovered on overtime at recovery cost (method of FMECA-2026-007). Process and utility stops use the $6,500/h rate from ROI-2026-005 because they halt all three lines.

WHAT THE EVIDENCE SUPPORTS

- CONFIRMED Downtime hours, from the production log, reconciled to shift reports.
- CONFIRMED Overtime, contractor, and expedite spend, from the general ledger.
- CONFIRMED Work-management metrics, from 14,100 CMMS work orders.
- SUPPORTED Product loss and re-sanitation, from QA hold records; some events are not coded to a cause.

WHAT IT DOES NOT SUPPORT YET

With 22% failure-code completion, downtime cannot be split reliably by failure mode or asset outside the pilot areas. That is why the cost is given as a range (−18% / +20%) and why the program's target is set as a share of the pool, not as a list of asset fixes. **A bad-actor list is a month-6 deliverable, not an input to this report.**

HOW THE 18% / 20% RANGE WAS SET

Low end: assumes downtime that the log marks “unassigned” (11% of hours) was partly planned, and product-loss events without a cause code were not reliability-related. High end: adds minor stops under 10 minutes, which the log does not capture but operator interviews put at 30–60 hours a year. INFERENCE

SAMPLE — FICTIONAL D

2 Program Maturity

Ten elements scored 1–5 against the rubric in Appendix A. The pilots lifted criticality and RCA; the foundations they depend on (planning, data, lubrication) are still at level 1.5.

FIGURE 2.1 — MATURITY BY ELEMENT, NOW AND 18-MONTH TARGET

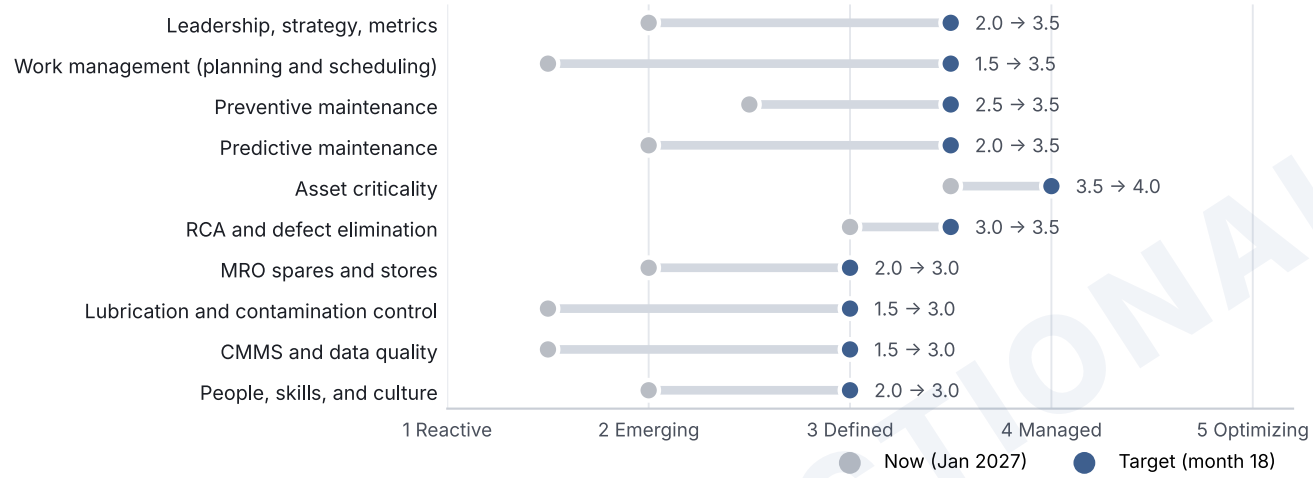


TABLE 2.1 — ELEMENT FINDINGS

ELEMENT	ISO 55001	SMRP PILLAR	NOW	KEY EVIDENCE	GRADE	MAIN GAP
Leadership, strategy, metrics	Cl. 5, 6, 9	1, 4	**2.0**	No maintenance strategy or KPI review; downtime reported in hours, never dollars	CONFIRMED	No one owns reliability across maintenance and production
Work management (planning and scheduling)	Cl. 8	5	**1.5**	No planner; 46% of labor hours break the weekly schedule; jobs kitted 9% of the time	CONFIRMED	Technicians plan their own jobs on the fly
Preventive maintenance	Cl. 8	3	**2.5**	1,773 PM h/yr; 41% of tasks are inspect-only with no acceptance criteria	CONFIRMED	PM content not tied to failure modes
Predictive maintenance	Cl. 8, 9.1	3	**2.0**	Quarterly contract vibration on 35% of tier A; no oil analysis trending; IR annual	CONFIRMED	Coverage gaps on tier A; findings not tracked to closure
Asset criticality	Cl. 6.1, 6.2	3	**3.5**	CA-2026-003 complete: 36 assets ranked, tiers in CMMS	CONFIRMED	Extend to remaining 140 tier C assets
RCA and defect elimination	Cl. 10	2	**3.0**	RCA-2026-014 run to standard; no trigger criteria or action tracking	SUPPORTED	RCA happens by exception, not by rule
MRO spares and stores	Cl. 7.1, 8	1	**2.0**	2,180 stocked items; 31% no movement in 24 months; 14 stock-outs on tier A in 2026	CONFIRMED	Stock set by habit, not criticality
Lubrication and contamination control	Cl. 8	3	**1.5**	Open containers in a shared room; no lube routes; FMECA found water ingress	CONFIRMED	No storage, filtration, or route standard
CMMS and data quality	Cl. 7	5	**1.5**	22% failure-code completion; 38% of WOs closed with no labor hours	CONFIRMED	Data cannot support bad-actor or MTBF analysis
People, skills, and culture	Cl. 7.2, 7.3	4	**2.0**	No skills matrix; reactive work praised in shift handover; strong craft experience	INFERENCE	Firefighting rewarded more than prevention

Element scores are a structured judgment, not a measurement; the grade shows the strength of the evidence behind each score. SMRP pillars: 1 Business and management, 2 Manufacturing process reliability, 3 Equipment reliability, 4 Organization and leadership, 5 Work management.

SAMPLE — FICTIONAL D

3 Why Earlier Funding Requests Stalled

Plant 2 asked for a planner and PdM tools in 2024 and 2025. Both requests were declined. The reasons were about the request, not the need.

TABLE 3.1 — WHAT STALLED THE EARLIER REQUESTS, AND HOW THIS PROPOSAL ANSWERS IT

WHY IT STALLED	EVIDENCE	HOW THIS PROPOSAL ANSWERS IT
One lump sum, all or nothing	2025 request: $310,000 in one line; review notes say "too large to approve without proof"	Three phases. Only phase 1 is at risk; phases 2–3 release on measured gates.
No dollar baseline	Benefits stated as "reduce downtime"; downtime reported in hours only	A $1,500K cost baseline, reconciled to the ledger and the downtime log, with a stated range.
Cost and benefit in different budgets	Headcount charged to maintenance; benefits land in production margin, which maintenance does not report	One program P&L view owned by the Controller (Table 3.2).
No measure of success or exit point	No KPIs, review dates, or stop criteria in either request	Two gates with numeric thresholds and pre-agreed actions (Section 6).
Requested by maintenance alone	Neither request had a production or finance sponsor	Joint sponsorship: Plant Manager owns the program; Controller validates the benefit.

WHO PAYS AND WHO BENEFITS (YEAR 3, EXPECTED RUN RATE)

TABLE 3.2 — BUDGET VIEW

ITEM	ANNUAL
Program OPEX (maintenance budget)	−$236,000
Benefit landing in maintenance budget	$65,784
Net change, maintenance budget	**−$170,216**
Benefit landing in production margin	$365,877
Net change, plant	**$195,661**

WHY THIS MATTERS TO FINANCE

Judged on the maintenance budget alone, the program looks like a $170K/yr cost increase, and maintenance cost rises from 5.0% to 5.3% of RAV. Judged at plant level, it adds $196K/yr. Earlier requests were judged on the first view. **The decision belongs at plant level, with benefits validated by the Controller, not claimed by maintenance.**

SAMPLE — FICTIONAL D

4 18-Month Roadmap

Foundations first. Planning, data, and condition monitoring come before PM optimization, because PM optimization needs the failure data that phase 1 creates.

TABLE 4.1 — WORKSTREAMS BY QUARTER

WORKSTREAM	OWNER	ELEMENT	Q1	Q2	Q3	Q4	Q5	Q6
PHASE 1 · STABILIZE (MONTHS 1–6)								
Hire planner/scheduler; weekly schedule, kitting, backlog review	Maint. Mgr.	Work mgmt.	■	■	■	■	■	■
CMMS clean-up; failure codes to ISO 14224; WO closure standard	Planner	CMMS	■	■				
PdM tools; tier A vibration, IR, and oil routes; findings tracked to closure	Maint. Mgr.	PdM		■	■	■	■	■
RCA trigger rules and action tracking	Ops Mgr.	RCA	■	■				
Monthly KPI review; program P&L view set up with Controller	Plant Controller	Leadership	■	■	■	■	■	■
PHASE 2 · PREVENT (MONTHS 7–12, AFTER GATE 1)								
Hire reliability engineer	Plant Mgr.	People			■			
PM optimization on tier A, tied to failure modes	Reliability Eng.	PM			■	■	■	
Lubrication program: storage, filtration, routes	Reliability Eng.	Lubrication			■	■		
Spares rationalization by criticality; stores reorganization	Stores, Rel. Eng.	MRO			■	■	■	
PHASE 3 · SUSTAIN (MONTHS 13–18, AFTER GATE 2)								
Skills matrix and craft qualification	Maint. Mgr.	People				■	■	■
Design-for-maintainability standard (MA-2026-006) in capital process	Engineering	Leadership				■	■	
Extend criticality to remaining tier C assets	Reliability Eng.	Criticality				■	■	■

Q1 starts at approval. Gate 1 falls at the end of Q2 and Gate 2 at the end of Q4. Phase 2 starts only if Gate 1 is met.

TABLE 4.2 — PROGRAM COST BY YEAR

ITEM	TYPE	YR 1	YR 2	YR 3+
Maintenance planner/scheduler (1 FTE, loaded)	OPEX · headcount	$96.0K	$96.0K	$96.0K
Reliability engineer (1 FTE from month 7, after Gate 1)	OPEX · headcount	$64.0K	$128.0K	$128.0K
External program support (Apex)	OPEX	$72.0K	$24.0K	$0.0K
CMMS clean-up and failure-code build	OPEX · one-time	$22.0K	$0.0K	$0.0K
Training and qualification	OPEX	$38.0K	$12.0K	$12.0K
Implementation backfill (internal labor)	OPEX · one-time	$30.0K	$0.0K	$0.0K
OPEX total		**$322.0K**	**$260.0K**	**$236.0K**
PdM tools: vibration analyzer and software, IR camera, ultrasound	CAPEX	$46.0K	—	—
Lubrication storage and filtration	CAPEX	$26.0K	—	—
Stores reorganization (bins, labels, cages)	CAPEX	$18.0K	—	—
Total		**$412.0K**	**$260.0K**	**$236.0K**

SAMPLE — FICTIONAL DATA

5 Financial Case

Expected value is positive and robust to cost overruns; it is not robust to slow adoption. That is the risk the gates are built to catch.

TABLE 5.1 — RESULTS BY SCENARIO (5 YR, 10% HURDLE, PRE-TAX)

SCENARIO	POOL REDUCTION	RUN-RATE BENEFIT	NPV	IRR
Conservative	21%	$259K/yr	−$275K	-34%
Expected	**35%**	**$432K/yr**	**$289K**	**44%**
High impact	45%	$555K/yr	$631K	80%

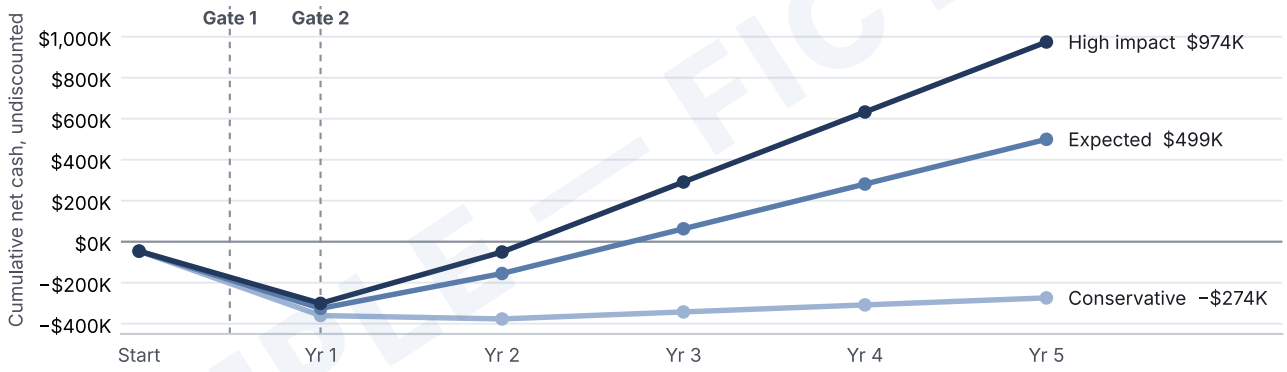
Benefits ramp 20% / 65% / 100% over years 1–3. MRO release of $150K in year 2 (50% in the conservative case) is working capital, beyond the release already counted in CA-2026-003; carrying-cost savings at 15%/yr follow.

TABLE 5.2 — STRESS TESTS ON THE EXPECTED CASE

STRESS APPLIED	NPV
Base case (expected)	**$289,107**
Benefits arrive one year late	−$91,596
Program costs +25%	$19,446
No MRO release	$118,897
COUR at low end of range	$26,937

Break-even: the program pays at the hurdle rate if it removes 27% of the addressable pool, against 35% expected.

FIGURE 5.1 — CUMULATIVE NET CASH BY SCENARIO



Year 1 is negative in every scenario: headcount starts before the benefit does. The scenarios separate in year 2, which is why Gate 2 sits at month 12.

TABLE 5.3 — EXPECTED CASH FLOWS

	START	YR 1	YR 2	YR 3	YR 4	YR 5
Reliability benefit	—	$86.3K	$280.6K	$431.7K	$431.7K	$431.7K
MRO release and carrying cost	—	$0.0K	$150.0K	$22.5K	$22.5K	$22.5K
Program OPEX	—	−$322.0K	−$260.0K	−$236.0K	−$236.0K	−$236.0K
CAPEX	−$46.0K	−$44.0K	—	—	—	—
Net cash	**−$46.0K**	**−$279.7K**	**$170.6K**	**$218.2K**	**$218.2K**	**$218.2K**

ACCOUNTING TREATMENT

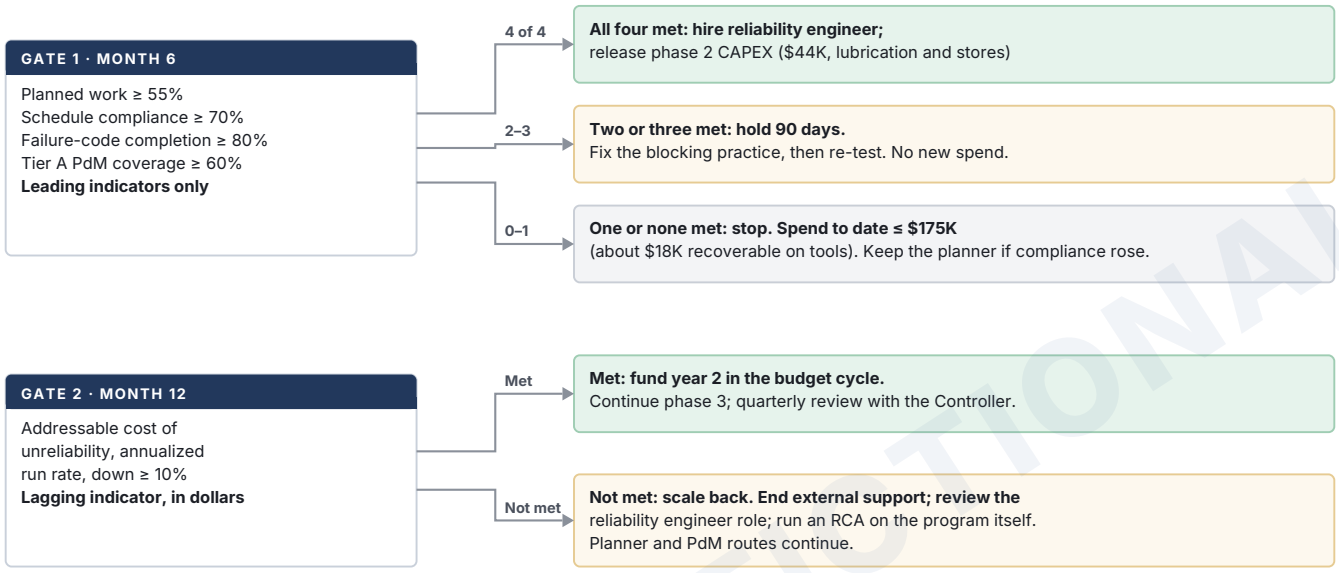
Headcount, support, training, and CMMS work are OPEX and hit the P&L in the year incurred. Tools and storage ($90,000) are CAPEX, depreciated over 5–7 years under the plant's policy; bonus depreciation may apply if the Controller elects it. The MRO release improves working capital and cash, not EBITDA. Two FTE are added to the maintenance headcount plan.

SAMPLE — FICTIONAL DATA

6 Gates, Governance, and Approval

Each gate has numeric thresholds and a pre-agreed action, so a weak result leads to a smaller program, not a debate.

FIGURE 6.1 — GATE DECISION TREE



Thresholds sit between the expected path (about 14% run-rate reduction at month 12) and the conservative path (about 8%), so the gates separate the two.

TABLE 6.1 — GOVERNANCE

FORUM	CADENCE	OWNER
Weekly schedule and backlog review	Weekly	Planner, Maintenance Mgr.
Reliability review: KPIs, bad actors, RCA actions	Monthly	Reliability Eng., Ops Mgr.
Program P&L and benefit validation	Quarterly	Plant Controller
Gate decisions	Months 6, 12	Plant Manager

TABLE 6.2 — PROGRAM RISKS

RISK	MITIGATION
Planner pulled into breakdowns	Written role charter; breakdown hours tracked
Benefit claimed but not real	Controller validates against the ledger and downtime log
Hiring delay	Gate dates move with the start date, not the approval date

APPROVAL ROUTING

Prepared by
Lead Reliability Engineer, Apex Reliability Engineering — Signature — Date

Benefit baseline validated
Plant Controller — Signature — Date

Program sponsor
Plant Manager — Signature — Date

Headcount approval
Operations Director — Signature — Date

SAMPLE — FICTIONAL D

A Scoring Rubric and References

TABLE A.1 — APEX RELIABILITY MATURITY MODEL: LEVEL DEFINITIONS

LEVEL	WHAT IT LOOKS LIKE
1 Reactive	Work is driven by failures. Practices depend on individuals and are not written down. Data is missing or unused.
2 Emerging	Some practices exist but are applied unevenly. Results are tracked in places, rarely acted on.
3 Defined	Practices are written, applied across the plant, and owned. Basic metrics are reviewed on a schedule.
4 Managed	Practices are measured against targets and corrected when off track. Decisions use reliability data and cost.
5 Optimizing	Continuous improvement is routine. Reliability is designed in at purchase and modification. Results are sustained through staff changes.

Half-point scores mean most, but not all, of the next level's criteria are met. Each element has 6–10 scored criteria in the full assessment workbook, provided to the client.

TABLE A.2 — EVIDENCE BASE

SOURCE	SCOPE
Interviews	24: plant leadership, maintenance, production, QA and food safety, stores, finance
Site walk	3 days, all shifts; stores, lube room, shops, three lines, utilities
CMMS extract	14,100 work orders, 2,180 stocked items, PM library (12 months)
Production and finance	Downtime log, QA hold records, general ledger (maintenance accounts), 2024 and 2025 funding requests

TABLE A.3 — STANDARDS AND REFERENCES

REFERENCE	TITLE AND USE
ISO 55001:2024	Asset management — Asset management system — Requirements. Clause mapping of maturity elements.
SMRP Best Practices, 6th ed.	Maintenance and reliability metric definitions and the five-pillar Body of Knowledge. Metric definitions (1.4, 1.5, 5.3.1, 5.4.1).
ISO 14224:2016	Collection and exchange of reliability and maintenance data for equipment. Failure-code structure for the CMMS clean-up.
IEC 60300-3-3:2017	Dependability management — Life cycle costing. Program cost structure.
Plant 2 pilot reports	RCA-2026-014, FMECA-2026-007, CA-2026-003, ROI-2026-005, MA-2026-006, PR-2026-008. Downtime rates and excluded benefits.

SAMPLE — FICTIONAL D

ASSET CRITICALITY ANALYSIS

Plant 2 Asset Criticality: Re-Ranking What Matters Most

36 production and utility assets scored on consequence of failure, re-tiered against the 2019 register, and translated into maintenance effort, spares policy, and working capital.

SAMPLE — FICTIONAL DAT

CLIENT	Larkspur Valley Foods, Inc. — Plant 2 (cultured dairy)
SCOPE	36 assets and asset groups across process, utilities, Lines 1–3, warehouse, and facilities
REPORT NO.	CA-2026-003 · Revision 0 · Issued December 4, 2026
METHOD	Consequence-weighted scoring (safety, food safety, production, environmental and regulatory, repair) with override rules; likelihood used to sequence work within a tier
RELATED WORK	RCA-2026-014 (GR-305) and FMECA-2026-007 (Line 3 filler), whose figures are reused and whose benefits are excluded here
TEAM	Apex Reliability Engineering (facilitator) · Maintenance & Engineering Manager · Production Manager · Food Safety & QA Manager · EHS Manager · Storeroom Lead · Plant Controller

> **Demonstration document.** Sample report. All company names, people, data, and financial figures are fictional and shown for demonstration only. The structure, methods, and level of detail match Apex Reliability Engineering client deliverables.

Executive Summary

Decision brief for the Plant Manager and Plant Controller. Sections 1–6 contain the supporting detail.

BOTTOM LINE

Plant 2's 2019 criticality register no longer reflects the plant. **19 of 36 assets change tier**, including the constraint line's gearbox, product pump, and seal heads, which were all ranked B. Today, tier A assets carry 67% of failure risk but get 41% of preventive maintenance hours. Re-tiering moves effort and spares to where the risk is, with **8% more PM hours** and inventory funded largely by releasing low-tier stock.

ASSETS CHANGING TIER	TIER A SHARE OF RISK	PM HOURS ON TIER C TODAY	INVENTORY RELEASED	5-YR NPV, EXPECTED
19 of 36	**67%**	**27%**	**$72.2K**	**$249K**
6 raised, 13 lowered	vs. 41% of PM hours today	for 9% of the risk	vs. $52.0K added to tier A and B	Range $43K–$433K

DECISIONS REQUESTED

1. **Adopt the 36-asset register** as the plant's criticality basis for work priority, PM, PdM, and spares.
2. **Approve the spares re-balance:** add $52.0K on tier A and B assets, and release $72.2K of tier C and excess stock through return, consignment, or run-down.
3. **Fund 240 h of implementation** ($18.7K) and a six-month review gate before the remaining rollout.

WHAT THE ANALYSIS SHOWS

- FINDING The constraint's three highest-risk assets were ranked B because the 2019 register predates Line 3 becoming the constraint.
- FINDING 27% of PM hours go to tier C assets, including office HVAC and the shop compressor.
- JUDGMENT 11 assets are tier A by override (safety, food safety, or no-redundancy stoppage); for 5 of them, the override is the only reason they reach A.

FINANCIAL SUMMARY (PRE-TAX)

	CONSERV.	EXPECTED	HIGH
Net annual benefit	$20.5K	$69.2K	$113.8K
Year-0 cash outlay	$34.6K	$12.9K	Self-funding
Payback (months)	20.2	2.2	Immediate
5-yr NPV at 10%	**$43K**	**$249K**	**$433K**

Benefits from GR-305, P-310, and the seal heads ($185.2K/yr of risk) are excluded, because RCA-2026-014 and FMECA-2026-007 already claim them.

CONFIDENCE

MODERATE Consequence scores are team judgments against defined anchors (Appendix). Risk reduction on tier A drives the case, and two stress tests turn the conservative NPV negative. The six-month gate exists to test that assumption before full rollout.

SAMPLE — FICTIONAL D

1 Method: Consequence First

Criticality answers one question: **how bad is it when this asset fails?** How often it fails is a reliability question. Mixing the two produces a "bad actor" list, not a criticality ranking.

TABLE 1.1 — CONSEQUENCE CATEGORIES AND WEIGHTS

CATEGORY	WEIGHT	SCORED ON (1–5)
Production (P)	30%	Throughput lost; constraint and redundancy
Personnel safety (S)	25%	Credible injury from failure or its repair
Food safety and quality (F)	25%	CCP, preventive control, or product hold
Environmental and regulatory (E)	10%	Release, permit, or compliance exposure
Repair cost and time (R)	10%	Parts, labor, and lead time per failure

Score = weighted average rescaled to 0–100. Tier A ≥ 55, B 30–54, C < 30. The anchor definitions for each level are in the Appendix.

OVERRIDE RULES

Any asset scoring **5 in safety (S), food safety (F), or production (P)** is tier A whatever its weighted score. P = 5 means the asset stops the whole plant or the constraint and has no redundancy. Weighted averages dilute exactly these single-point consequences, and the overrides exist to stop that.

WHERE LIKELIHOOD FITS

Likelihood (failures per year from CMMS history) does not set the tier. It sequences work *within* a tier and values risk in dollars for the business case. A rarely failing tier A asset still gets tier A protection.

TABLE 1.2 — MAINTENANCE STRATEGY BY TIER

TIER	MAINTENANCE	SPARES	FAILURE RESPONSE	PM + PDM H/YR
A	Condition monitoring (monthly routes) plus OEM/RCM-based PM; priority-1 work orders	Critical spares on site, min/max set	RCA after any failure	110
B	Time-based PM plus quarterly PdM route	Vendor-stocked or consignment	RCA on a repeat (2 in 12 months)	45
C	Run to failure or a minimal inspection	Buy on demand	Repair; no RCA	8

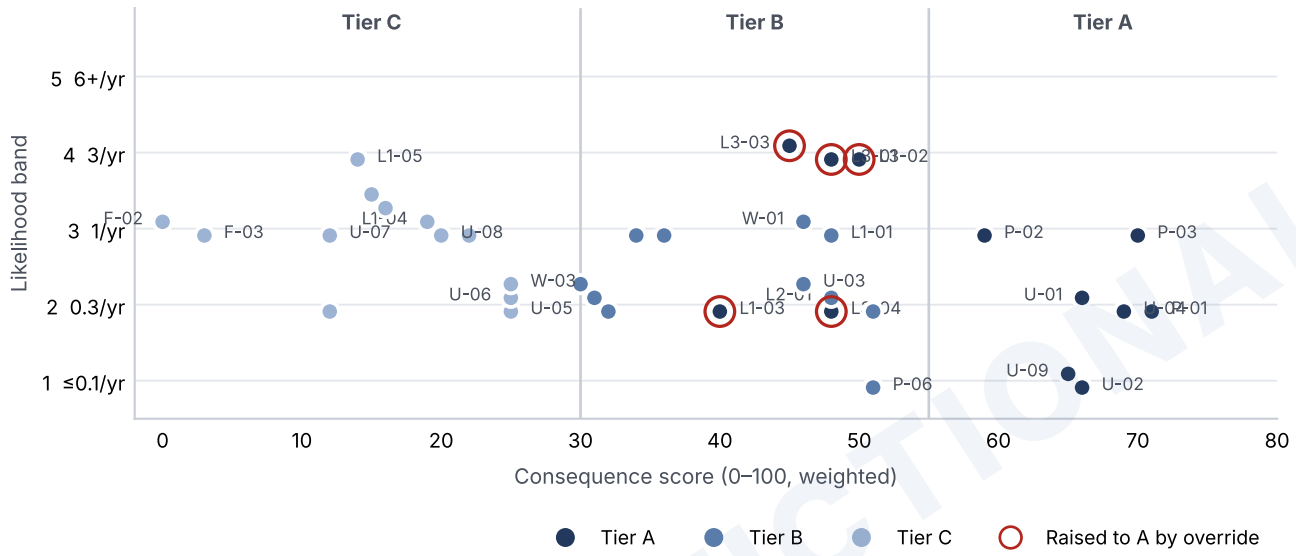
Hours are planning averages per asset. Individual tasks are set by FMECA or RCM, as FMECA-2026-007 did for the Line 3 filler.

SAMPLE — FICTIONAL D

2 Results

12 assets rank tier A, 11 tier B, and 13 tier C. Effort and inventory today do not follow that ranking.

FIGURE 2.1 — ASSETS BY CONSEQUENCE SCORE AND LIKELIHOOD



Labels mark tier A assets and assets that changed tier. Ringed points are raised to tier A by an override despite a weighted score below 55.

TABLE 2.1 — TIER SUMMARY, 2019 REGISTER VS. THIS ANALYSIS

TIER	ASSETS 2019	ASSETS NOW	ANNUAL RISK	PM H TODAY	PM H PROPOSED	SPARES TODAY	SPARES TARGET
A	11	12	$382,436	728	1320	$88,450	$128,400
B	20	11	$137,100	560	495	$96,500	$79,000
C	5	13	$52,700	485	104	$60,000	$17,300
Total	**36**	**36**	**$572,236**	**1773**	**1919**	**$244,950**	**$224,700**

Annual risk = failures per year × (production consequence + repair cost) for each asset. For L3-01, L3-02, and L3-03, values are taken from RCA-2026-014 and FMECA-2026-007 so the three reports reconcile.

SAMPLE — FICTIONAL D

3 Criticality Register

All 36 assets, sorted by tier and score. This register becomes the CMMS criticality field.

ID	ASSET	S	F	P	E	R	SCORE	L	RISK $/YR	2019	NOW
P-01	HTST pasteurizer (timing pump, FDD)	2	5	5	3	3	71	2	$19,800	A	A
P-03	CIP skid CIP-1	3	5	4	3	3	70	3	$31,000	A	A
U-04	Boiler B-1	4	3	4	4	4	69	2	$12,000	A	A
U-01	Ammonia screw compressor C-1	5	2	3	5	5	66	2	$14,700	A	A
U-02	Ammonia screw compressor C-2	5	2	3	5	5	66	1	$4,900	A	A
U-09	Main switchgear / MCC-A	5	1	5	1	5	65	1	$10,000	A	A
P-02	Homogenizer HG-1	2	3	5	1	5	59	3	$100,000	A	A
L3-02	Seal heads (12 lanes)	1	5	4	1	2	50	4	$40,072	B	A · F
L3-01	Filler main drive GR-305	2	2	5	1	3	48	4	$104,028	B	A · P
L3-04	Metal detector	1	5	3	3	2	48	2	$3,300	B	A · F
L3-03	Product pump P-310	1	3	5	1	2	45	4	$41,136	B	A · P
L1-03	Metal detector	1	5	2	3	2	40	2	$1,500	B	A · F
P-07	Glycol chiller	2	3	4	2	4	51	2	$12,000	B	B
P-06	Separator / clarifier	2	3	4	1	5	51	1	$6,500	A	B
L1-01	Cup filler	2	4	3	1	4	48	3	$24,000	A	B
L2-01	Bottle filler	2	4	3	1	4	48	2	$7,200	A	B
W-01	Palletizer (shared, all lines)	4	1	4	1	3	46	3	$31,000	C	B
U-03	Ammonia evaporative condenser	4	1	3	4	3	46	2	$4,500	A	B
L1-02	Lidder	1	4	3	1	2	36	3	$11,000	B	B
L3-06	Case packer	2	1	4	1	3	34	3	$31,000	B	B
P-05	Raw milk receiving pump	1	3	3	2	2	32	2	$3,300	B	B
L3-05	Checkweigher	1	2	3	4	2	31	2	$3,300	B	B
P-04	Fermentation tank agitators (6)	1	3	3	1	2	30	2	$3,300	B	B
U-05	Air compressor AC-1 (N+1)	2	2	2	1	3	25	2	$2,700	B	C
U-06	Air compressor AC-2 (N+1)	2	2	2	1	3	25	2	$2,700	B	C
W-03	Cold-storage evaporators	1	3	2	2	2	25	2	$1,500	B	C
L2-02	Shrink tunnel	3	1	2	1	2	22	3	$5,000	C	C
U-08	Wastewater pH system	1	1	2	5	2	20	3	$5,000	B	C
L1-04	Case packer	2	1	2	1	3	19	3	$9,000	B	C
W-02	Stretch wrapper	2	1	2	1	2	16	3	$5,000	C	C
W-04	Dock levelers	3	1	1	1	2	15	3	$2,500	C	C
L1-05	Transfer conveyors	2	1	2	1	1	14	4	$10,500	B	C
U-07	Cooling tower fan CT-1	1	1	2	2	2	12	3	$5,000	B	C
F-01	Forklift charging station	3	1	1	1	1	12	2	$300	C	C
F-03	Office HVAC	1	1	1	1	2	3	3	$2,500	B	C
F-02	Shop air compressor	1	1	1	1	1	0	3	$1,000	B	C

S safety · F food safety · P production · E environmental/regulatory · R repair; each scored 1–5. L is the likelihood band. A letter after the tier shows the override that raised it. Section 4 lists every tier change with its reason.

SAMPLE — FICTIONAL DATA

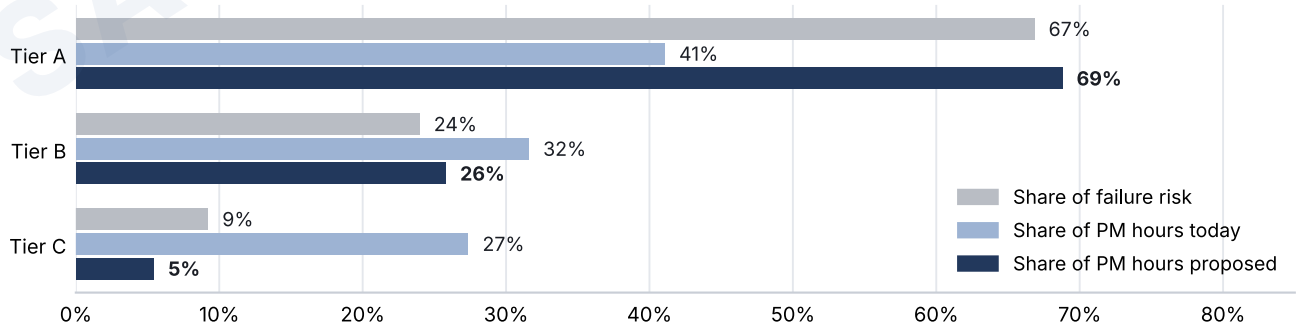
4 What Changes and Why

Every tier change has a stated reason that the owning department can challenge. Most downgrades come from redundancy that the 2019 register did not credit.

TABLE 4.1 — TIER CHANGES

ID	ASSET	CHANGE	REASON
L1-03	Metal detector	B → A	Metal detection is a critical control point (F override).
L3-01	Filler main drive GR-305	B → A	Stops the plant constraint with no redundancy (P override). Subject of RCA-2026-014.
L3-02	Seal heads (12 lanes)	B → A	Seal integrity is a food-safety preventive control (F override).
L3-03	Product pump P-310	B → A	Stops the plant constraint with no redundancy (P override).
L3-04	Metal detector	B → A	Metal detection is a critical control point (F override).
W-01	Palletizer (shared, all lines)	C → B	Single palletizer serves all lines; crush-point safety exposure (score 46).
F-02	Shop air compressor	B → C	No production, safety, or food-safety consequence.
F-03	Office HVAC	B → C	No production, safety, or food-safety consequence.
L1-01	Cup filler	A → B	Line 1 is not the constraint; lost volume is recoverable on overtime.
L1-04	Case packer	B → C	Line 1 is not the constraint; accumulation conveyor buffers stops.
L1-05	Transfer conveyors	B → C	Low-cost, quick-swap components; redundant transfer paths.
L2-01	Bottle filler	A → B	Line 2 is not the constraint; lost volume is recoverable on overtime.
P-06	Separator / clarifier	A → B	Rare failures; production impact recoverable within the shift (score 51).
U-03	Ammonia evaporative condenser	A → B	Multiple condenser cells; one cell out still meets load most of the year.
U-05	Air compressor AC-1 (N+1)	B → C	N+1 redundancy with AC-2.
U-06	Air compressor AC-2 (N+1)	B → C	N+1 redundancy with AC-1.
U-07	Cooling tower fan CT-1	B → C	Multiple tower cells; seasonal load.
U-08	Wastewater pH system	B → C	Holding tank gives response time; compliance is covered by the continuous pH alarm, not tier.
W-03	Cold-storage evaporators	B → C	Multiple evaporators; product stays in temperature during repair.

FIGURE 4.1 — WHERE THE RISK IS VS. WHERE THE HOURS GO



SAMPLE — FICTIONAL D

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Sample report. All company names, people, data, and financial figures are fictional and shown for demonstration only.

5 Financial Justification

This is a reallocation, not a new program. Labor rises 8%, inventory is re-pointed rather than grown, and the return comes from lower failure risk on the assets that matter.

TABLE 5.1 — CASH, WORKING CAPITAL, AND ACCOUNTING TREATMENT

ITEM	CLASS	AMOUNT	TREATMENT
Implementation labor, 240 h at $78/h	OPEX	$18,720	CMMS re-tiering, PM rewrites, spares review. Mostly non-incremental; included so cost is not understated.
Spares added to tier A and B assets	INVENTORY	$51,950	Balance-sheet MRO inventory
Spares released from tier C and excess stock	INVENTORY	($72,200)	Vendor return, consignment, or run-down. Realized share varies by scenario; any write-down is a P&L item for Controller review.
PM and PdM labor change, 1773 → 1919 h/yr	OPEX/YR	$11,388	Net of hours moved off tier C
Carrying cost on the net inventory change	OPEX/YR	20%	Applied to the net change in each scenario

TABLE 5.2 — SCENARIO ANALYSIS (PRE-TAX, 5-YEAR HORIZON, 10% HURDLE RATE)

	CONSERVATIVE	EXPECTED	HIGH IMPACT
Tier A risk avoided (excl. linked assets)	$49,300	$78,880	$108,460
Tier B risk avoided	$6,855	$13,710	$20,565
Tier C risk added (less PM)	($21,080)	($13,175)	($7,905)
Net risk avoided per year	**$35,075**	**$79,415**	**$121,120**
Labor change and carrying cost	−$14,558	−$10,226	−$7,338
Net annual benefit	**$20,517**	**$69,189**	**$113,782**
Net inventory change (release − additions)	−$15,850	$5,810	$20,250
Year-0 cash outlay	$34,570	$12,910	Self-funding
Payback (months)	20.2	2.2	Immediate
5-year NPV at 10%	**$43,206**	**$249,371**	**$432,853**

Conservative: A-tier risk cut 25%, B-tier 5%; C-tier risk up 40%; only half the excess inventory is actually released. **Expected:** A-tier risk cut 40%, B-tier 10%; C-tier risk up 25%; 80% of excess inventory released. **High impact:** A-tier risk cut 55%, B-tier 15%; C-tier risk up 15%; all excess inventory released.

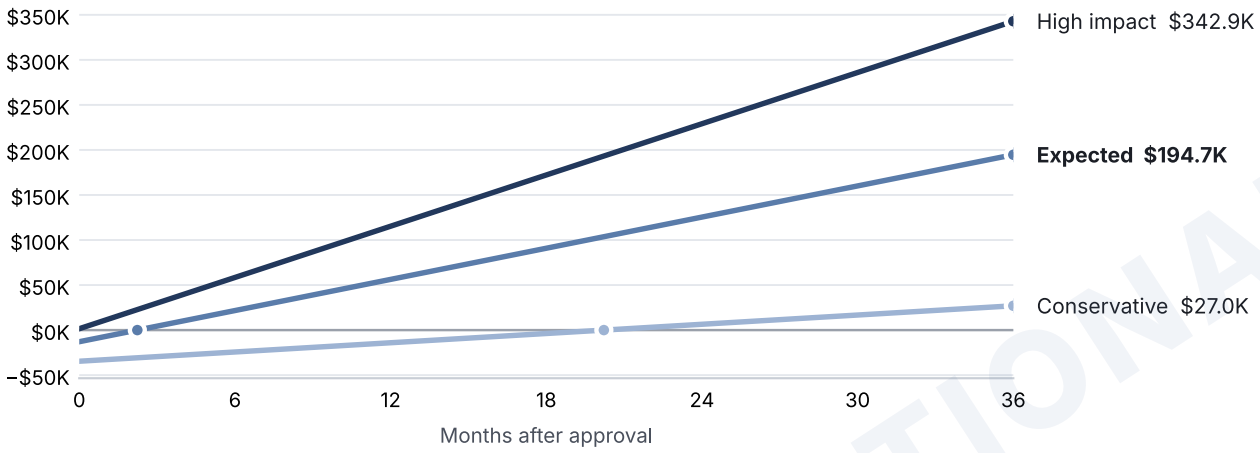
SAMPLE / FICTIONAL D

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5 Financial Justification (continued)

The expected and high cases are strong. The conservative case is positive but thin, and that is what the review gate is for.

FIGURE 5.1 — CUMULATIVE NET CASH POSITION BY SCENARIO (UNDISCOUNTED)



Dots on the zero line mark payback. In the high-impact case, released inventory exceeds year-0 cost, so the line starts above zero.

TABLE 5.3 — STRESS TESTS ON THE CONSERVATIVE CASE

STRESS APPLIED	5-YEAR NPV
Base case (Conservative)	**$43,206**
A-tier risk reduction halved	−$50,237
No inventory released	−$20,264
Implementation cost doubled	$24,486
Discount rate 15%	$34,206

WHERE THE CASE IS FRAGILE

Two stresses turn the conservative NPV negative: halving the tier A risk reduction, and releasing no inventory. Both can be measured within six months. The gate in Section 6 checks them before the remaining rollout is funded.

CONSERVATISM IN THESE FIGURES

Pre-tax and unlevered. Benefits already claimed by RCA-2026-014 and FMECA-2026-007 ($185.2K/yr of risk) are excluded. A higher failure risk on tier C assets is charged against the case, not ignored.

SAMPLE — FICTIONAL D

6 Implementation, Governance, and Limitations

Criticality only pays off if it drives daily decisions. These are the mechanisms that make it do so.

TABLE 6.1 — IMPLEMENTATION AND REVIEW GATE

WINDOW	WORK	OWNER
Months 0–2	Load tiers into the CMMS criticality field; link work-order priority to tier; start the spares returns and consignment talks	Planner · Storeroom Lead
Months 2–4	Rewrite PMs for tier A and B; cut tier C PMs to inspection or run-to-failure; extend PdM routes to all tier A assets	Reliability Engineer
Month 6 gate	**Check: tier A failure rate and downtime trend, inventory actually released, and PM compliance on tier A. Continue, adjust, or stop.**	Plant Manager · Controller
Ongoing	Re-score an asset after any change in duty, redundancy, or regulation. Full review annually.	Reliability Engineer

TABLE 6.2 — VERIFICATION MEASURES

MEASURE	TARGET
Tier A unplanned downtime	≥ 25% reduction against the trailing 12 months by month 12
Share of PM hours on tier A	≥ 60% (from 41%)
Inventory released	≥ 50% of $72.2K by month 6
Tier C failures with a consequence above tier C	Zero; any occurrence triggers a re-score

TABLE 6.3 — LIMITATIONS

GAP	EFFECT
Consequence scores are team judgments INFERENCE	Anchored definitions and cross-department review limit, but do not remove, subjectivity
Likelihood bands from CMMS history without failure coding	Risk dollars are approximate; tiers do not depend on them
Risk-reduction factors by tier are estimates	Covered by the scenario range and tested at the month-6 gate
Analysis covers 36 assets and groups, not every asset	Remaining assets default to tier C until scored

SAMPLE — FICTIONAL D

Larkspur Valley Foods, Inc. — Plant 2 · Confidential, client internal · Prepared by Apex Reliability Engineering
Sample report. All company names, people, data, and financial figures are fictional and shown for demonstration only.

A Scoring Anchors, References, and Approval

TABLE A.1 — SCORING ANCHORS (LEVELS 1, 3, 5; LEVELS 2 AND 4 INTERPOLATE)

CATEGORY	1	3	5
Production	No throughput impact, or full redundancy	Line slowed or stopped; volume recoverable on overtime	Stops the plant or the constraint; no redundancy
Safety	No credible injury	Credible recordable injury	Credible serious injury or fatality; PSM-covered (e.g., ammonia)
Food safety	No product contact or quality effect	Quality defect; product held for evaluation	CCP or preventive control; potential recall
Environ. / regulatory	None	Reportable internally; minor permit deviation	Release or permit violation requiring agency report
Repair	Under $1K; same shift	$5K–15K; days of lead time	Over $30K or weeks of lead time

TABLE A.2 — STANDARDS AND REFERENCES

REFERENCE	TITLE AND USE
ISO 55001:2024	Asset management — Asset management system — Requirements. Decision criteria and risk-based prioritization of assets.
IEC 60812:2018	Failure modes and effects analysis (FMEA and FMECA). Basis for task selection within tiers.
29 CFR 1910.119	Process safety management of highly hazardous chemicals. Ammonia system safety override (U-01 to U-03).
21 CFR Part 117	CGMP and risk-based preventive controls for human food. Food-safety override (CCPs, preventive controls).
RCA-2026-014 · FMECA-2026-007	Prior Apex analyses at Plant 2. Source of Line 3 risk values; benefits excluded here.

REVIEW AND APPROVAL

Prepared by
Lead Reliability Engineer, Apex Reliability Engineering — Signature _____ Date _____

Financials validated by
Plant Controller — Signature _____ Date _____

Approved by
Plant Manager — Signature _____ Date _____

SAMPLE — FICTIONAL D

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Sample report. All company names, people, data, and financial figures are fictional and shown for demonstration only.

ROOT CAUSE FAILURE ANALYSIS (RCFA)

Recurring Gearbox Failure: Line 3 Filler Main Drive (GR-305)

Three seizures in 13 months on the plant's constraint line. This report covers cause, cost of unreliability, and a corrective action package for capital approval.

SAMPLE — FICTIONAL DAT

CLIENT	Larkspur Valley Foods, Inc. — Plant 2 (cultured dairy)
ASSET	GR-305 filler main drive gear reducer · Line 3 · 12-lane cup filler
REPORT NO.	RCA-2026-014 · Revision 0 · Issued November 6, 2026
ANALYSIS WINDOW	July 1, 2025 – October 31, 2026 (16 months)
TRIGGER	Repeat failure on a constraint asset (two or more corrective work orders in 12 months)
METHOD	Evidence-verified cause-and-effect logic tree (physical, human, and latent roots), change analysis, and cost of unreliability valued at contribution margin
RCA TEAM	Apex Reliability Engineering (facilitator) · Maintenance Supervisor · Line 3 Lead Mechanic · Sanitation Supervisor · Line 3 Production Supervisor · Food Safety & QA Manager · Plant Controller (financial validation)
DISTRIBUTION	Plant Manager · Maintenance & Engineering Manager · Plant Controller · Sanitation Manager · QA Manager

Demonstration document. Sample report. All company names, people, data, and financial figures are fictional and shown for demonstration only. The structure, methods, and level of detail match Apex Reliability Engineering client deliverables.

Executive Summary

Decision brief for the Plant Manager and Plant Controller. Sections 1–7 contain the supporting detail.

BOTTOM LINE

GR-305 has failed three times in 13 months because **washdown water and cleaning solution enter the gearbox during sanitation**, not because of a defective gearbox. The unit installed today shows the same contamination after six weeks, so its next failure is expected around March 2027. A **$36.9K package** (a washdown-duty gearbox, a critical spare, and procedure changes) removes the cause. It pays back in **4.5 months** in the expected case and has a positive NPV in all three scenarios.

COST OF UNRELIABILITY, 16 MONTHS	UNPLANNED DOWNTIME	CASH OUTLAY REQUESTED	PAYBACK, EXPECTED CASE	5-YEAR NPV AT 10%
$225.4K	**62.0 h**	**$36.9K**	**4.5 mo**	**$335K**
Only $28.4K (13%) appeared in maintenance spend	On the plant constraint across three events	CAPEX $13.6K · Inventory $11.9K · OPEX $11.4K	Range 2.7–20.2 months	Range $46K–$583K; positive in all cases

DECISIONS REQUESTED

1. **Approve $13.6K CAPEX** for a sealed, washdown-duty reducer (CA-1) and **$11.9K in inventory** for a matching critical spare (CA-6).
2. **Endorse the sanitation procedure revision** (CA-3) and management-of-change coverage for sanitation changes (CA-11), with Sanitation and QA sign-off.
3. **Authorize the survey** of 14 other washdown-zone reducers (CA-10; $630 plus internal labor).

WHAT THE EVIDENCE SHOWS

- CONFIRMED The failed unit's oil held **4,850 ppm water** (57× new oil). Its sodium content points to cleaning solution.
- CONFIRMED **Life fell from 73 months to about 6.6 months** after the May 2025 sanitation program change.
- RULED OUT The working assumption of a **defective gearbox or batch**. Restocking the same model resets the clock to about 200 days.
- CONFIRMED The 41-hour event was a **spares failure**. It cost $137.1K more than an average event with a spare on hand.

FINANCIAL SUMMARY (PRE-TAX)

	CONSERV.	EXPECTED	HIGH
Annual loss avoided	$26.5K	$102.6K	$168.1K
Net annual benefit	$21.9K	$98.0K	$163.5K
Payback (months)	20.2	4.5	2.7
5-yr NPV at 10%	**$46K**	**$335K**	**$583K**

Break-even: the package pays for itself if it prevents one spare-on-hand failure every 2.1 years. Since the sanitation change, GR-305 has failed every 6.6 months.

CONFIDENCE

HIGH for Event 3, from physical, oil, and thermal evidence and the same ingress measured on a new unit. MODERATE for Events 1–2, whose units were scrapped without teardown. The corrective actions do not depend on Events 1–2.

SAMPLE — FICTIONAL DATA

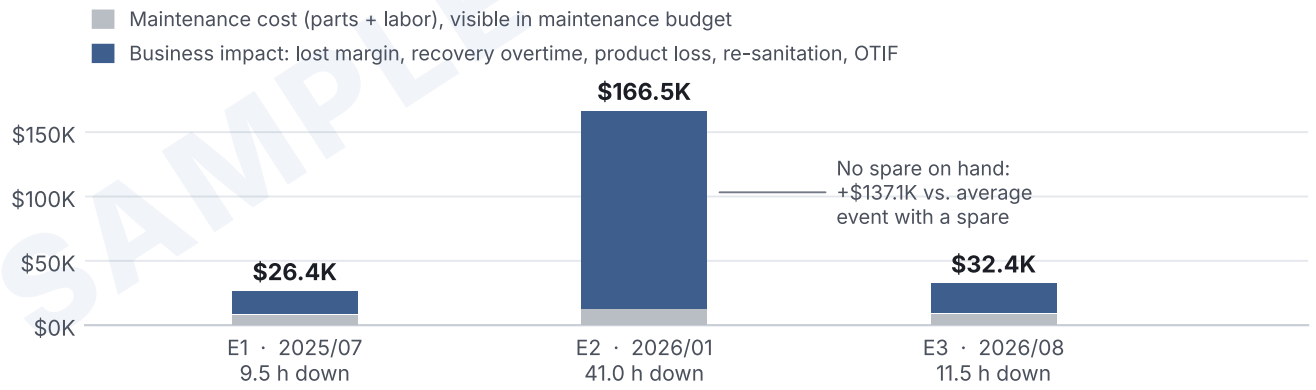
1 Event and Financial Impact

Three unplanned seizures cost $225.4K over 16 months, or $169.0K annualized. The maintenance budget recorded $28.4K of that total. The rest fell on margin, customer penalties, and product loss.

TABLE 1.1 — COST OF UNRELIABILITY BY EVENT (USD, PRE-TAX)

COST ELEMENT	E1 · JUL 18, 2025	E2 · JAN 27, 2026	E3 · AUG 21, 2026	TOTAL
Unplanned downtime (h)	9.5	41.0	11.5	62.0
of which recovered on overtime (h)	7.1 (75%)	16.4 (40%)	8.1 (70%)	31.6
Lost contribution margin (unrecovered h × $4,620)	$10,972	$113,652	$15,939	$140,563
Recovery cost (recovered h × $610)	$4,346	$10,004	$4,910	$19,260
Customer OTIF deductions	$0	$18,400	$0	$18,400
Product and WIP loss (standard cost)	$1,334	$8,568	$1,472	$11,374
Re-sanitation cycles	$1,850	$3,700	$1,850	$7,400
Subtotal: business impact	**$18,502**	**$154,324**	**$24,171**	**$196,997**
Parts, including expedite premium	$6,450	$9,300	$6,450	$22,200
Maintenance labor (fully burdened)	$1,482	$2,912	$1,794	$6,188
Subtotal: maintenance cost	**$7,932**	**$12,212**	**$8,244**	**$28,388**
Total cost of unreliability	**$26,434**	**$166,536**	**$32,415**	**$225,385**

FIGURE 1.1 — MAINTENANCE COST VS. BUSINESS IMPACT, BY EVENT



FINANCIAL METHODOLOGY (VALIDATED BY THE PLANT CONTROLLER)

- **Downtime is valued at lost contribution margin, not revenue:** 1,200 cases/h × $3.85 contribution margin per case = $4,620 per line-hour (FY2026 standard).
- **Recovered volume is charged at recovery cost, not lost margin.** Recovery cost covers the overtime crew at the burdened overtime rate, incremental utilities, and the added sanitation cycle. Recovery percentages come from production records.
- **Idle direct labor during downtime is excluded.** It is a period cost, not incremental cash, and it already appears as under-absorbed conversion cost. Counting it here would double count.
- Parts are valued at replacement cost. Sunk costs are excluded. All historical figures are pre-tax and undiscounted.

SAMPLE — FICTIONAL D

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Sample report. All company names, people, data, and financial figures are fictional and shown for demonstration only.

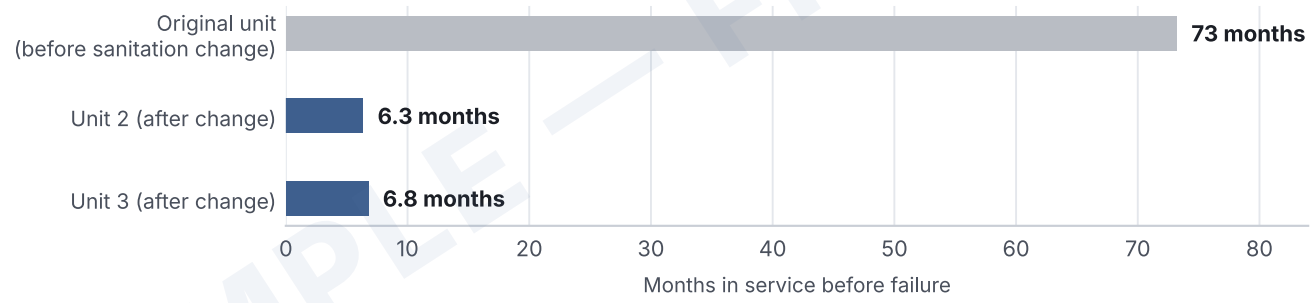
2 Asset Context and Change Analysis

GR-305 drives the 12-lane cup filler on Line 3, the plant constraint, and has no redundancy. It is a standard-duty, vented, painted reducer with NBR seals and H1 PAO VG 220 oil, installed in a washdown zone. It was ranked criticality B in 2019 and never re-ranked. Its life fell by a factor of eleven after the May 2025 sanitation change.

TABLE 2.1 — SEQUENCE OF EVENTS

DATE	EVENT AND SIGNIFICANCE
Jun 2019	GR-305 installed; OEM-standard reducer accepted for a washdown zone
Mar 2024	SKU rationalization makes Line 3 the plant constraint; criticality not re-ranked
May 2025	**Sanitation program revised** (SSOP-L3-07 Rev C): chlorinated alkaline foam, high-volume rinse, ambient final rinse. No equipment review.
Jul 18, 2025	**E1**: original unit seizes after 6.1 years. The stocked spare is installed and never reordered.
Jan 27, 2026	**E2**: seizes after 193 days. No spare on hand, so a unit is expedited: **41 h down**. WO note: “oil milky.”
Aug 21, 2026	**E3**: seizes after 206 days. Unit retained for teardown; RCA chartered Aug 24.
Oct 2, 2026	Oil from the unit installed at E3 shows **1,900 ppm water after 6 weeks**. Mechanism still active.

FIGURE 2.1 — CHANGE ANALYSIS: TIME IN SERVICE BEFORE FAILURE



Post-change mean life is 199.5 days, about 1.83 failures per year if nothing changes. The next failure of the current unit is expected around March 2027.

SAMPLE — FICTIONAL D

3 Evidence and Hypotheses

Every finding is graded by how it is known. Six hypotheses were tested against the evidence: one is confirmed, and the rest are ruled out, including the one the plant had been acting on.

TABLE 3.1 — KEY EVIDENCE

ID	EVIDENCE (METHOD)	RESULT	STATUS
EV-01	Oil, failed E3 unit (lab: KF ASTM D6304, ICP, ISO 4406)	Water **4,850 ppm** (new oil 85 ppm), milky; **Na 58 ppm** (new < 2); Fe 312 ppm; ISO 22/20/17	CONFIRMED
EV-02	Oil, unit installed at E3, after 6 weeks	Water **1,900 ppm**, Na 21 ppm: **ingress active on a new unit**	CONFIRMED
EV-04	Teardown, witnessed (ISO 15243:2017)	Corrosion etching at roller spacing; spalling starts at corrosion sites; rust above oil line; no tooth fracture	CONFIRMED
EV-06	Output-shaft NBR lip seal	Hardened (+14 Shore A), radially cracked; chemical attack inferred from compatibility data	SUPPORTED
EV-08	IR thermography, 2 sanitation cycles	Housing 67 °C → 23 °C in 8 min of ambient rinse (**−44 °C**); open vent, no desiccant	CONFIRMED
EV-09	Sanitation observation, 2 shifts	Foam and rinse applied directly to the drive; SSOP silent on drive protection	CONFIRMED
EV-10	CMMS work orders and PMs	No failure or cause codes; spare coded non-stock; “cloudy oil” noted twice and topped off	CONFIRMED
EV-12	VFD fault log, 30 days before E3	No overcurrent trips; motor current 62–71% of FLA	CONFIRMED
EV-13	E1 and E2 physical evidence	Units scrapped without teardown; E2 note: “oil milky”	INFERENCE

TABLE 3.2 — HYPOTHESES TESTED

HYPOTHESIS	DECIDING EVIDENCE	RESULT
H1 · Water and cleaner ingress → moisture corrosion	EV-01, 02, 04, 08, 09: water 57× baseline, sodium signature, corrosion-initiated spalling, active ingress on a new unit	CONFIRMED
H2 · Defective unit or batch (working assumption)	Three units, two bearing lots, identical environmental damage; original unit lasted 6.1 years until the sanitation change	RULED OUT
H3 · Overload from filler jams	No overcurrent trips (EV-12); no tooth fracture or plastic deformation	RULED OUT
H4 · Misalignment	Normal bearing load zone; torque arm serviceable; no fretting	RULED OUT
H5 · Wrong lubricant	H1 PAO VG 220 matches OEM spec; viscosity about 4% below new oil	RULED OUT
H6 · Particulate contamination	Silicon 4 ppm; particle load tracks iron wear debris, so it is an effect, not a cause	RULED OUT

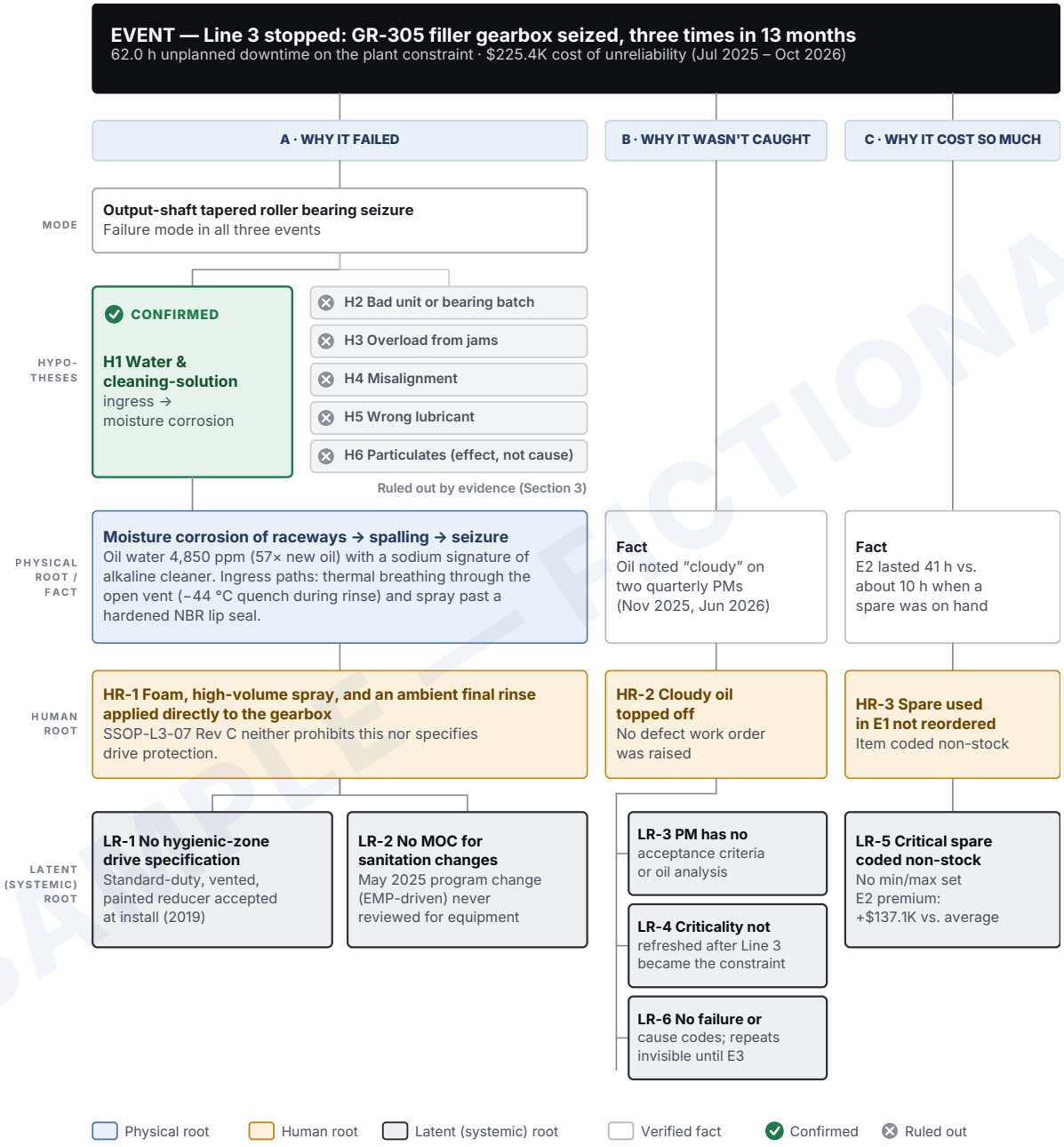
ASSUMPTION CHALLENGED

After E2, the working explanation was a defective gearbox, so the plant restocked the same model. Like-for-like replacement would have reset the clock to roughly 200 days at about $29.4K per event. **What would reopen this analysis:** dry oil at a future failure, or bearing damage that does not start at corrosion sites.

SAMPLE — FICTIONAL DATA

4 Cause-and-Effect Logic Tree and Root Causes

The tree has three branches: why the gearbox failed, why the plant did not catch it, and why one event cost more than five times the others. Every latent root has a corrective action in Section 5.



Each level answers "how could the level above occur?" Human roots are decisions made inside the system; latent roots explain why those decisions were reasonable at the time. No individual blame is assigned.

ROOT CAUSE STATEMENT

Physical: water and alkaline cleaner in the oil caused moisture corrosion of the output-shaft bearing, which progressed to spalling and seizure (ISO 15243:2017). **Human:** sanitation sprays the drive, cloudy oil was topped off without escalation, and the used spare was never reordered. **Latent:** no hygienic-zone drive specification, no MOC for sanitation changes, PMs without acceptance criteria, an outdated criticality ranking, a non-stock critical spare, and no CMMS failure coding. Three of these are plant-wide.

SAMPLE — FICTIONAL D

5 Corrective and Preventive Action Plan

Eleven actions, each traced to a root. The plan favors engineering controls that remove the ingress path over procedures that depend on daily compliance.

ID	ACTION	CLOSES	CONTROL	OWNER	DAYS	COST	CLASS
CA-1	**Replace GR-305 with a sealed, washdown-duty reducer**: stainless housing, FKM double-lip seals, no open vent, IP69K rating, NSF H1 factory fill	Physical, LR-1	Engineering (removes path)	Maint. & Eng. Mgr	30	$13,600	CAPEX
CA-2	**Interim protection until CA-1**: desiccant breather, cleanable stainless splash shield, oil change, monthly oil sample	Physical	Engineering (interim)	Maint. Supervisor	7	$1,150	OPEX
CA-3	**Revise SSOP-L3-07**: no direct foam or spray on drives; cover drives during foaming; revised final-rinse sequence; joint Sanitation and Maintenance sign-off; train all crews	HR-1, LR-2	Admin.	Sanitation Mgr + QA	21	$1,400	OPEX
CA-4	**Quarterly oil-analysis route** for the 12 highest-criticality reducers, including all Line 3 units: KF water, elemental with sodium, ISO 4406, with alarm limits (Figure 7.1)	LR-3, LR-4	Detection	Reliability Engineer	30	$2,160/ yr	OPEX
CA-5	**Rewrite the PM**: replace “check and top off” with inspect and sample; set acceptance criteria; cloudy or milky oil automatically raises a defect WO	HR-2, LR-3	Admin. / detection	Planner	30	6 h	OPEX
CA-6	**Stock one washdown-duty spare**; set min 1 / max 1; flag it as a critical spare in the CMMS	HR-3, LR-5	Admin.	Storeroom / Purchasing	45	$11,900	INVENTORY
CA-7	**Re-rank criticality** for Line 3 and every asset whose duty changed in the 2024 volume shift; update PdM routes	LR-4	Admin.	Reliability Engineer	60	24 h	OPEX
CA-8	**Add failure mode, cause, and action codes** to the CMMS (adapted from ISO 14224); flag any asset with two or more corrective WOs in 12 months for RCA screening	LR-6	Detection	Maint. Mgr / CMMS admin	60	32 h	OPEX
CA-9	**Issue a hygienic-zone drive specification** for capital projects and MRO purchasing: sealed reducers, FKM seals, washdown-rated motors, NSF H1 lubricants	LR-1	Design standard	Engineering	90	16 h	OPEX
CA-10	**Extent of condition**: oil-sample and inspect 14 reducers in washdown zones; rank them and request replacements separately	Physical (fleet)	Detection	Reliability Engineer	30	$630 + 20 h	OPEX
CA-11	**Extend MOC to sanitation program and SSOP changes**, with a mandatory Maintenance and Engineering review step	LR-2	Admin.	Plant Manager	60	8 h	OPEX

Days: due date counted from approval. Internal labor costed at $78/h fully burdened. **Food-safety guardrail:** CA-2 and CA-3 require QA approval. Shields must be cleanable and must not create harborage; cleaning thoroughness does not change (21 CFR 117.35, 117.40).

SAMPLE — FICTIONAL D

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Sample report. All company names, people, data, and financial figures are fictional and shown for demonstration only.

6 Financial Justification

A $36.9K outlay, two-thirds of it CAPEX and balance-sheet inventory, produces a positive 5-year NPV in every scenario tested. The expected case pays back in 4.5 months.

TABLE 6.1 — INVESTMENT AND ACCOUNTING TREATMENT

ITEM	CLASS	AMOUNT	ACCOUNTING TREATMENT
CA-1 washdown-duty reducer, installed	CAPEX	$13,600	Betterment (upgraded design), not like-for-like repair. Capitalization subject to Controller review under plant policy.
CA-6 critical spare (matching unit)	INVENTORY	$11,900	MRO inventory on the balance sheet. P&L impact is carrying cost until the spare is issued.
CA-2 interim guards, breather, oil change	OPEX	$1,150	Expensed as incurred
CA-3 SSOP revision and crew training	OPEX	$1,400	Expensed as incurred
Internal labor, 106 h at $78/h (CA-5, 7–11)	OPEX	$8,268	Mostly non-incremental; included so cost is not understated
CA-10 oil samples, 14 reducers	OPEX	$630	Expensed as incurred
Total cash outlay (year 0)		**$36,948**	
Recurring: oil-analysis route (CA-4)	OPEX/YR	$2,160	12 reducers × 4 samples × $45
Recurring: spare carrying cost (CA-6)	OPEX/YR	$2,380	20% of inventory value per year

TABLE 6.2 — SCENARIO ANALYSIS (PRE-TAX, 5-YEAR HORIZON, 10% HURDLE RATE)

	CONSERVATIVE	EXPECTED	HIGH IMPACT
Failures per year without action	1.20	1.83	2.25
Cost per failure without action	$29,424	$56,846	$75,128
Annual loss exposure without action	**$35,309**	**$104,028**	**$169,038**
Residual failures per year with action	0.30	0.15	0.10
Residual cost per failure	$29,424	$9,800	$9,800
Residual annual loss	($8,827)	($1,470)	($980)
Recurring OPEX added	($4,540)	($4,540)	($4,540)
Net annual benefit	**$21,942**	**$98,018**	**$163,518**
Payback (months, undiscounted)	20.2	4.5	2.7
5-year NPV at 10%	**$46,229**	**$334,617**	**$582,914**
IRR	52%	> 100%	> 100%
PV benefit ÷ outlay	2.3×	10.1×	16.8×

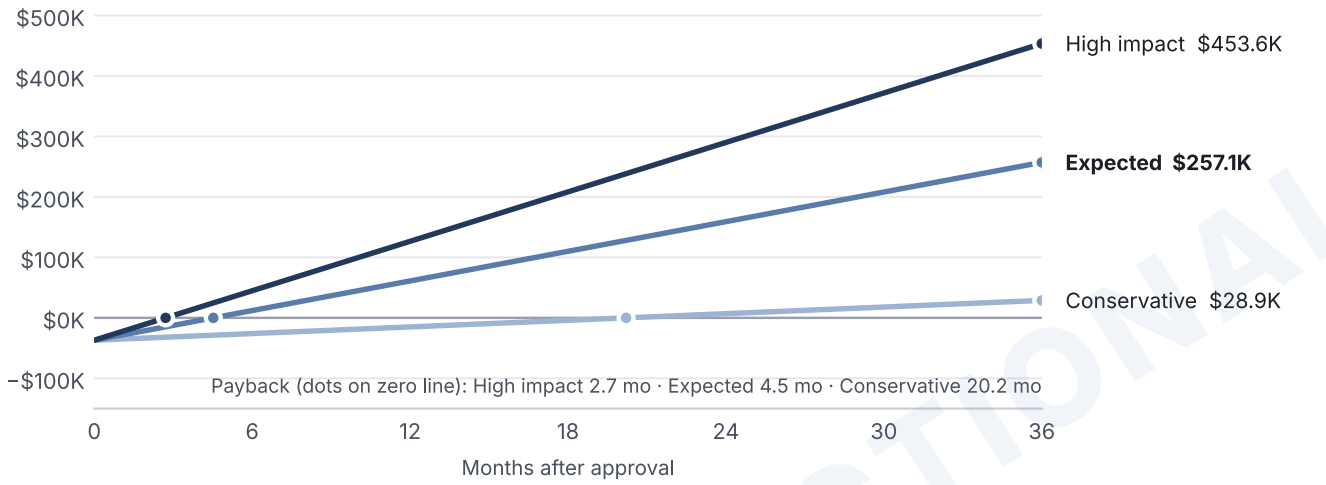
Conservative: 1.2 failures/yr, every one with a spare on hand; residual 0.30/yr at full event cost.
Expected: 1.83 failures/yr implied by post-change life (200 days); 20% of events without a spare; residual 0.15/yr, detected early.
High impact: 2.25 failures/yr (observed rate) at the observed average cost; residual 0.10/yr, detected early.
Cost per failure: $29,424 is the average of E1 and E3 (spare on hand); $166,536 is E2 (no spare); $75,128 is the observed average; $9,800 is a condition-detected, planned replacement in a sanitation window.

SAMPLE — FICTIONAL D

6 Financial Justification (continued)

The cash curve, the stress tests, and the break-even point all lead to the same conclusion: the decision holds even under pessimistic assumptions.

FIGURE 6.1 — CUMULATIVE NET CASH POSITION BY SCENARIO (UNDISCOUNTED)



Line ends show the cumulative cash position at 36 months.

TABLE 6.3 — STRESS TESTS ON THE CONSERVATIVE CASE

STRESS APPLIED	5-YEAR NPV
Base case (Conservative)	**$46,229**
Contribution margin −15%	$39,342
Cash outlay +25%	$36,991
Residual failure rate doubled (0.6/yr)	$12,766
Discount rate 15%	$36,604

NPV stays positive under every single stress. The largest sensitivity is the residual failure rate, which is why verification (Section 7) tracks it directly.

BREAK-EVEN

NPV reaches zero if the package avoids $14,287 of loss per year. That equals about **one spare-on-hand failure every 2.1 years**. Since May 2025, GR-305 has failed every 6.6 months.

CONSERVATISM IN THESE FIGURES

Figures are pre-tax and unlevered. They exclude the CA-1 depreciation tax shield, spare salvage value at year 5, and any benefit from the 14 other reducers (Section 7). Internal labor is included even though most of it is not incremental cash.

SAMPLE — FICTIONAL D

7 Extent of Condition and Verification of Effectiveness

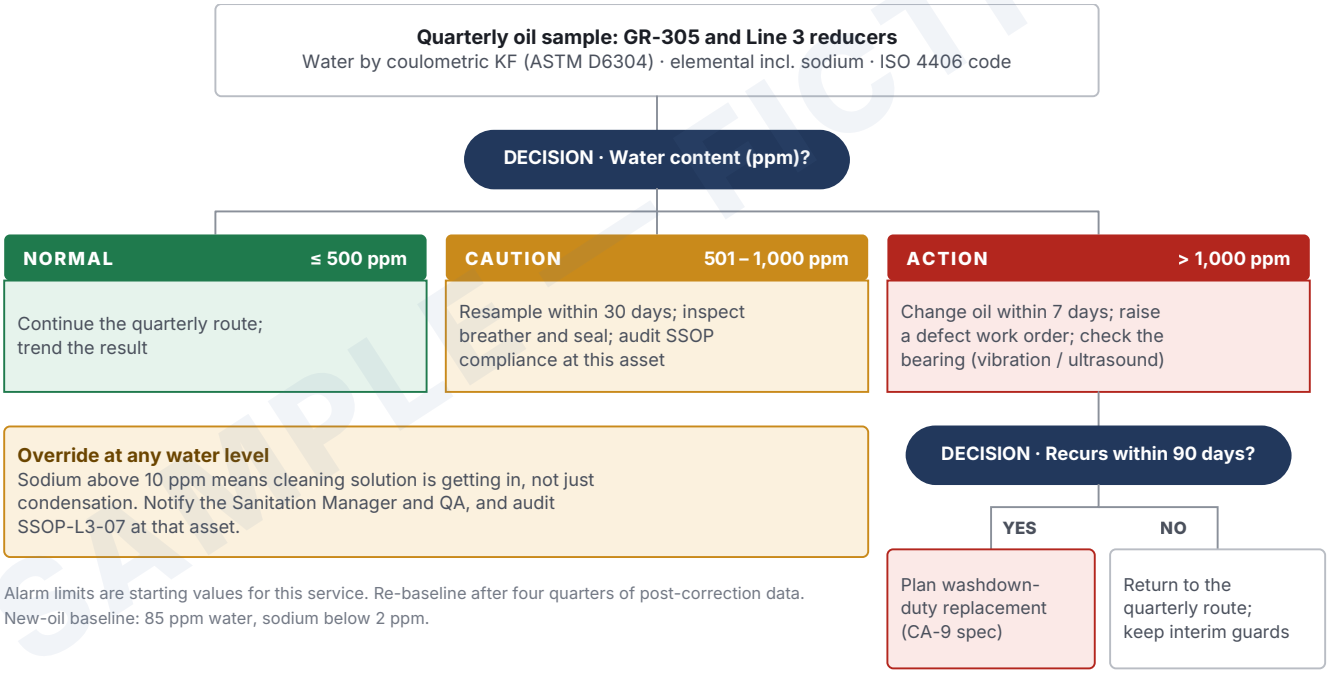
The same sanitation practice reaches 14 other reducers in washdown zones, five of them criticality A. All 14 will be oil-sampled within 30 days (CA-10). That exposure is not included in Section 6 INFERENCE: it may exceed this single-asset case.

TABLE 7.1 — VERIFICATION OF EFFECTIVENESS

MEASURE	TARGET	OWNER · CADENCE
Unplanned GR-305 failures	Zero for 18 months after CA-1	Reliability · monthly
Oil water, Line 3 reducers	≤ 500 ppm and sodium < 10 ppm, 4 consecutive quarters	Reliability · quarterly
SSOP drive-protection compliance	≥ 95% of audited cycles, 3 consecutive months	QA · monthly audit
Corrective WOs with mode and cause coded	100% within 5 days of close	Maint. Mgr · monthly

Why 18 months: at an unchanged 1.83 failures per year, the chance of 18 failure-free months by luck is 6.4%, so 18 clean months gives about 94% confidence that the rate has dropped.

FIGURE 7.1 — DECISION TREE: RESPONSE TO OIL-ANALYSIS RESULTS (CA-4, CA-5)



Alarm limits are starting values for this service. Re-baseline after four quarters of post-correction data. New-oil baseline: 85 ppm water, sodium below 2 ppm.

SAMPLE — FICTIONAL D

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Sample report. All company names, people, data, and financial figures are fictional and shown for demonstration only.

A Limitations, References, and Approval

TABLE A.1 — LIMITATIONS AND THEIR EFFECT ON CONCLUSIONS

GAP	EFFECT
E1 and E2 units scrapped without teardown	E1–E2 attribution is MODERATE. Actions do not change; the mechanism is confirmed on E3 and on the active unit.
Sanitation observed on 2 of about 12 weekly cycles	Variation between crews is unknown; CA-3 audits will measure it.
Recovery percentages from production records	Lost margin uncertain by about ±15%; the conservative NPV stays positive (Table 6.3).
Seal hardening attributed from compatibility data, not lab-tested	Graded SUPPORTED; no effect, because CA-1 specifies FKM seals.

TABLE A.2 — STANDARDS AND REFERENCES

REFERENCE	TITLE AND USE
ISO 15243:2017	Rolling bearings — Damage and failures — Terms, characteristics and causes. Classification of the bearing damage mode (EV-04)
ISO 14224:2016	Petroleum, petrochemical and natural gas industries — Collection and exchange of reliability and maintenance data for equipment. Failure taxonomy adapted for CMMS coding (CA-8). The standard's scope is petroleum industries, but its taxonomy is widely adapted elsewhere.
ASTM D6304-25	Standard Test Method for Determination of Water in Petroleum Products, Lubricating Oils, and Additives by Coulometric Karl Fischer Titration. Water content (EV-01 to EV-03); CA-4 alarm limits
ISO 4406:2021	Hydraulic fluid power — Fluids — Method for coding the level of contamination by solid particles. Particle cleanliness code reported by the laboratory (applied to gear oil by convention)
21 CFR 178.3570	Lubricants with incidental food contact. Basis for the NSF H1 lubricant requirement (CA-1, CA-9)
21 CFR 117.35, 117.40	Current Good Manufacturing Practice — Sanitary operations; Equipment and utensils. Food-safety guardrail for CA-2 and CA-3: equipment must be designed and used to avoid adulterating food with lubricants or contaminated water
ISO 21469:2006	Safety of machinery — Lubricants with incidental product contact — Hygiene requirements. Preferred lubricant certification in the CA-9 specification
Client documents	SSOP-L3-07 Rev C · PM-L3-GR-Q · MOC procedure ADM-012 · Asset criticality register (2019). Internal procedures and records reviewed

REVIEW AND APPROVAL

Prepared by
Lead Reliability Engineer, Apex Reliability Engineering
Signature _____ Date _____

Financials validated by
Plant Controller
Signature _____ Date _____

Approved by
Plant Manager
Signature _____ Date _____

SAMPLE — FICTIONAL D

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ROOT CAUSE FAILURE ANALYSIS · CASE STUDY

"We're Rough on Motors Here": VFD Bearing Damage Hidden in Plain Sight

Six premature motor failures in seven weeks, explained away as normal. Teardowns, shaft-voltage measurements, and an installation survey traced them to VFD-induced electrical discharge machining.

SANITIZED CASE STUDY

SETTING	Multi-line food manufacturing plant with washdown production areas
POPULATION	136 motors fed by variable frequency drives (VFDs)
TRIGGER	6 motor failures in 7 weeks: 2 × 25 hp washdown inverter-duty motors and 4 × 3 hp motors, none older than three years
INVESTIGATOR	Apex Reliability Engineering principal, then the site Reliability Engineer
METHODS	Bearing teardown and failure-mode classification, oscilloscope shaft-voltage measurement, drive and cable installation survey, at-risk motor screening
INSTRUMENTS	Rigol DHO814 oscilloscope with a shaft-voltage probe

> **About this document.** Sanitized account of an actual investigation. Site, people, and identifying details removed; costs are approximate. Unlike the Apex Reliability Engineering sample reports, the technical findings here are real. Planning-level cost estimates are labeled as such.

Executive Summary

What happened, what the evidence showed, and why it matters to any plant running VFDs.

BOTTOM LINE

A cluster of premature motor failures was being explained away as normal for a washdown plant. The evidence said otherwise. Every drive-end bearing torn down showed **fluting**, the signature of VFD-induced electrical discharge machining (EDM). Shaft voltages of **21–34 V** were measured, and the installation survey found the conditions that produce them across the plant. The fixes are standard, inexpensive per motor, and small next to the **$90K** that the two 25 hp failures alone cost.

FAILURES IN 7 WEEKS	TEARDOWNS WITH FLUTING	SHAFT VOLTAGE MEASURED	COST, TWO 25 HP FAILURES	VFD MOTORS EXPOSED
6	**4 of 4**	**21–34 V**	**$90K**	**136**
2 × 25 hp, 4 × 3 hp; all under 3 years old	Drive-end bearings; grease blackened and viscous	On suspect motors, by oscilloscope	$30K replacement + $15K downtime, each	Installation gaps were plant-wide

WHAT THE INVESTIGATION FOUND

- CONFIRMED **Electrical bearing damage.** Drive-end fluting in all four teardowns, with degraded grease.
- CONFIRMED **Shaft voltage at damaging levels:** 21–34 V on suspect motors.
- CONFIRMED **Installation conditions known to drive bearing currents:** no direct motor-to-drive ground bond, unshielded runs over 100–140 ft, little drive filtering, and few motors with shaft grounding.
- SUPPORTED **Normalization of deviance.** Three stock explanations had kept the cluster from being investigated (Section 1).

WHAT WAS RECOMMENDED

1. **Bond each motor directly to its drive** with a dedicated ground conductor.
2. **Use shielded VFD cable**, prioritizing runs over 100 ft.
3. **Install shaft grounding rings** on at-risk motors.
4. **Add drive output filtering** (reactors or filters) on long runs.
5. **Work a red-flag list** of at-risk motors, ranked by known contributing factors (Section 4).

OUTCOME

NOT VERIFIED The investigator left the site before implementation could be confirmed, so this case reports findings and recommendations, not results.

SANITIZED CASE STUDY

1 The Signal That Was Being Normalized

Normalization of deviance is what happens when repeated abnormal results stop looking abnormal. Each failure gets a plausible local explanation, and the pattern never gets examined.

TABLE 1.1 — THE TRIGGER CLUSTER

MOTORS	COUNT	SERVICE	AGE AT FAILURE	CONSEQUENCE
25 hp inverter-duty	2	Washdown production	Under 3 years	$30K replacement and about $15K downtime each; 5.5–7 h down
3 hp	4	Production, with redundancy	Under 3 years	Lower; redundant equipment limited downtime (not quantified)
Total	**6**	**Over 7 weeks**		**At least $90K**

TABLE 1.2 — WHAT PEOPLE SAID, AND WHAT THE EVIDENCE SHOWED

EXPLANATION IN CIRCULATION	WHAT THE EVIDENCE SHOWED	VERDICT
"We're rough on motors here."	Rough handling and overload leave mechanical damage patterns. The teardowns showed fluting, a regular washboard pattern produced by electrical discharge. These motors were also under three years old and rated inverter-duty.	NOT SUPPORTED
"It's a washdown facility, so the chemicals cause it."	Chemical and water ingress produce corrosion damage. Fluting is classified separately, as electrical erosion (ISO 15243:2017). Washdown was not ruled out as a co-factor, but it does not explain the damage found.	NOT SUPPORTED as primary cause
"We don't have that many motors fail, considering how many we have."	6 of 136 VFD motors (4.4%) failed in 7 weeks. If sustained, that pace is about 45 failures a year, or 33% of the fleet. The point is not a forecast; it is that the cluster was far outside normal background.	NOT SUPPORTED

WHY THIS MATTERS

Each explanation was plausible on its own, and that is what made them effective. None of them was tested. A single teardown, done early, would have redirected the conversation from "motors fail here" to "something is destroying our bearings."

SANITIZED CASE STUDY

2 Investigation and Evidence

The investigation moved from the failed parts outward: what the bearings showed, what voltage was present, and what in the installation produced it.

FIGURE 2.1 — FLUTING ON A DRIVE-END BEARING INNER RACE (TEARDOWN PHOTO)



The evenly spaced transverse lines across the raceway are fluting: repeated electrical discharges between the rolling elements and race. Mechanical wear and corrosion do not produce this pattern.

INVESTIGATION SEQUENCE

1. **Failure history review:** establish the cluster.
2. **Four teardowns:** classify the damage mode.
3. **Shaft-voltage measurement:** confirm damaging voltage.
4. **Installation survey:** find what generates and routes bearing current.
5. **Red-flag screening:** rank at-risk motors.

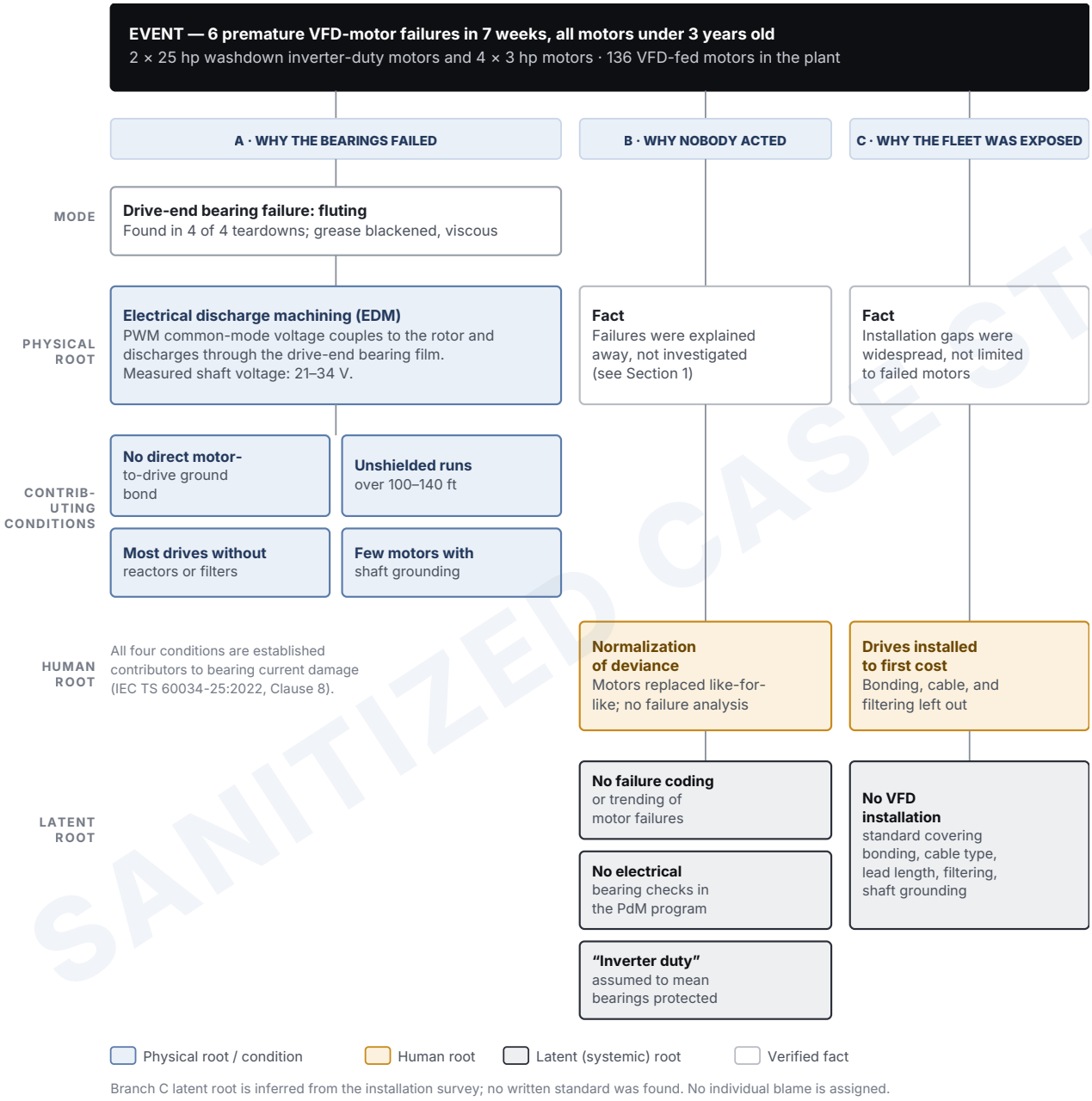
TABLE 2.1 — EVIDENCE REGISTER

ID	EVIDENCE	RESULT	STATUS
EV-01	Bearing teardowns (4 motors)	Drive-end (output shaft) bearings showed **fluting**, the washboard pattern of repeated electrical discharge (Figure 2.1)	CONFIRMED
EV-02	Drive-end grease condition	Blackened and highly viscous. Consistent with electrical degradation of the lubricant.	SUPPORTED
EV-03	Shaft voltage, suspect motors	**21–34 V**, measured with a Rigol DHO814 oscilloscope and shaft-voltage probe. Consistent with VFD-induced EDM. For context, NEMA MG 1 Part 31 cites 300 mV peak for bearing insulation on large motors (a different mechanism).	CONFIRMED
EV-04	Motor-to-drive grounding	Many VFDs had no direct ground bond to their motors	CONFIRMED
EV-05	Motor cable	Many unshielded runs from drive to motor exceeded 100 ft, and some exceeded 140 ft	CONFIRMED
EV-06	Drive filtering	Most drives had no reactors or filters	CONFIRMED
EV-07	Shaft grounding	Only a few motors in the plant had shaft grounding brushes	CONFIRMED
EV-08	Motor rating	The failed 25 hp motors were inverter-duty. That rating protects winding insulation, not bearings.	CONFIRMED

SANITIZED CASE STUDY

3 Cause-and-Effect Logic Tree

The tree has three branches: why the bearings failed, why nobody acted on the pattern, and why the whole VFD fleet carried the same exposure.



Branch C latent root is inferred from the installation survey; no written standard was found. No individual blame is assigned.

SANITIZED CASE STUDY

ROOT CAUSE STATEMENT

Physical: VFD common-mode voltage discharged through drive-end bearings (EDM), producing fluting and grease breakdown. **Contributing:** no direct motor-to-drive bonding, long unshielded runs, little drive filtering, and almost no shaft grounding. **Human:** failures were normalized and motors replaced like-for-like. **Latent:** no VFD installation standard, no failure coding or trending, no electrical bearing checks in PdM, and a belief that “inverter duty” meant protected bearings.

Sanitized case study · Multi-line food manufacturing plant · Apex Reliability Engineering
Sanitized account of an actual investigation. Site, people, and identifying details removed; costs are approximate.

4 Red-Flag Screening and Recommendations

With 136 VFD motors exposed, the practical question was where to start. A red-flag list ranked motors by the established contributors to shaft voltage and bearing current, each with a recommendation.

TABLE 4.1 — SCREENING FACTORS USED FOR THE RED-FLAG LIST

FACTOR	WHY IT RAISES RISK
No direct motor-to-drive ground bond	High-frequency current lacks a low-impedance return path and finds one through the bearings and driven equipment
Unshielded cable, especially over 100–140 ft	Long, unshielded leads increase reflected-wave voltage and common-mode current, and give the current no defined return path
No drive output filtering	Nothing limits voltage rise time or common-mode content reaching the motor
No shaft grounding	Shaft voltage builds until it discharges through the bearing film
Failure history or measured shaft voltage	Direct evidence that damage is already happening
Criticality and redundancy	Sets the cost of a failure; the 25 hp washdown motors had no redundancy

TABLE 4.2 — RECOMMENDATIONS

RECOMMENDATION	WHAT IT DOES	PRIORITY
Direct motor-to-drive bonding	Gives high-frequency current a defined return path that bypasses the bearings	All red-flag motors
Shielded VFD cable	Contains and returns common-mode current; specified for new installs and replacements	Runs over 100 ft first
Shaft grounding rings	Bleeds shaft voltage to ground before it can discharge through the bearing	Red-flag motors; all new VFD motors
Drive output filtering (load reactor, dV/dt, or common-mode filter)	Reduces voltage stress and common-mode content on long leads	Long runs and critical motors
VFD installation standard	Makes bonding, cable type, maximum lead length, filtering, and shaft grounding the default	Before the next project
Failure coding and shaft-voltage checks	Lets the next cluster be seen early and gives PdM an electrical bearing check	Ongoing

Guidance basis: IEC TS 60034-25:2022, Clause 8 (bearing currents in converter-fed machines); NEMA MG 1 Part 31 (definite-purpose inverter-fed polyphase motors).

SANITIZED CASE STUDY

5 The Financial Case

The plant's records could not support a reliable baseline failure rate, because motor failures were not coded. That gap is itself a finding. The case is therefore made as break-even: how much mitigation one avoided failure pays for.

TABLE 5.1 — KNOWN COST OF THE TRIGGER CLUSTER

ITEM	PER 25 HP FAILURE	TWO FAILURES
Motor replacement	$30,000	$60,000
Downtime (5.5–7 h)	$15,000	$30,000
Total	**$45,000**	**$90,000**

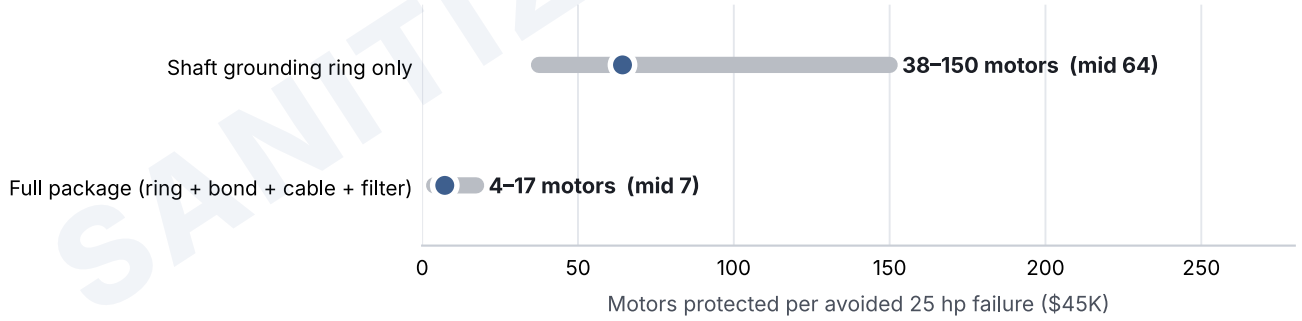
The four 3 hp failures are excluded. Redundancy kept their cost lower, and it was not quantified.

TABLE 5.2 — MITIGATION COST PER MOTOR (PLANNING-LEVEL ESTIMATES, NOT FROM THE INVESTIGATION)

MEASURE	LOW	MID	HIGH
Shaft grounding ring, installed	$300	$700	$1,200
Motor-to-drive bonding correction	$200	$500	$1,000
Shielded VFD cable re-pull (100–150 ft)	$1,500	$3,500	$6,000
Output reactor or filter	$600	$1,500	$3,500
Full package, one motor	**$2,600**	**$6,200**	**$11,700**

ESTIMATE Typical small-to-mid-size motor and drive pricing, including labor. Validate with quotes; cable cost varies most with run length and routing.

FIGURE 5.1 — MOTORS PROTECTED BY THE COST OF ONE AVOIDED 25 HP FAILURE



BREAK-EVEN IN PLAIN TERMS

One avoided 25 hp failure ($45,000) pays for the full package on 4–17 motors, or shaft grounding rings on 38–150. Rings for all 136 VFD motors would cost an estimated $41K–$163K, in the same range as the $90K the two 25 hp failures cost in seven weeks.

SANITIZED CASE STUDY

6 Outcome, Limitations, and Lessons

This case reports what the evidence showed and what was recommended. It does not claim results that were never verified.

TABLE 6.1 — LIMITATIONS

GAP	EFFECT ON CONCLUSIONS
Implementation and results not verified; the investigator left the site first	No post-mitigation failure rate or shaft-voltage data is claimed
Four motors torn down, out of six failures	The damage mode is confirmed for those four. The other two are attributed by shared conditions, not physical evidence.
Grease condition assessed visually, not by lab analysis	Electrical degradation of the grease is graded Supported, not Confirmed
Washdown exposure not ruled out as a co-factor	It does not explain fluting, but it may shorten bearing life further
No coded failure history	No baseline failure rate, so the financial case is made as break-even

WHAT THIS CASE SHOWS

FOR PLANT LEADERSHIP

A cluster of failures is a signal, even when every individual failure has a convenient explanation. Ask for one teardown before accepting “that's normal here.”

FOR MAINTENANCE MANAGERS

“Inverter duty” protects windings, not bearings. If your VFD installations lack bonding, shielded cable, or shaft grounding, check your drive-end bearings and measure shaft voltage before the next failure.

FOR FINANCE

The two 25 hp failures alone cost about as much as protecting every VFD motor in the plant with shaft grounding rings. Prevention here is a small, one-time cost per motor.

TABLE 6.2 — STANDARDS AND REFERENCES

REFERENCE	TITLE AND USE
IEC TS 60034-25:2022	Rotating electrical machines — Part 25: AC electrical machines used in power drive systems — Application guide. Clause 8: bearing currents and prevention.
NEMA MG 1, Part 31	Definite-purpose inverter-fed polyphase motors. Shaft voltage and bearing current guidance.
ISO 15243:2017	Rolling bearings — Damage and failures — Terms, characteristics and causes. Classification of fluting as electrical erosion.

SANITIZED CASE STUDY

FAILURE MODES, EFFECTS AND CRITICALITY ANALYSIS (FMECA)

Line 3 Cup Filler System: Risk-Ranked Maintenance Strategy

29 failure modes across 10 subsystems, ranked by annualized dollar risk and food-safety consequence, converted into a funded maintenance strategy.

SAMPLE — FICTIONAL DAT

CLIENT	Larkspur Valley Foods, Inc. — Plant 2 (cultured dairy)
SYSTEM	Line 3 cup filler, from product infeed through case-packer infeed, including its CIP and utility interfaces
REPORT NO.	FMECA-2026-007 · Revision 0 · Issued November 20, 2026
DATA BASIS	24 months of CMMS and downtime history (Nov 2024 – Oct 2026), OEM manuals, plant finance FY2026 standards, and team workshops
METHOD	IEC 60812:2018 FMECA, with criticality ranked in annualized dollars and food-safety, personnel-safety, and regulatory overrides
RELATED WORK	RCA-2026-014 (GR-305 gearbox), whose corrective actions are funded separately and excluded from this business case
TEAM	Apex Reliability Engineering (facilitator) · Maintenance Supervisor · Line 3 Lead Mechanic · Controls Technician · Line 3 Production Supervisor · Food Safety & QA Manager · Plant Controller (financial validation)

Demonstration document. Sample report. All company names, people, data, and financial figures are fictional and shown for demonstration only. The structure, methods, and level of detail match Apex Reliability Engineering client deliverables.

Executive Summary

Decision brief for the Plant Manager and Plant Controller. Sections 1–6 contain the supporting detail.

BOTTOM LINE

Line 3's filler carries **$367.1K a year in failure risk**, and ten failure modes account for 70% of it. A targeted package of 23 maintenance tasks and design fixes costs **$49.5K up front and $14.3K a year**. It is expected to cut risk by $194.8K a year and pays back in **3.3 months**. Four failure modes are deliberately left to run to failure because no task pays for itself.

ANNUALIZED RISK TODAY	CLASS A FAILURE MODES	CASH OUTLAY REQUESTED	PAYBACK, EXPECTED CASE	5-YEAR NPV AT 10%
$367.1K	**12**	**$49.5K**	**3.3 mo**	**$635K**
29 failure modes, 10 subsystems	7 raised to A for food safety, safety, or regulatory reasons	Plus $14.3K/yr recurring maintenance budget	Range 2.6–7.5 months	Range $251K–$820K

DECISIONS REQUESTED

1. **Approve $17.5K CAPEX** for four design changes (FM-01, 17, 22, 29) and **$5.7K** in critical spares inventory.
2. **Raise the Line 3 maintenance budget by $14.3K a year** for new condition-based and time-based tasks. The expected return is 14× the added cost.
3. **Endorse run-to-failure** for FM-10, 19, 23, and 26, each with a spare or exchange plan.

WHAT THE ANALYSIS SHOWS

- FINDING The largest single risk, the GR-305 gearbox ($72.0K/yr), is already being fixed under RCA-2026-014. The rest of the line carries $295.1K/yr.
- FINDING Seal-integrity modes (FM-11, 12, 13) cost $40.1K/yr, mostly in held product rather than downtime. Their risk would not show up in a downtime report.
- JUDGMENT 7 modes have modest dollar risk but are treated as Class A because they touch food safety, guarding, or labeling. They are funded regardless of ROI.

FINANCIAL SUMMARY (PRE-TAX)

	CONSERV.	EXPECTED	HIGH
Risk avoided / yr	$93.5K	$194.8K	$243.6K
Net annual benefit	$79.2K	$180.5K	$229.3K
Payback (months)	7.5	3.3	2.6
5-yr NPV at 10%	**$251K**	**$635K**	**$820K**

Break-even: the package pays for itself if tasks deliver just 14% of their rated risk reduction.

CONFIDENCE

MODERATE Failure frequencies come from CMMS records that lack failure coding (RCA-2026-014, LR-6), so minor stops are likely under-recorded. Task effectiveness factors are engineering estimates. The conservative case cuts both, and it still pays back in 7.5 months.

SAMPLE — FICTIONAL D

1 Scope and Method

The analysis covers the whole filler system as the plant constraint sees it: everything whose failure stops Line 3, degrades the product, or puts food safety at risk.

TABLE 1.1 — SYSTEM BOUNDARY AND RESULTS BY SUBSYSTEM

SUBSYSTEM	FAILURE MODES	CLASS A	ANNUAL RISK TODAY	AFTER PACKAGE
Main drive	3	1	$90,899	$78,077
Conveying	4	1	$49,378	$16,020
Product infeed	3	1	$47,308	$15,933
Sealing	4	3	$45,294	$12,286
Dosing	2	1	$32,858	$10,247
Sanitation	2	2	$29,614	$5,189
Cup handling	3	0	$23,934	$13,384
Controls	4	1	$18,214	$6,563
Inspection	2	2	$15,342	$7,417
Utilities	2	0	$14,268	$7,150
Total	**29**	**12**	**$367,109**	**$172,266**

"After package" keeps GR-305 (FM-04) at today's risk, because its fix is credited to RCA-2026-014 and not to this business case.

WHY DOLLARS INSTEAD OF RPN

A risk priority number multiplies three ordinal 1–10 scores, so equal RPNs can hide very different risks, and an RPN cannot be compared with a budget. IEC 60812:2018 allows criticality-matrix methods as well as RPN. Here each mode is ranked by **annualized risk = failures per year × cost per failure**, which puts every mode on the same scale as the money needed to treat it.

HOW CONSEQUENCE IS VALUED

Cost per failure = downtime hours × $2,615/h + parts and labor + product loss. The $2,615/h blended rate assumes 50% of lost volume is recovered on overtime ($610/h) and 50% is lost at contribution margin ($4,620/h), the same basis as RCA-2026-014.

OVERRIDE RULES

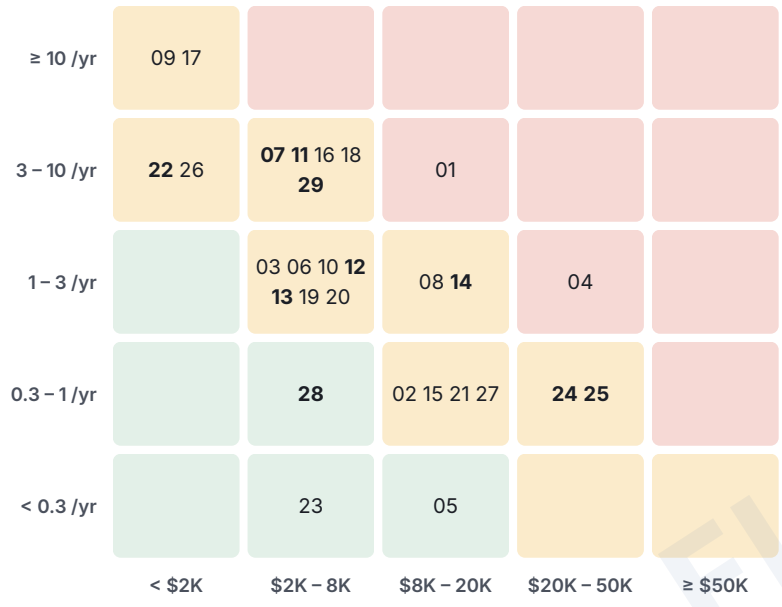
Any mode that can put food safety (F), personnel safety (S), or labeling compliance (R) at risk is Class A whatever its dollar value. Its treatment is justified on risk acceptance, not ROI. Dollar classes: A ≥ $20K/yr, B $5K–20K/yr, C < $5K/yr.

SAMPLE — FICTIONAL D

2 Criticality Results

Risk is concentrated: ten modes carry 70% of the total. The matrix shows where each mode sits; the Pareto ranks them in dollars.

FIGURE 2.1 — CRITICALITY MATRIX (FREQUENCY × COST PER FAILURE)

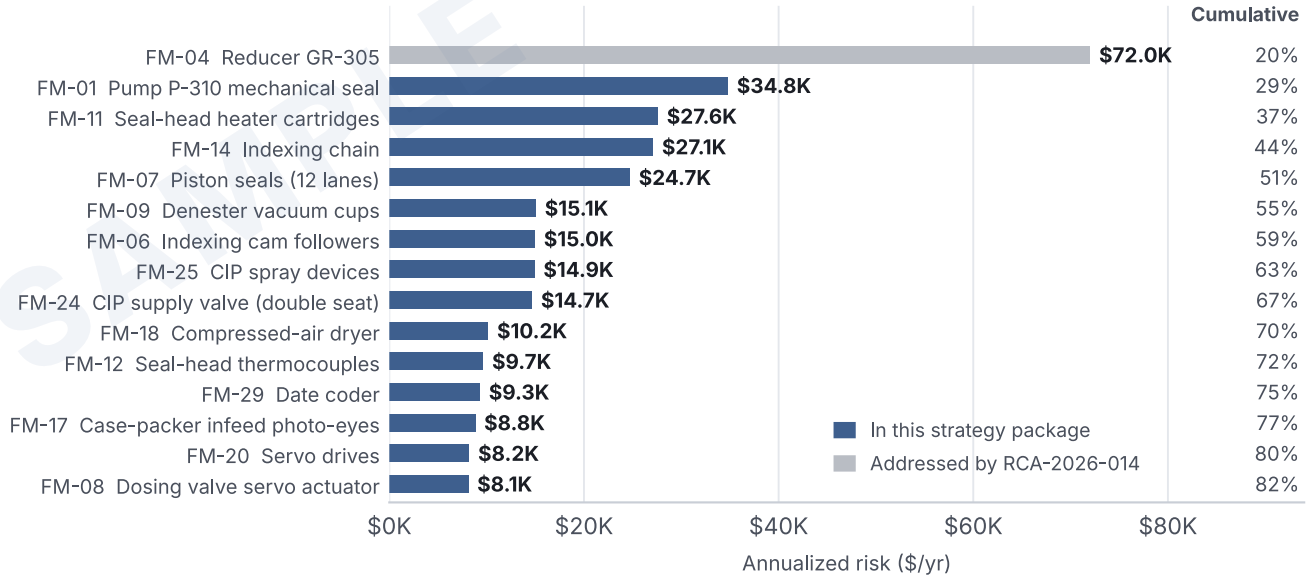


READING THE MATRIX

Rows are failures per year and columns are cost per failure. Shading shows the combined band score: HIGH 7 or more, MEDIUM 5–6, LOW 4 or less. **Bold** IDs carry a food-safety, safety, or regulatory flag.

The matrix is a screening view. Two modes in the same cell can differ in risk by a factor of three, so funding follows the dollar ranking in Figure 2.2. For example, FM-25 and FM-24 sit in a medium cell, but each carries more than $14K/yr in risk.

FIGURE 2.2 — PARETO OF ANNUALIZED RISK, TOP 15 FAILURE MODES



SAMPLE — FICTIONAL DATA

3 FMECA Worksheet

The twelve highest-risk modes in full worksheet form. The remaining 17 are summarized on the next page; the complete worksheet is maintained in the plant CMMS.

ID	ITEM · FAILURE MODE	EFFECT	CAUSE	CURRENT DETECTION	PER YR	$ / FAILURE	$ / YR	CLASS
FM-04	**Reducer GR-305** Bearing seizure from water ingress	Line stop 10–41 h	Washdown ingress (RCA-2026-014)	None	1.8	$39,358	**$72,025**	A
FM-01	**Pump P-310 mechanical seal** Seal leak	Product loss; line stop to replace seal	Dry running after CIP; face wear	Visual	3.0	$11,602	**$34,806**	A
FM-11	**Seal-head heater cartridges** Heater open circuit	Incomplete lid seal; leakers held	Thermal fatigue	Hourly leak check	4.0	$6,902	**$27,608**	A · F
FM-14	**Indexing chain** Elongation / wear	Mis-index; metal wear debris	Wear; lubrication	None	1.5	$18,075	**$27,112**	A · F
FM-07	**Piston seals (12 lanes)** Seal wear	Fill variation; seal fragments in product	Abrasive wear	Checkweigher rejects	8.0	$3,091	**$24,728**	A · F
FM-09	**Denester vacuum cups** Wear / loss of grip	Misfeeds; minor stops	Wear	Minor-stop count	12.0	$1,256	**$15,072**	B
FM-06	**Indexing cam followers** Bearing wear	Mis-index; cup damage	Wear; grease washout	Noise (operator)	2.0	$7,488	**$14,976**	B
FM-25	**CIP spray devices** Blocked / not rotating	Incomplete clean; micro hold	Debris; bearing wear	Visual post-CIP	0.60	$24,890	**$14,934**	A · F
FM-24	**CIP supply valve (double seat)** Leak-by	Cleaning solution in product	Seal wear	None	0.50	$29,360	**$14,680**	A · F
FM-18	**Compressed-air dryer** Wet air (dryer bypassed)	Valve sticking; erratic motion	Dryer fault; drains	None	4.0	$2,542	**$10,168**	B
FM-12	**Seal-head thermocouples** Drift low	Under-temperature seals	Junction degradation	None	2.0	$4,828	**$9,656**	A · F
FM-29	**Date coder** Missing or wrong code	Rework; label non-compliance	Printhead; setup	Manual check	3.0	$3,108	**$9,324**	A · R

Class pills show the final class. A flag letter (F food safety, S personnel safety, R regulatory) marks a mode raised by an override.

SAMPLE — FICTIONAL DATA

3 FMECA Worksheet (continued)

The remaining modes, with the strategy selected for each. Low-risk modes still get a deliberate decision, even when that decision is to run to failure.

ID	ITEM · FAILURE MODE	PER YR	$ / YR	CLASS	SELECTED STRATEGY
FM-02	**Pump P-310 motor bearing** · Bearing failure	0.50	$6,330	B	Monthly vibration route
FM-03	**Balance-tank level transmitter** · Drift / failure	1.5	$6,172	B	Quarterly calibration check
FM-05	**Motor M-305 winding** · Insulation failure	0.20	$3,898	C	Quarterly IR scan + annual PI test
FM-08	**Dosing valve servo actuator** · Actuator failure	1.0	$8,130	B	Stock one actuator; track run hours
FM-10	**Denester air cylinder** · Cylinder failure	1.2	$3,678	C	Run to failure with one spare on hand
FM-13	**Seal pressure regulator** · Pressure drift	1.0	$2,808	A · F	Monthly pressure verification
FM-15	**Chain sprockets** · Tooth wear	0.40	$5,950	B	Inspect with FM-14 check
FM-16	**Discharge belt** · Tracking / belt damage	3.0	$7,476	B	Weekly belt inspection
FM-17	**Case-packer infeed photo-eyes** · Contamination / failure	20.0	$8,840	B	Replace with IP69K sensors
FM-19	**Valve-bank solenoids** · Coil failure	2.0	$4,100	C	Run to failure; spares on hand
FM-20	**Servo drives** · Over-temperature trip	2.5	$8,220	B	Monthly cabinet filter PM + IR scan
FM-21	**PLC I/O card** · Card failure	0.30	$2,924	C	Stock one I/O card
FM-22	**Guard-door interlocks** · Switch failure	6.0	$5,544	A · S	Coded RFID interlocks; annual proof test
FM-23	**HMI panel** · Touchscreen failure	0.20	$1,526	C	Run to failure; vendor exchange
FM-26	**Cup magazine guides** · Wear	6.0	$5,184	B	Run to failure
FM-27	**Lid-feed vacuum pump** · Pump failure	0.50	$5,222	B	Add to vibration route
FM-28	**Checkweigher load cell** · Drift / failure	0.80	$6,018	A · R	Keep daily verification; no change

RUN-TO-FAILURE IS A DECISION, NOT A DEFAULT

FM-10, 19, 23, and 26 have no task cheaper than the failures it would prevent, and none carries a food-safety, safety, or regulatory flag. Each has a spare or vendor exchange in place to keep downtime short. FM-28 keeps its existing daily verification, which already controls its regulatory risk.

SAMPLE · FICTIONAL D

4 Recommended Maintenance Strategy

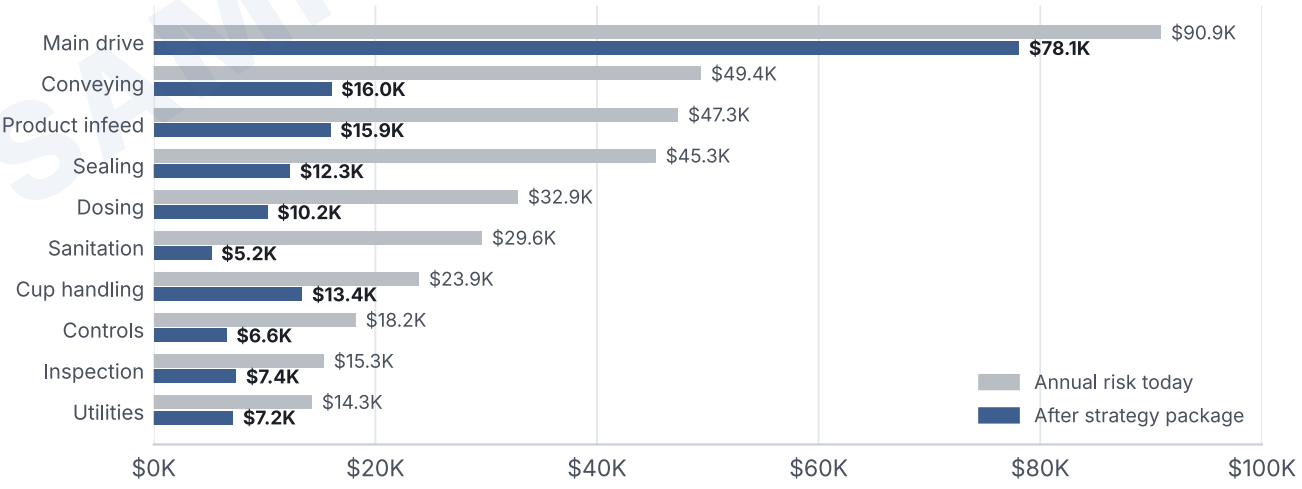
23 tasks grouped by strategy type. Condition-based tasks are chosen where a detectable warning precedes failure, time-based tasks where wear is predictable, and redesign where no task can manage the risk well enough.

TABLE 4.1 — STRATEGY PACKAGE BY TASK TYPE

STRATEGY	FAILURE MODES	TYPICAL TASKS	ONE-TIME	PER YEAR	RISK AVOIDED/YR
Redesign	FM-01, FM-17, FM-22, FM-29	Dry-run interlock, IP69K sensors, coded RFID interlocks, vision code check	$17,500	$0	$42,056
Condition-based	FM-02, FM-05, FM-06, FM-11, FM-14, FM-15, FM-18, FM-25, FM-27	Vibration and ultrasound routes, IR scans, heater-current and dew-point alarms, chain gauging, spray rotation sensors	$12,300	$2,880	$82,183
Time-based	FM-03, FM-07, FM-09, FM-12, FM-13, FM-16, FM-20, FM-24, FM-28	Seal replacements, calibration checks, proof tests, inspections, filter PMs	$0	$10,280	$65,077
Spares	FM-08, FM-21	Servo actuator and PLC I/O card on the shelf	$4,800	$0	$5,527
Run to failure	FM-10, FM-19, FM-23, FM-26	Spare or vendor exchange on hand; no PM	$900	$0	$0
Total			**$35,500**	**$13,160**	**$194,843**

One-time figures exclude 180 h of implementation labor ($14,040), which appears in Section 5. Spares include the FM-10 spare, which supports a run-to-failure decision.

FIGURE 4.1 — ANNUAL RISK BY SUBSYSTEM, BEFORE AND AFTER THE PACKAGE



SAMPLE — FICTIONAL D

Larkspur Valley Foods, Inc. — Plant 2 · Confidential, client internal · Prepared by Apex Reliability Engineering
Sample report. All company names, people, data, and financial figures are fictional and shown for demonstration only.

5 Financial Justification

A $49.5K outlay and $14.3K of added annual OPEX return a positive 5-year NPV in every scenario. Most of the return is avoided lost margin; the maintenance budget goes up while total cost of operation goes down.

TABLE 5.1 — INVESTMENT AND ACCOUNTING TREATMENT

ITEM	CLASS	AMOUNT	ACCOUNTING TREATMENT
Design changes (FM-01, 17, 22, 29)	CAPEX	$17,500	Betterments; capitalization subject to Controller review against the plant threshold
Critical spares (FM-08, 10, 21)	INVENTORY	$5,700	MRO inventory; P&L impact is carrying cost until issued
Monitoring hardware (FM-11, 18, 25)	OPEX	$12,300	Expensed. FM-11 ($6,800) could be capitalized at Controller discretion.
Implementation labor, 180 h	OPEX	$14,040	CMMS task build, routes, procedures, training. Mostly non-incremental; included so cost is not understated.
Total cash outlay (year 0)		**$49,540**	
Recurring task cost (parts, labs, labor)	OPEX/YR	$13,160	New maintenance budget line for Line 3
Spares carrying cost (20%)	OPEX/YR	$1,140	20% of inventory value per year

TABLE 5.2 — SCENARIO ANALYSIS (PRE-TAX, 5-YEAR HORIZON, 10% HURDLE RATE)

	CONSERVATIVE	EXPECTED	HIGH IMPACT
Rated risk reduction (expected frequencies)	$194,843	$194,843	$194,843
Frequency adjustment	-20%	+0%	+25%
Task effectiveness realized	60%	100%	100%
Risk avoided per year	**$93,525**	**$194,843**	**$243,554**
Recurring OPEX added	($14,300)	($14,300)	($14,300)
Net annual benefit	**$79,225**	**$180,543**	**$229,254**
Payback (months, undiscounted)	7.5	3.3	2.6
5-year NPV at 10%	**$250,785**	**$634,860**	**$819,513**
IRR	> 100%	> 100%	> 100%
PV benefit ÷ outlay	6.1×	13.8×	17.5×

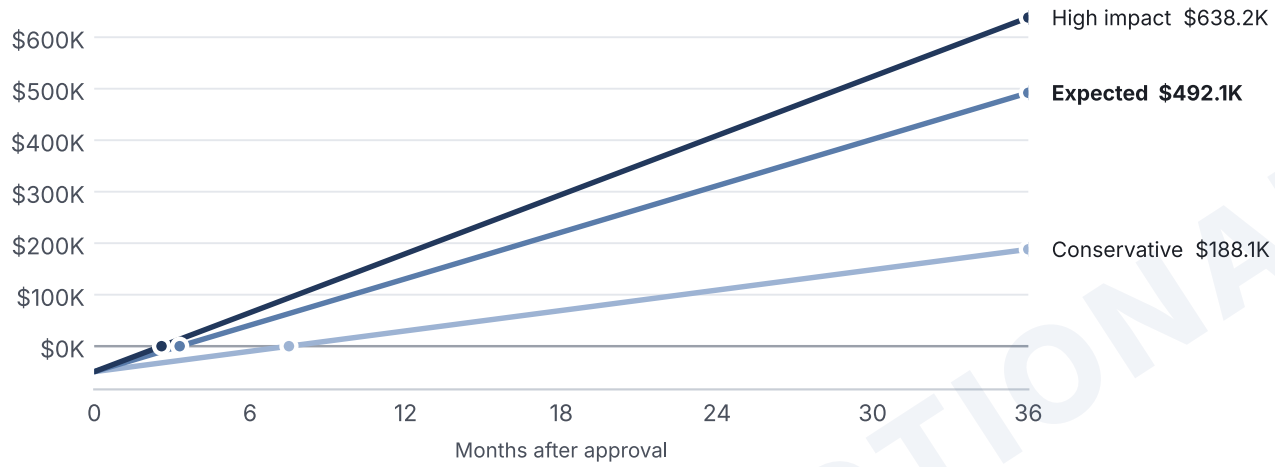
Conservative: Frequencies 20% lower than the CMMS history shows; tasks deliver 60% of their rated risk reduction. **Expected:** Frequencies as in the CMMS history; tasks deliver their rated risk reduction. **High impact:** Frequencies 25% higher (minor stops under-recorded); tasks deliver their rated reduction.

SAMPLE — FICTIONAL D

5 Financial Justification (continued)

The cash curve, the stress tests, and the break-even point all lead to the same conclusion: the case holds under pessimistic assumptions.

FIGURE 5.1 — CUMULATIVE NET CASH POSITION BY SCENARIO (UNDISCOUNTED)



Dots on the zero line mark payback. Line ends show the cumulative position at 36 months.

TABLE 5.3 — STRESS TESTS ON THE CONSERVATIVE CASE

STRESS APPLIED	5-YEAR NPV
Base case (Conservative)	**$250,785**
Downtime cost rate −25%	$190,249
One-time cost +30%	$235,923
Recurring task cost +30%	$234,523
Discount rate 15%	$216,034

The largest sensitivity is the downtime cost rate, because about 68% of avoided cost is downtime.

BREAK-EVEN

NPV reaches zero if the tasks deliver **14% of their rated risk reduction**. The conservative case already assumes 60%.

CONSERVATISM IN THESE FIGURES

Figures are pre-tax and unlevered, with no depreciation tax shield or spares salvage value. They exclude GR-305 (credited to RCA-2026-014) and any quality or customer-confidence benefit beyond recorded product loss.

SAMPLE — FICTIONAL D

6 Implementation and Verification

A 90-day rollout, scheduled into existing sanitation windows so no production time is lost.

TABLE 6.1 — 90-DAY IMPLEMENTATION PLAN

WINDOW	WORK	OWNER
Days 0–30	Load all 23 tasks, routes, and acceptance criteria into the CMMS; order spares and hardware; add failure-mode codes for all 29 modes	Planner · Reliability Engineer
Days 31–60	Install the design changes and monitoring hardware during sanitation windows; first condition-monitoring baselines	Maintenance Supervisor · Controls
Days 61–90	Train crews; QA sign-off on seal-integrity and CIP tasks; first monthly risk review	Reliability Engineer · QA

TABLE 6.2 — VERIFICATION OF EFFECTIVENESS

MEASURE	TARGET	OWNER · CADENCE
Realized annual risk, Line 3 filler	≤ $172.3K/yr by month 12 (from failure-coded work orders)	Reliability · monthly
PM and route compliance	≥ 95% completed on time	Planner · weekly
Seal-integrity holds (FM-11, 12, 13)	≥ 70% fewer held lots than the trailing 12 months	QA · monthly
Minor stops (FM-09, 17)	≥ 60% fewer, measured from line counters	Production · weekly
FMECA review	Re-rank annually, or after any Class A failure	Reliability · annual

TABLE 6.3 — LIMITATIONS AND THEIR EFFECT ON CONCLUSIONS

GAP	EFFECT
CMMS history has no failure coding; frequencies were reconstructed from work-order text and downtime logs	Minor stops are likely under-recorded, so true risk is probably higher. This is covered by the high-impact case.
Task effectiveness factors are engineering estimates INFERENCE	The conservative case assumes 60% effectiveness; break-even is 14%.
Recovery share of 50% assumed for all modes	Mode-level recovery varies. A 25% lower downtime rate still leaves the conservative NPV positive (Table 5.3).

SAMPLE — FICTIONAL D

Sample report. All company names, people, data, and financial figures are fictional and shown for demonstration only.

A Rating Bands, References, and Approval

Scales used in the criticality matrix, the standards applied, and sign-off.

TABLE A.1 — FREQUENCY BANDS

BAND	FAILURES PER YEAR
5	≥ 10 /yr
4	3 – 10 /yr
3	1 – 3 /yr
2	0.3 – 1 /yr
1	< 0.3 /yr

TABLE A.2 — CONSEQUENCE BANDS (COST PER FAILURE)

BAND	COST PER FAILURE
5	≥ $50K
4	$20K – 50K
3	$8K – 20K
2	$2K – 8K
1	< $2K

TABLE A.3 — STANDARDS AND REFERENCES

REFERENCE	TITLE AND USE
IEC 60812:2018	Failure modes and effects analysis (FMEA and FMECA). Analysis method; criticality-matrix approach.
ISO 14224:2016	Petroleum, petrochemical and natural gas industries — Collection and exchange of reliability and maintenance data for equipment. Failure-mode taxonomy adapted for CMMS coding.
21 CFR 117.35, 117.40	Current Good Manufacturing Practice — Sanitary operations; Equipment and utensils. Basis for food-safety (F) overrides.
21 CFR 178.3570	Lubricants with incidental food contact. H1 lubricant requirement in conveying tasks (FM-14).
RCA-2026-014	Root Cause Failure Analysis, GR-305 filler main drive. Source of FM-04 data; consequence valuation basis.

REVIEW AND APPROVAL

Prepared by
Lead Reliability Engineer, Apex Reliability Engineering
Signature _____ Date _____

Food safety review
Food Safety & QA Manager
Signature _____ Date _____

Financials validated by
Plant Controller
Signature _____ Date _____

Approved by
Plant Manager
Signature _____ Date _____

SAMPLE — FICTIONAL D

Larkspur Valley Foods, Inc. — Plant 2 · Confidential, client internal · Prepared by Apex Reliability Engineering
Sample report. All company names, people, data, and financial figures are fictional and shown for demonstration only.

SINGLE-ASSET RELIABILITY ROI ESTIMATE

Homogenizer HG-1: Maintain, Monitor, or Replace?

A Weibull analysis of failure history and a 10-year lifecycle-cost comparison of four options for the plant's highest-risk process asset, with an after-tax view and a pre-agreed rebuild-or-replace trigger.

SAMPLE — FICTIONAL DAT

CLIENT	Larkspur Valley Foods, Inc. — Plant 2 (cultured dairy)
ASSET	HG-1 homogenizer (register P-02, tier A), feeding all filling lines
REPORT NO.	ROI-2026-005 · Revision 0 · Issued December 11, 2026
DATA BASIS	10 valve and seal set failures (run-to-failure history), major-failure and overhaul records, OEM quotes, plant finance FY2026 standards
METHODS	Weibull analysis (IEC 61649:2008), age-replacement optimization, life cycle costing (IEC 60300-3-3:2017), NPV / IRR / EAC, after-tax with MACRS 7-year
RELATED WORK	CA-2026-003 ranks HG-1 the highest-risk process asset at about $100K/yr; this report reconciles to that baseline

Demonstration document. Sample report. All company names, people, data, and financial figures are fictional and shown for demonstration only. The structure, methods, and level of detail match Apex Reliability Engineering client deliverables.

Executive Summary

Decision brief for the Plant Manager and Plant Controller. Sections 1–6 contain the supporting detail.

BOTTOM LINE

HG-1's valve and seal failures are **wear-out failures (β = 3.2)**, so replacing the set on a schedule beats running it to failure. Doing that in sanitation windows, with oil and vibration routes, needs **no capital** and is worth **$300K** over 10 years. Adding online monitoring raises that to **$318K** for $28K of CAPEX, and gives the plant early warning on the $150K failure mode. **Replacing the homogenizer is not justified today.** A pre-agreed trigger (Section 5) says when it would be.

COST OF UNRELIABILITY TODAY	WEIBULL SHAPE (B)	RECOMMENDED (O2) NPV	O2 PAYBACK	REPLACE (O3) VS. O2
$99.1K/yr	**3.24**	**$318K**	**6.0 mo**	**−$141K**
Reconciles to CA-2026-003 within 1%	Wear-out; η = 3,222 h	Pre-tax, 10 yr; $236K after tax	On $28K monitoring CAPEX	NPV gap; O3 negative in conservative case

DECISIONS REQUESTED

1. **Implement O1 now:** planned valve and seal set changes every 1,500 operating hours, plus oil and vibration routes. No CAPEX; $2,400/yr in route costs.
2. **Approve $28K CAPEX for online monitoring** (O2) on crankcase bearings and seal leakage, at $3,000/yr.
3. **Adopt the rebuild-or-replace trigger** in Section 5, so a replacement decision can be made in days if a major failure occurs.

OPTIONS COMPARED (10-YEAR, PRE-TAX, 10%)

OPTION	PV OF COST	NPV VS. O0	EAC
O0 · Status quo	$713K	—	$116K
O1 · Optimized PM	$413K	$300K	$67K
O2 · Optimized PM + online monitoring	**$395K**	**$318K**	**$64K**
O3 · Replace with new homogenizer	$536K	$176K	$87K

EAC: equivalent annual cost, the PV of cost spread evenly over 10 years. Lowest is best.

THE HONEST READ ON MONITORING

Most of the value comes from O1, which needs no capital. Monitoring adds $18K of expected NPV on top of O1, and it loses to O1 in the conservative case. It is recommended as low-cost insurance on the $150K failure mode and as the data feed for the replace trigger, not as the main source of return.

SAMPLE — FICTIONAL DATA

1 Asset and Baseline

HG-1 sits upstream of every filling line. When it stops, the plant stops, which is why a $4K seal set can cost more than $33K when it fails in production.

TABLE 1.1 — ASSET PROFILE

ATTRIBUTE	DETAIL
Function	Homogenizes cultured base before filling; single unit, no bypass
Duty	About 6,000 operating h/yr; one full sanitation per day
Criticality	Tier A (P-02): production 5, repair 5
Downtime cost	$6,500/h (all filling lines idle, net of recovery)
Age and support	14 years; OEM parts supported; overhauls due in years 3 and 8 of this horizon

TABLE 1.2 — COST OF UNRELIABILITY TODAY (STATUS QUO)

FAILURE TYPE	PER YR	$ / FAILURE	$ / YR
Valve and seal set, run to failure	2.08	$33,268	$69,131
Major mechanical failure	0.20	$150,000	$30,000
Total			**$99,131**

Valve and seal failure rate = 6,000 h ÷ Weibull mean life of 2,887 h. Cost per unplanned failure = parts $3,800 + labor + 4 h downtime + $3,000 product loss.

WHY THE SAME PART COSTS EIGHT TIMES MORE WHEN IT FAILS

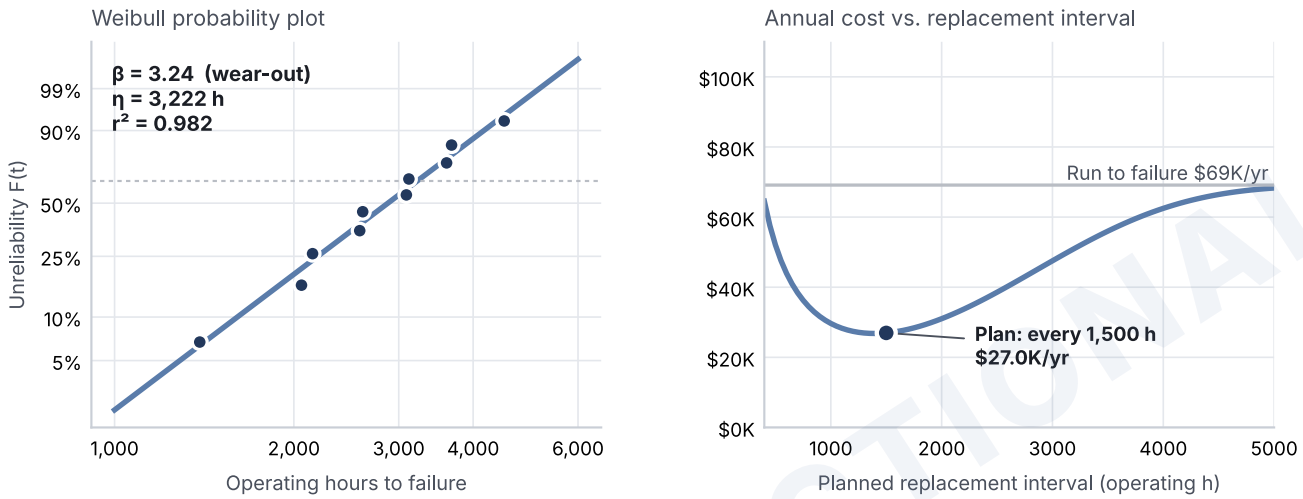
A planned set change in a sanitation window costs $4,268: parts and labor, with no lost production. The same change after an in-production failure costs $33,268. That 8:1 ratio, combined with wear-out behavior, is what makes planned replacement pay.

SAMPLE — FICTIONAL D

2 Failure Data Analysis

If failures were random (β ≈ 1), replacing parts early would waste money. They are not random: the risk of failure rises steeply with operating hours.

FIGURE 2.1 — WEIBULL FIT AND COST-OPTIMAL REPLACEMENT INTERVAL



Left: median-rank regression on 10 run-to-failure intervals. Right: expected annual cost of the valve and seal set by planned interval (age-replacement model), against run-to-failure cost.

TABLE 2.1 — WEIBULL RESULTS

PARAMETER	VALUE	MEANING
Shape β	3.24	Above 1 means wear-out; above 3 means strongly age-related
Scale η	3,222 h	63.2% of sets fail by this age
Mean life	2,887 h	About 5.8 months of operation
Fit (r^2)	0.982	Good linear fit on the Weibull plot

TABLE 2.2 — REPLACEMENT INTERVAL CHOICE

INTERVAL	RELIABILITY AT CHANGE	ANNUAL COST
Run to failure	—	$69,131
Mathematical optimum, 1,400 h	93%	$26,808
Recommended, 1,500 h	**92%**	**$26,967**

1,500 h lines up with a quarterly sanitation window and costs $158/yr more than the optimum, because the cost curve is flat near its minimum.

SAMPLE — FICTIONAL D

3 Options Evaluated

Four mutually exclusive options, each costed over the same 10-year horizon so they can be compared directly.

TABLE 3.1 — OPTIONS AND THEIR EFFECTS

OPTION	WHAT IT INCLUDES	CAPITAL	ANNUAL OPERATING COST
O0 · Status quo	Run seals and valves to failure; time-based lubrication; overhauls in years 3 and 8	$0	$99,131
O1 · Optimized PM	Planned valve and seal set change every 1,500 h in sanitation windows; quarterly oil analysis and monthly vibration route	$0	$50,367
O2 · Optimized PM + online monitoring	O1 plus wireless vibration and temperature on crankcase bearings and seal-leak detection, with alarms to the CMMS	$28,000	$42,867
O3 · Replace with new homogenizer	New unit with ceramic plungers and a higher-efficiency drive, plus O2 practices; old unit sold	$520,000	$6,732

Annual operating cost = task costs + expected failure cost + energy change, excluding overhauls. O3's figure is low because the new unit's energy savings ($18,000/yr) offset most of its failure and task costs.

TABLE 3.2 — KEY ASSUMPTIONS

ASSUMPTION	VALUE AND BASIS
Major-failure risk reduction	O1 30% (early detection by oil and vibration routes); O2 65% (continuous monitoring); O3 85% (new unit)
Valve and seal failures, O3	45% lower than O1/O2 (ceramic plungers, OEM data). ESTIMATE
Overhauls, existing unit	$85,000 in years 3 and 8 (OEM quote); none for O3 within the horizon
O3 capital	$520,000 installed, including removal; old unit sold for $25,000
Finance	10% pre-tax hurdle rate; 25% tax rate; MACRS 7-year depreciation; bonus depreciation excluded (Controller to confirm eligibility)

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4 Financial Analysis

On lifecycle cost, O2 is lowest, O1 is a close second with no capital, and replacement costs more than either over 10 years.

FIGURE 4.1 — 10-YEAR PRESENT VALUE OF COST BY OPTION

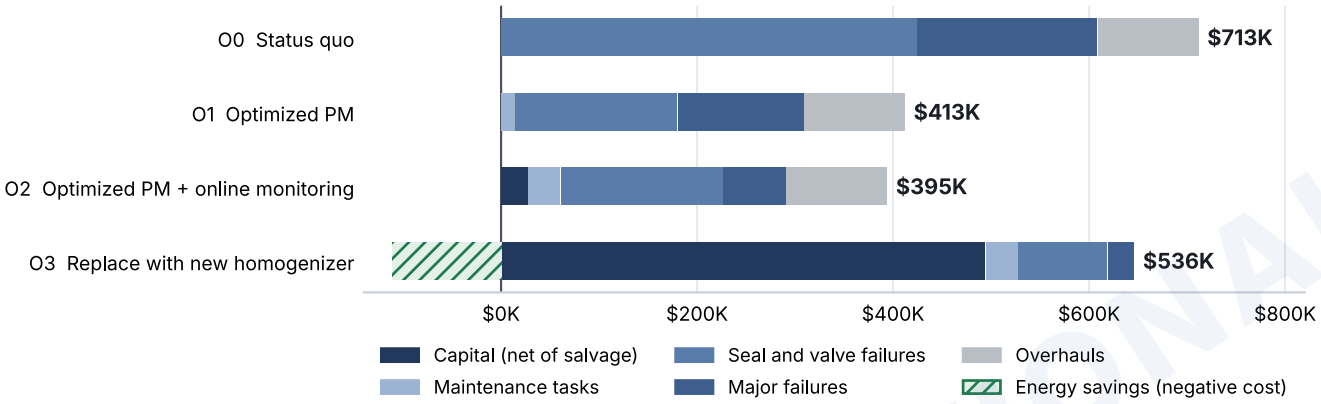


TABLE 4.1 — INCREMENTAL RETURNS AGAINST THE STATUS QUO

	O1	O2	O3
Year-0 investment	$0	$28,000	$495,000
Year-1 savings vs. O0	$48,764	$56,264	$92,399
NPV, pre-tax	**$299,636**	**$317,720**	**$176,269**
NPV, after tax	$224,727	$236,340	$102,241
IRR	n/a	> 100%	18%
Payback	Immediate	6.0 mo	53.2 mo
Profitability index (PV ÷ investment)	n/a	12.3×	1.4×

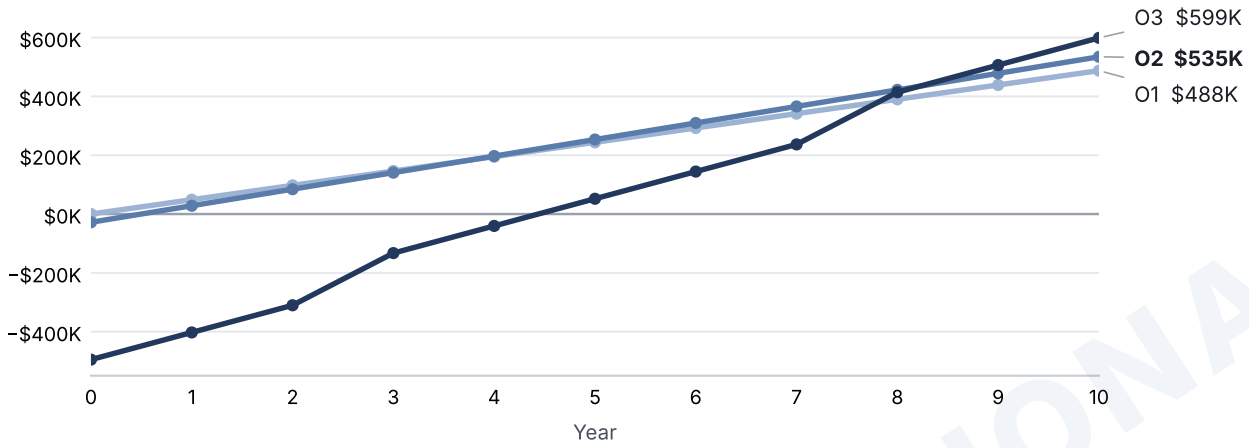
Choosing between O1 and O2: they are mutually exclusive, so the deciding figure is the increment. O2 over O1 is $18,084 of NPV (24% IRR) on $28,000. That is positive but modest. O1 has no investment, so IRR and payback do not apply to it.

SAMPLE — FICTIONAL D

4 Financial Analysis (continued)

How the options behave over time and under pessimistic assumptions.

FIGURE 4.2 — CUMULATIVE SAVINGS AGAINST THE STATUS QUO (UNDISCOUNTED)



O3 starts $495K down, crosses zero in year 5, and ends highest on undiscounted savings. Its savings arrive late, though, so on a discounted basis (Table 4.1) it trails O2 by $141K. The jumps in years 3 and 8 are the overhauls O3 avoids.

TABLE 4.2 — NPV BY SCENARIO (PRE-TAX)

SCENARIO	O1	O2	O3
Conservative	$136K	$121K	−$79K
Expected	**$300K**	**$318K**	**$176K**
High impact	$378K	$412K	$299K

Conservative: 60% of rated benefit, downtime cost −20%. **High impact:** downtime cost +25%. O3 is the only option that goes negative.

TABLE 4.3 — STRESS TESTS ON O2

STRESS APPLIED	NPV
Base case (expected)	**$317,720**
Only half of the rated benefit realized	$128,270
Downtime cost rate −30%	$204,050
Monitoring CAPEX doubled	$289,720
All of the above	$43,435

ACCOUNTING TREATMENT

O1 is entirely OPEX. O2's monitoring hardware ($28,000) is CAPEX, depreciated over 7 years under MACRS. O3 is CAPEX of $520,000, with a $25,000 disposal proceed; any gain or loss on disposal is for Controller review. After-tax NPVs include depreciation tax shields at 25% and exclude bonus depreciation.

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5 Recommendation and Replace Trigger

Maintain and monitor now. Decide in advance what would justify replacement, so that a major failure leads to a quick, prepared decision rather than an emergency purchase.

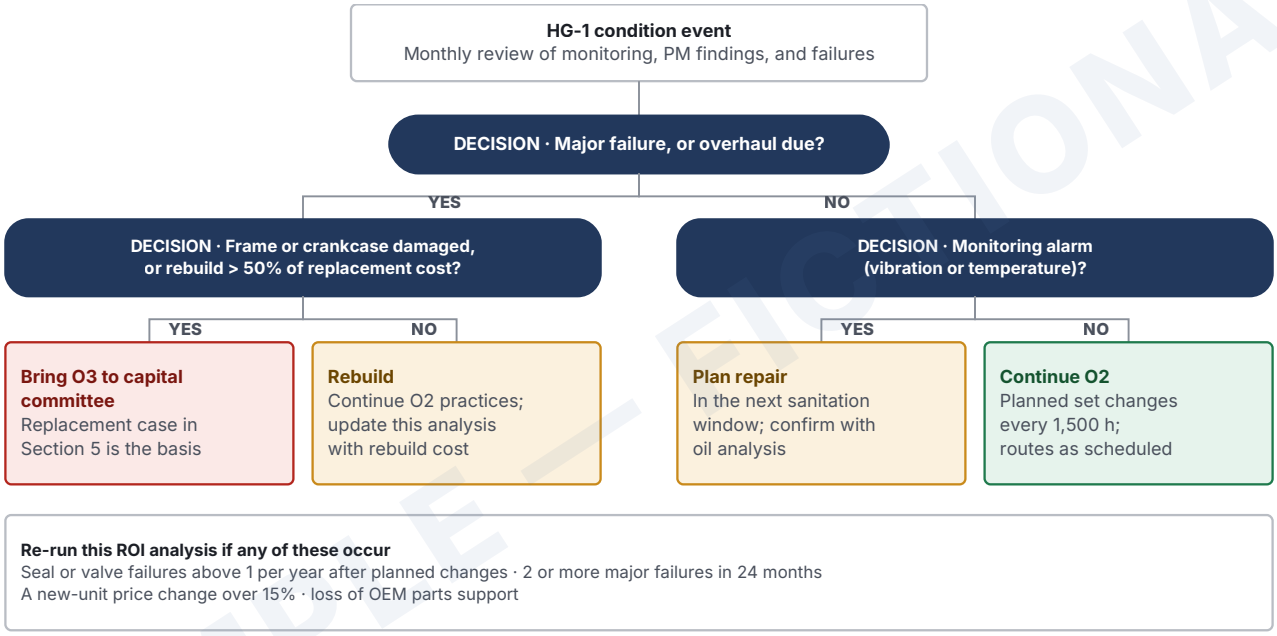
RECOMMENDATION

Adopt **O2**: implement O1's planned changes and routes immediately, and add online monitoring for $28,000. Expected NPV $317,720 pre-tax, $236,340 after tax.

WHY NOT REPLACE NOW

O3 trails O2 by $141,451 of NPV and goes negative in the conservative case. Its case gets stronger if a major failure damages the frame or if rebuild costs climb, and the trigger below covers both.

FIGURE 5.1 — DECISION TREE: REBUILD OR REPLACE HG-1



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6 Implementation, Verification, and Limitations

What gets done, how success is measured, and what the analysis cannot see.

TABLE 6.1 — IMPLEMENTATION

WINDOW	WORK	OWNER
Weeks 0–4	Create the 1,500 h set-change PM on run-hour meter; stock two seal and valve sets; add oil and vibration routes	Planner · Reliability
Weeks 4–10	Install wireless sensors on crankcase bearings and seal-leak detection; set alarm limits; route alarms to the CMMS	Controls · Reliability
Month 12	Compare realized failures and costs with the model; refit the Weibull with new data	Reliability · Controller

TABLE 6.2 — VERIFICATION MEASURES

MEASURE	TARGET
Unplanned valve and seal failures	≤ 1 per year (from 2.1)
Planned set changes on schedule	≥ 95% within ±10% of 1,500 h
HG-1 unplanned downtime	≥ 50% reduction against the trailing 12 months
Monitoring alarms acted on	100% assessed within 24 h; outcome logged

TABLE 6.3 — LIMITATIONS

GAP	EFFECT
Weibull fit on 10 failures	Adequate for a shape estimate, but β has a wide confidence band. The cost curve is flat near the optimum, so the interval choice is robust to it.
Major-failure rate (0.2/yr) from limited history	Drives the monitoring increment. Tested in the scenarios and stress tests.
Risk-reduction factors are estimates ESTIMATE	Checked at the month-12 review; the conservative case assumes 60% of rated benefit
O3 performance from OEM claims	Not field-verified at this plant. One reason replacement waits for the trigger.

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A Data, References, and Approval

TABLE A.1 — VALVE AND SEAL SET FAILURE DATA (OPERATING HOURS TO FAILURE)

RANK	1	2	3	4	5	6	7	8	9	10
Hours	1,390	2,060	2,150	2,580	2,610	3,090	3,120	3,610	3,680	4,510
Median rank	0.067	0.163	0.260	0.356	0.452	0.548	0.644	0.740	0.837	0.933

Median ranks by Bernard's approximation, (i − 0.3) / (n + 0.4). All intervals are complete failures with no suspensions. Age-replacement cost rate $C(T) = [Cp \cdot R(T) + Cf \cdot (1 - R(T))] \div \int_0^T R(t)\,dt$.

TABLE A.2 — STANDARDS AND REFERENCES

REFERENCE	TITLE AND USE
IEC 61649:2008	Weibull analysis. Parameter estimation and goodness of fit.
IEC 60300-3-3:2017	Dependability management — Part 3-3: Application guide — Life cycle costing. LCC structure and option comparison.
ISO 55001:2024	Asset management — Asset management system — Requirements. Lifecycle decision-making context.
CA-2026-003	Asset Criticality Analysis, Plant 2. Tier A ranking and baseline risk for HG-1.

REVIEW AND APPROVAL

Prepared by
Lead Reliability Engineer, Apex Reliability Engineering
Signature _____ Date _____

Financials validated by
Plant Controller
Signature _____ Date _____

Approved by
Plant Manager
Signature _____ Date _____

SAMPLE — FICTIONAL D

MAINTAINABILITY ANALYSIS

Faster Repairs on Critical Assets: Where the Repair Time Goes

A repair-time element study of the seven highest-impact repair tasks on Line 3 and homogenizer HG-1, with levers ranked by return and a maintainability standard for new equipment.

SAMPLE — FICTIONAL DAT

CLIENT	Larkspur Valley Foods, Inc. — Plant 2 (cultured dairy)
SCOPE	7 repair tasks on tier A assets: HG-1, P-310, seal heads, indexing chain, GR-305, denester
REPORT NO.	MA-2026-006 · Revision 0 · Issued December 18, 2026
METHOD	Elapsed-time breakdown into eight repair elements from observed repairs, CMMS records, and trial repairs with improved methods (IEC 60300-3-10:2025; IEC 60706-3:2006)
RELATED WORK	Failure rates are taken after the RCA-2026-014, FMECA-2026-007, and ROI-2026-005 actions, so no benefit is double counted

Demonstration document. Sample report. All company names, people, data, and financial figures are fictional and shown for demonstration only. The structure, methods, and level of detail match Apex Reliability Engineering client deliverables.

Executive Summary

Decision brief for the Plant Manager and Plant Controller. Sections 1–6 contain the supporting detail.

BOTTOM LINE

Only **34% of repair time on these tasks is hands-on work**. The rest is diagnosis, lockout, fetching parts, access, and restart. One finding matters most: the HG-1 planned seal change takes 3.6 h against a 3.0 h sanitation window. That costs a hidden **$15.6K/yr**, which ROI-2026-005 assumed was zero. A **$13.0K** package fixes it, pays back in about 8 months, and is positive in every scenario. The other three levers are deferred because they do not pay at today's lower failure rates.

HANDS-ON SHARE OF REPAIR TIME	HG-1 CHANGE VS. WINDOW	HIDDEN OVERRUN COST	RECOMMENDED SPEND	L1 NPV, 5 YR
34%	**3.6 / 3.0 h**	**$15.6K/yr**	**$13.0K**	**$58K**
Weighted by task frequency	2.35 h with the L1 package	$96K PV over the ROI's 10 years	of $42.5K identified	$20K conservative

DECISIONS REQUESTED

1. **Fund L1, the HG-1 set-change package** ($12,996): lifting fixture, torque multiplier, pre-staged kit, group LOTO, standard work.
2. **Convert P-310 to a cartridge seal at its next failure** (L2). It is break-even as a stand-alone project and positive when done with a repair already planned.
3. **Adopt the design-for-maintainability standard** (Section 6) for all new equipment and major modifications.

WHAT THE ANALYSIS SHOWS

- FINDING Parts and tools logistics alone is 17% of repair time, the largest non-repair element.
- FINDING The ROI case for HG-1 holds only if its planned changes fit the sanitation window. Today they do not.
- JUDGMENT Earlier actions have already cut failure rates, so repair-speed projects must now clear a higher bar. Three of four do not, yet.

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1 Scope and Method

Maintainability is how quickly and safely an asset can be restored. It is measured here as elapsed time per repair, broken into the elements a planner can actually change.

TABLE 1.1 — TASKS STUDIED

ID	ASSET · TASK	PER YR	ELAPSED NOW	$/DOWNTIME H	FREQUENCY SOURCE
T1	**HG-1 homogenizer** · Valve and seal set change (planned)	4.00	3.60 h	$6,500	ROI-2026-005 (1,500 h interval)
T1u	**HG-1 homogenizer** · Valve and seal set change (unplanned)	0.32	4.00 h	$6,500	ROI-2026-005 residual
T2	**P-310 product pump** · Mechanical seal replacement	1.05	3.50 h	$2,615	FMECA FM-01 residual
T3	**Line 3 seal heads** · Heater cartridge replacement	1.00	1.20 h	$2,615	FMECA FM-11 residual
T4	**Line 3 indexing chain** · Chain replacement and timing	0.45	5.00 h	$2,615	FMECA FM-14 residual
T5	**GR-305 filler drive** · Gear reducer change (spare on hand)	0.27	10.50 h	$2,615	RCA-2026-014 residual
T6	**Line 3 denester** · Vacuum cup replacement	3.60	0.40 h	$2,615	FMECA FM-09 residual

Frequencies are residual rates *after* earlier actions. T1 is planned, so only time beyond the sanitation window costs production. HG-1 downtime is valued at $6,500/h because it idles every filling line; Line 3 uses the blended $2,615/h from FMECA-2026-007.

TABLE 1.2 — REPAIR ELEMENTS

CODE	ELEMENT	WHAT IT COVERS
D	Diagnose	From call to known cause and part
L	Permit and LOTO	Permits, isolation, verification of zero energy
P	Parts and tools logistics	Finding, fetching, and waiting for parts, tools, and lifting gear
A	Access and disassembly	Guards, covers, and components removed to reach the failed part
R	Repair or replace	The hands-on fix
S	Reassemble and adjust	Reassembly, alignment, torque, timing, tension
Q	Sanitation and QA release	Re-cleaning after the intervention and food-safety release
T	Test and restart	Functional test and return to production

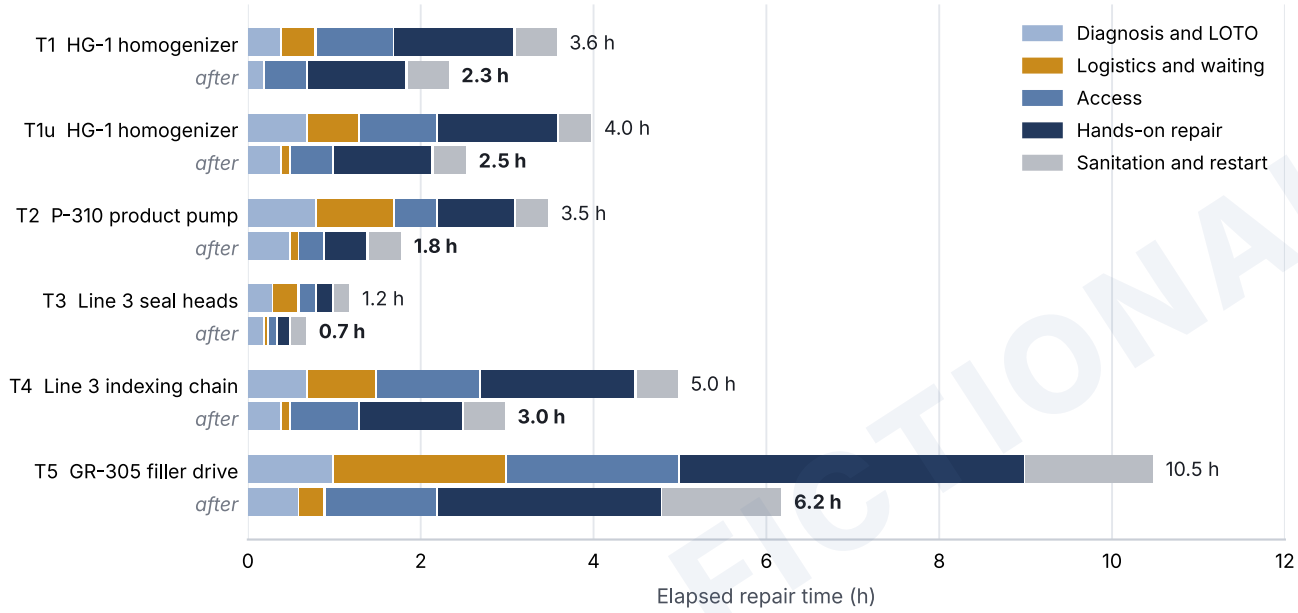
Baselines come from 21 observed repairs and CMMS timestamps. Improved times come from trial repairs using the proposed methods and tooling.

SAMPLE — FICTIONAL D

2 Where the Repair Time Goes

Across these tasks, 27.1 h a year of elapsed repair time would drop to 16.7 h. Nearly all of the cut comes from elements other than the hands-on repair.

FIGURE 2.1 — ELAPSED REPAIR TIME BY ELEMENT, NOW AND AFTER IMPROVEMENT



T6 (denester cups, 0.4 h) is omitted for scale. Its figures are in the Appendix.

TABLE 2.1 — ANNUAL ELAPSED REPAIR HOURS BY ELEMENT (FREQUENCY-WEIGHTED)

ELEMENT	D	L	P	A	R	S	Q	T	TOTAL
Now	1.1	2.8	4.5	5.9	5.2	4.1	2.8	0.8	**27.1**
After	0.8	1.5	0.3	3.5	4.6	2.5	2.8	0.7	**16.7**

WHY THIS MATTERS BEYOND THESE TASKS

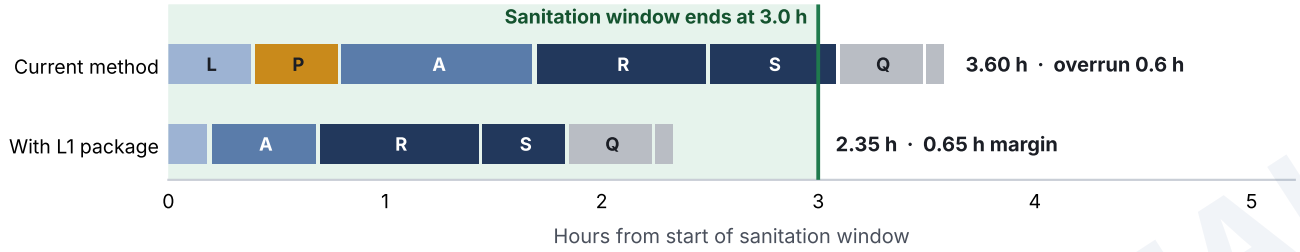
Logistics, access, and lockout delays are system problems: kitting, storeroom location, guard design, and LOTO practice. Fixing them once shortens every future repair, including failures nobody has predicted.

SAMPLE — FICTIONAL D

3 The HG-1 Sanitation-Window Finding

ROI-2026-005 recommends changing HG-1's valve and seal set every 1,500 h, inside a sanitation window, at no production cost. Timing the task showed that the assumption does not hold yet.

FIGURE 3.1 — HG-1 PLANNED SET CHANGE AGAINST THE SANITATION WINDOW



Segments are labeled by element code (Table 1.2). L1 removes the parts fetch (P), halves access time with a lifting fixture, and shortens LOTO and reassembly.

TABLE 3.1 — HG-1 PLANNED CHANGE, ELEMENT TIMES (H)

ELEMENT	NOW	WITH L1
L · Permit and LOTO	0.40	0.20
P · Parts and tools logistics	0.40	0.00
A · Access and disassembly	0.90	0.50
R · Repair or replace	0.80	0.75
S · Reassemble and adjust	0.60	0.40
Q · Sanitation and QA release	0.40	0.40
T · Test and restart	0.10	0.10
Total	**3.60**	**2.35**

EFFECT ON ROI-2026-005

Each planned change overruns the window by 0.6 h. At four changes a year and $6,500/h, that is **$15,600/yr**, or $95,855 of present value over the ROI's 10-year horizon. The ROI's recommendation still holds, but only with L1 in place. Without it, the ROI overstates O1 and O2 by that amount.

MARGIN AFTER L1

2.35 h leaves 0.65 h of margin for the occasional seized fastener or extra QA check, so the gain does not depend on everything going right.

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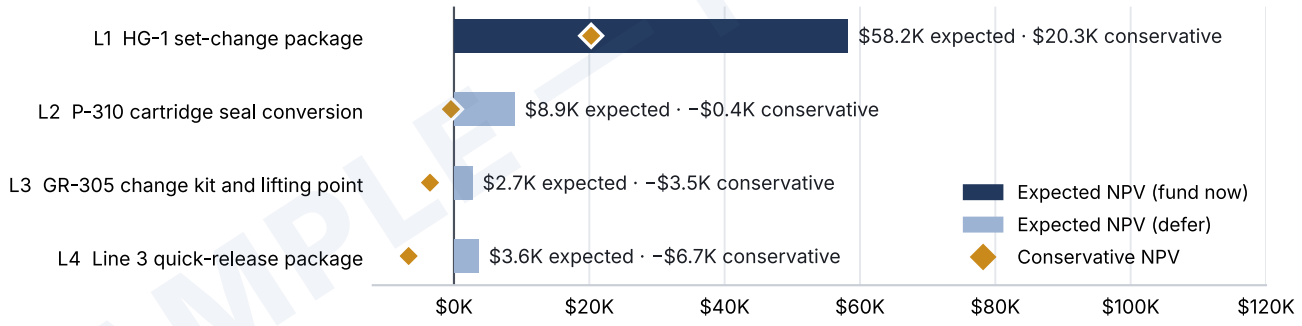
4 Improvement Levers

Four packages were costed and tested in trial repairs. Each is judged on its own, because each has to earn its place.

TABLE 4.1 — LEVERS AND THEIR ECONOMICS (5-YEAR, 10% HURDLE RATE)

ID	LEVER	WHAT IT INCLUDES	COST	BENEFIT/YR	PAYBACK	DECISION
L1	**HG-1 set-change package** Tasks T1, T1u	Valve-block lifting fixture, torque multiplier, pre-staged kit, group LOTO, standard work	$12,996	$19,442	8.3 mo	FUND NOW
L2	**P-310 cartridge seal conversion** Tasks T2	Cartridge seal adapter, point-of-use seal stock, LOTO and standard work	$7,748	$4,794	21.1 mo	ON NEXT FAILURE
L3	**GR-305 change kit and lifting point** Tasks T5	Trolley lifting point, kitted torque-arm hardware, alignment card	$7,948	$3,214	33.9 mo	DEFER
L4	**Line 3 quick-release package** Tasks T3, T4, T6	Quick-release guards, heater quick-disconnects, chain timing marks, point-of-use stock	$13,796	$5,295	36.0 mo	DEFER

FIGURE 4.1 — NPV BY LEVER, EXPECTED AND CONSERVATIVE



WHY DEFER GOOD ENGINEERING

L3 and L4 make repairs faster and safer, but those repairs are now rare, because RCA-2026-014 and FMECA-2026-007 cut their frequency. At today's rates they lose money in the conservative case. They go into the design-for-maintainability standard (Section 6), so new equipment arrives with these features at little extra cost.

SAMPLE — FICTIONAL D

5 Financial Justification

The recommendation is to fund L1 now. The full package is shown alongside it so the decision to defer is visible.

TABLE 5.1 — INVESTMENT BY LEVER AND ACCOUNTING TREATMENT

ITEM	CLASS	AMOUNT	TREATMENT
Point-of-use spares cabinets and task kits (Line 3, HG-1)	CAPEX	$6,200	Tooling and fixtures; capitalize if above plant threshold (Controller review)
HG-1 valve-block lifting fixture and torque multiplier	CAPEX	$7,800	Tooling and fixtures; capitalize if above plant threshold (Controller review)
P-310 cartridge seal conversion (adapter + first seal)	CAPEX	$4,600	Tooling and fixtures; capitalize if above plant threshold (Controller review)
Quick-release guards and quick-disconnects (filler, chain, heaters)	CAPEX	$8,900	Tooling and fixtures; capitalize if above plant threshold (Controller review)
GR-305 lifting trolley point and pre-kitted mounting hardware	CAPEX	$5,400	Tooling and fixtures; capitalize if above plant threshold (Controller review)
Group LOTO lockbox stations and verified procedures	OPEX	$2,100	Expensed as incurred
Standard work, visual aids, timing marks; training (96 h)	OPEX	$7,488	Expensed as incurred
Full package		**$42,488**	
Recommended now (L1)		**$12,996**	**Allocation of the items above; see Table 4.1**
Recurring: refresher training and kit replenishment	OPEX/YR	$2,148	Full package; $657 for L1

TABLE 5.2 — SCENARIO ANALYSIS (PRE-TAX, 5-YEAR HORIZON, 10% HURDLE RATE)

	CONSERVATIVE	EXPECTED	HIGH IMPACT
L1 only (recommended): NPV	**$20,276**	**$58,214**	**$75,834**
Full package: annual benefit	$15,885	$32,745	$40,583
Full package: payback (months)	37.1	16.7	13.3
Full package: NPV	$9,586	$73,499	$103,211
Value of deferring L2–L4 (L1 NPV − full NPV)	**$10,690**	**−$15,285**	**−$27,377**

Conservative: 60% of measured time savings sustained; downtime rates 20% lower. **Expected:** Time savings as demonstrated in trial repairs; downtime rates as stated. **High impact:** Time savings as demonstrated; downtime rates 25% higher (lost volume not recovered). A positive bottom line means funding L1 alone beats funding everything.

SAMPLE — FICTIONAL D

5 Financial Justification (continued)

L1 pays back quickly in every scenario. The full package depends heavily on L1, which is the clearest argument for funding L1 alone.

FIGURE 5.1 — CUMULATIVE NET CASH POSITION, L1 PACKAGE (UNDISCOUNTED)

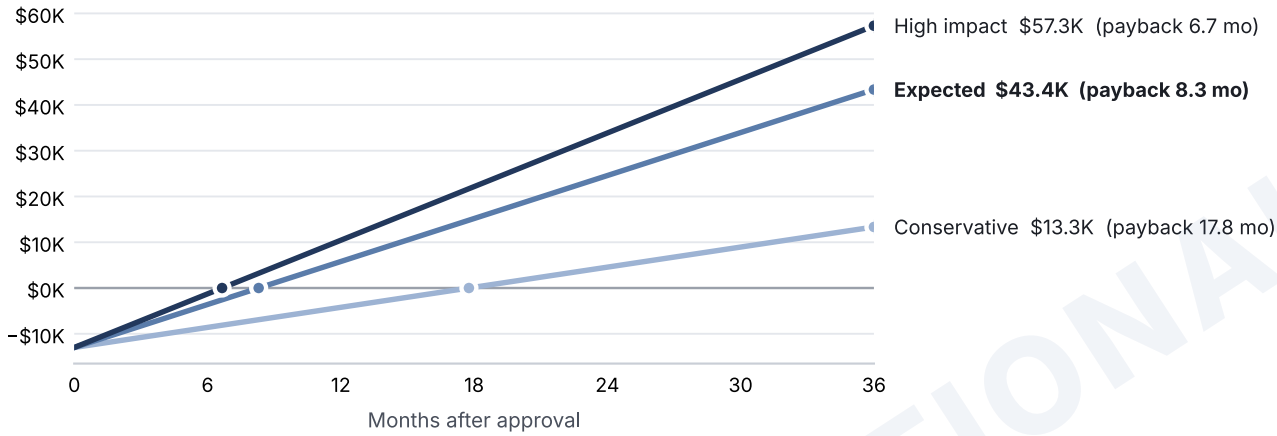


TABLE 5.3 — STRESS TESTS ON THE FULL PACKAGE (CONSERVATIVE)

STRESS APPLIED	5-YEAR NPV
Base case (Conservative)	**$9,586**
HG-1 window fix fails (no T1 benefit)	−$20,536
Investment +40%	−$7,409
Time savings halved again	−$20,524
Discount rate 15%	$3,561

Without the HG-1 fix, the full package loses money. T1 alone supplies 50% of the full package's benefit.

BREAK-EVEN

The full package breaks even if 41% of its measured benefit is realized. L1 alone breaks even well below that, because it carries 50% of the benefit for 31% of the cost.

CONSERVATISM IN THESE FIGURES

Benefits use failure rates *after* earlier actions, and the hidden HG-1 overrun is valued only at the planned-change frequency. Safety and ergonomic gains from lifting aids and group LOTO are real but are not valued.

SAMPLE — FICTIONAL D

6 Design-for-Maintainability Standard, Implementation, and Verification

The cheapest maintainability is designed in. These requirements go into every equipment specification and are verified at factory acceptance.

TABLE 6.1 — MAINTAINABILITY REQUIREMENTS FOR NEW EQUIPMENT (VERIFIED AT FAT/SAT)

#	REQUIREMENT	VERIFICATION
1	Wear parts reachable in ≤ 15 min without special tools	Timed demonstration at FAT
2	Lifting points or fixtures for any component over 23 kg (50 lb)	Drawing review; demonstration
3	Interlocked, tool-less guards on routine-access areas, with hygienic design	Inspection; QA sign-off
4	Cartridge seals and quick-disconnects where the duty allows	Specification review
5	Diagnostics to the failed component (HMI fault messages, LED status)	Fault-insertion test
6	Grouped, labeled isolation points; machine-specific LOTO procedure supplied	LOTO walk-down at SAT
7	Torque values, timing marks, and alignment references marked on the equipment	Inspection
8	Recommended spares list with lead times; task kits for planned work	Document review
9	Demonstrated MTTR for the top 3 expected repairs, stated in the contract	Timed demonstration at FAT

TABLE 6.2 — IMPLEMENTATION AND VERIFICATION

WHEN	ACTION AND MEASURE	OWNER
Weeks 0–6	Build and stage HG-1 kits; install the lifting fixture; issue standard work; train both crews	Planner · Reliability
First 4 changes	Time every HG-1 set change. **Target: ≤ 3.0 h, every time.**	Reliability Engineer
Next P-310 failure	Convert to cartridge seal (L2); time the repair against the 1.8 h target	Maintenance Supervisor
Annually	Re-run L3/L4 economics against actual failure rates; fund if conservative NPV turns positive	Reliability · Controller

SAMPLE — FICTIONAL D

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Sample report. All company names, people, data, and financial figures are fictional and shown for demonstration only.

A Element Data, Limitations, References, and Approval

TABLE A.1 — ELEMENT TIMES BY TASK, NOW → AFTER (HOURS)

TASK	D	L	P	A	R	S	Q	T	TOTAL
T1	0 → 0	0.4 → 0.2	0.4 → 0	0.9 → 0.5	0.8 → 0.75	0.6 → 0.4	0.4 → 0.4	0.1 → 0.1	**3.60 → 2.35**
T1u	0.3 → 0.2	0.4 → 0.2	0.6 → 0.1	0.9 → 0.5	0.8 → 0.75	0.6 → 0.4	0.3 → 0.3	0.1 → 0.1	**4.00 → 2.55**
T2	0.4 → 0.3	0.4 → 0.2	0.9 → 0.1	0.5 → 0.3	0.5 → 0.3	0.4 → 0.2	0.3 → 0.3	0.1 → 0.1	**3.50 → 1.80**
T3	0.1 → 0.1	0.2 → 0.1	0.3 → 0.05	0.2 → 0.1	0.1 → 0.1	0.1 → 0.05	0.15 → 0.15	0.05 → 0.05	**1.20 → 0.70**
T4	0.3 → 0.2	0.4 → 0.2	0.8 → 0.1	1.2 → 0.8	0.9 → 0.7	0.9 → 0.5	0.4 → 0.4	0.1 → 0.1	**5.00 → 3.00**
T5	0.5 → 0.3	0.5 → 0.3	2 → 0.3	2 → 1.3	2 → 1.6	2 → 1	1 → 1	0.5 → 0.4	**10.50 → 6.20**
T6	0.05 → 0.05	0.05 → 0.05	0.15 → 0	0.05 → 0.05	0.05 → 0.05	0 → 0	0.05 → 0.05	0 → 0	**0.40 → 0.25**

TABLE A.2 — LIMITATIONS

GAP	EFFECT
Improved times come from trial repairs, not sustained practice ESTIMATE	The conservative case assumes 60% of the savings are sustained
Small sample (21 observed repairs)	Element times are indicative; HG-1 timing is verified over its first 4 changes
Residual failure rates depend on earlier actions being delivered	If they slip, failure rates rise and the deferred levers become more valuable

TABLE A.3 — STANDARDS AND REFERENCES

REFERENCE	TITLE AND USE
IEC 60300-3-10:2025	Dependability management — Part 3-10: Application guide — Maintainability and maintenance. Maintainability programme and measures.
IEC 60706-2:2006	Maintainability of equipment — Part 2: Maintainability requirements and studies during the design and development phase. Basis for the Section 6 standard.
IEC 60706-3:2006	Maintainability of equipment — Part 3: Verification and collection, analysis and presentation of data. Element time collection and FAT verification.
ROI-2026-005 · FMECA-2026-007 · RCA-2026-014	Prior Apex analyses at Plant 2. Residual failure rates and downtime values.

REVIEW AND APPROVAL

Prepared by
Lead Reliability Engineer, Apex Reliability Engineering — Signature — Date

Approved by
Plant Manager — Signature — Date

SAMPLE — FICTIONAL D

PROCUREMENT RECOMMENDATION AND CAPITAL REQUEST

HG-1 Online Condition Monitoring: Vendor Selection and Award

Three bids evaluated against mandatory gates, weighted criteria, and 10-year total cost of ownership, and reconciled to the business case approved in ROI-2026-005.

SAMPLE — FICTIONAL DAT

CLIENT	Larkspur Valley Foods, Inc. — Plant 2 (cultured dairy)
REQUIREMENT	Wireless vibration and temperature monitoring of HG-1 crankcase bearings and seal leakage, with alarms to the CMMS
REPORT NO.	PR-2026-008 · Revision 0 · Issued January 8, 2027
BASIS	ROI-2026-005, option O2 (approved planning value $28,000 capital + $3,000/yr); maintainability requirements from MA-2026-006
EVALUATION TEAM	Apex Reliability Engineering (lead) · Maintenance & Engineering Manager · Controls Engineer · IT/OT Security Lead · Food Safety & QA Manager · Purchasing · Plant Controller

> **Demonstration document.** Sample report. All company names, people, data, and financial figures are fictional and shown for demonstration only. Vendors are anonymized and fictional. The structure, methods, and level of detail match Apex Reliability Engineering client deliverables.

Executive Summary

Award recommendation and capital request for approval by the Plant Manager and Plant Controller.

RECOMMENDATION

Award to **Vendor B** at **$31,900**, with a capital authorization of **$33,495** including 5% contingency. Vendor B has the highest bid but the **lowest 10-year cost of ownership** ($48.2K PV) and the highest evaluated score. The lowest bid (Vendor C, $22,800) fails three mandatory gates and would have cost the most to own. Against the approved business case, the award adds $1,723 of PV cost, and the case remains positive.

BID, RECOMMENDED	CAPITAL AUTHORIZATION	10-YR TCO (PV)	EVALUATED SCORE	CHANGE TO APPROVED CASE
$31.9K	**$33.5K**	**$48.2K**	**4.51 / 5**	**+$1.7K**
Turnkey, installed, integrated	Bid + 5% contingency	Lowest of the compliant bids	vs. 4.14 for Vendor A	PV cost; O2 NPV stays $316K

DECISIONS REQUESTED

1. **Approve the award to Vendor B** and a capital authorization of $33,495.
2. **Approve the commercial terms** in Section 5: 20% of payment held until site acceptance and a 30-day performance period, plus a 2-year warranty.
3. **Fund $3,372 of OPEX** for the network drop, IT/OT review, and commissioning labor.

WHY NOT THE LOWEST BID

- GATE Vendor C's field devices are not rated IP69K for daily washdown.
- GATE Raw data is available only through the vendor's cloud subscription.
- GATE The cloud-only architecture failed the plant's IT/OT security review.
- COST Annual battery changes and a higher subscription make it the costliest option over 10 years, even before the gates.

SAMPLE — FICTIONAL D

1 Need and Approved Business Case

This purchase implements option O2 of ROI-2026-005, which the plant approved. This document selects the supplier, confirms that the approved economics still hold at the actual price, and sets terms that protect the plant.

TABLE 1.1 — WHAT THE BUSINESS CASE REQUIRES

ITEM	FROM ROI-2026-005
Purpose	Early warning on HG-1's major mechanical failure mode ($150K per event); data feed for the rebuild-or-replace trigger
Expected effect	Major-failure risk cut 65% (vs. 30% with routes alone)
Planning values	$28,000 capital; $3,000/yr operating; $46,434 10-year PV of cost at 10%
Approved economics	O2 NPV $317,720; increment over O1 $18,084

WHAT THIS PURCHASE MUST NOT DO

The monitoring increment over O1 is positive but modest. A supplier choice that adds more than about $18K of PV cost would erase it. For that reason, total cost of ownership, not purchase price, is the financial test in this evaluation.

TABLE 1.2 — PROCUREMENT PROCESS

STEP	ACTIVITY
Market scan	Five suppliers screened; three invited to bid on a common specification
Bid and clarification	Written bids, a technical clarification call, and site walk-down with each bidder
Evaluation	Mandatory gates first, then weighted scoring (70% non-price, 30% TCO) by a cross-functional team
Due diligence	Two customer references per passing bidder; IT/OT architecture review; sample sensor washdown inspection

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Sample report. All company names, people, data, and financial figures are fictional and shown for demonstration only.

2 Mandatory Gates

Gates are pass/fail and come before any scoring. A bid that fails a gate is excluded however attractive its price, because each gate protects food safety, plant security, or the business case.

TABLE 2.1 — GATE RESULTS

GATE	VENDOR A	VENDOR B	VENDOR C
Washdown rating IP69K on all field devices	✓ Pass	✓ Pass	× Fail
Food-safe housings; no glass or brittle plastic over product zone	✓ Pass	✓ Pass	✓ Pass
Alarms delivered to the plant CMMS within 5 minutes	✓ Pass	✓ Pass	✓ Pass
Plant owns raw data; local export without subscription	✓ Pass	✓ Pass	× Fail
Passes plant IT/OT security review (zones and conduits per IEC 62443-3-3)	✓ Pass	✓ Pass	× Fail
Sensor replaceable in ≤ 10 min without special tools (MA-2026-006, req. 1)	✓ Pass	✓ Pass	✓ Pass
Result	**Proceeds**	**Proceeds**	**Excluded**

WHY THESE GATES

HG-1 sits over the open-product area and is washed down daily, so devices must be rated IP69K and food-safe. Monitoring data feeds the rebuild-or-replace decision, so the plant must own and be able to export it. Any device on the plant network must pass the IT/OT security review.

VENDOR C, IN CONTEXT

Vendor C offered a capable product at the lowest price. Its failures were all architectural (washdown rating, data access, cloud-only design), not minor documentation gaps that could be fixed during contracting.

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3 Bid Evaluation

The two compliant bids were scored on eight non-price criteria (70%) and 10-year TCO (30%). Vendor B leads by 0.37 points.

TABLE 3.1 — WEIGHTED SCORING (0–5 SCALE)

CRITERION	WEIGHT	VENDOR A	VENDOR B
Detection capability (bandwidth, analytics)	15%	4	5
Hygienic and washdown design	10%	4	5
Battery life and field maintainability	8%	3	4
CMMS and historian integration	7%	5	4
Local service and support	8%	3	4
Vendor viability and references	6%	4	4
Data ownership and portability	6%	3	5
Delivery lead time	10%	5	3
10-year TCO (lowest = 5; others pro rata)	30%	4.63	5.00
Weighted score	**100%**	**4.14**	**4.51**

Scores are the evaluation team's consensus against the rubric in the Appendix. Vendor A scores higher on CMMS integration and lead time; Vendor B leads on detection capability, washdown design, battery life, data ownership, and TCO.

ROBUSTNESS OF THE RESULT

Vendor B still wins if TCO is given zero weight, and still wins if lead time is weighted 20% (taken from TCO). The ranking does not depend on a single judgment call.

TRADE-OFF ACCEPTED

Vendor B's 8-week lead time is 4 weeks longer than Vendor A's. Planned changes and oil and vibration routes (O1) cover HG-1 in the meantime, so the delay costs little.

SAMPLE — FICTIONAL D

4 Total Cost of Ownership and Financial Impact

Over 10 years, the highest bid is the cheapest to own. Subscriptions and battery changes, not the purchase price, decide the ranking.

FIGURE 4.1 — 10-YEAR TOTAL COST OF OWNERSHIP, PRESENT VALUE AT 10%

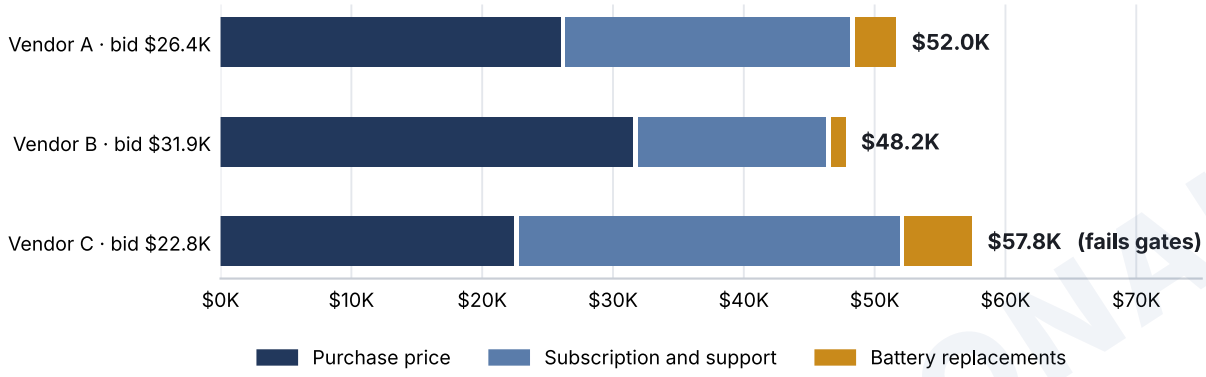


TABLE 4.1 — TCO COMPONENTS

	VENDOR A	VENDOR B	VENDOR C
Purchase price (installed, integrated)	$26,400	$31,900	$22,800
Annual subscription, support, IT upkeep	$3,600	$2,400	$4,800
Battery replacements over 10 years	$6,000	$3,000	$9,000
10-year cost, nominal	$68,400	$58,900	$79,800
10-year cost, present value	**$52,032**	**$48,157**	**$57,824**

TABLE 4.2 — RECONCILIATION TO ROI-2026-005

ITEM	VALUE
Approved planning PV of cost	$46,434
Vendor B PV of cost	$48,157
Change	**+$1,723**
O2 NPV, updated	$315,997
O2 increment over O1, updated	**$16,361**

ACCOUNTING AND CASH TIMING

The $31,900 is CAPEX, depreciated over 7 years under MACRS (year-1 depreciation $4,559; 100% bonus depreciation may apply if the Controller elects it), subject to Controller review. Contingency is released only on change order. Cash leaves in three milestones (Section 5), with $6,380 held until the system has proven itself in service.

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5 Commercial Terms and Risk

Payment tied to proven performance, measurable acceptance criteria, and a risk register owned by named roles.

TABLE 5.1 — PAYMENT MILESTONES

MILESTONE	SHARE	AMOUNT
Purchase order	30%	$9,570
Delivery and installation	50%	$15,950
Site acceptance plus 30-day performance period	20%	$6,380

TABLE 5.2 — KEY CONTRACT TERMS

TERM	REQUIREMENT
Warranty	2 years, parts and labor, from acceptance
Price hold	Support fee fixed for 3 years; then capped at CPI
Data	Plant owns all data; export in open format at no charge
Exit	Gateway and sensors keep working locally if support ends

TABLE 5.3 — ACCEPTANCE CRITERIA (SITE ACCEPTANCE PLUS 30-DAY PERFORMANCE PERIOD)

CRITERION	PASS CONDITION
Data availability	≥ 98% of expected readings received over 30 days
Alarm delivery	Test alarms reach the CMMS within 5 minutes, 10 of 10 times
Measurement validity	Vibration readings within ±10% of a calibrated portable analyzer on the same points
Washdown survival	No device faults or ingress after 30 daily sanitation cycles
Maintainability	Sensor swap demonstrated in ≤ 10 min without special tools

TABLE 5.4 — RISK REGISTER

RISK	RATING	MITIGATION	OWNER
False or nuisance alarms erode trust	MEDIUM	Alarm limits baselined over 30 days; two-stage alarms; monthly review	Reliability Engineer
Supplier exits the market	LOW	Local operation without support; data export; references checked	Purchasing
Network or security issue at go-live	MEDIUM	Gateway in a segmented OT zone; IT/OT sign-off before connection	IT/OT Security Lead
Monitoring benefit below the business case	MEDIUM	Tracked at the ROI's month-12 review; O1 practices continue regardless	Reliability · Controller

SAMPLE — FICTIONAL D

6 Implementation and Approval

From approval to accepted system in about 14 weeks.

TABLE 6.1 — SCHEDULE

WEEK	MILESTONE	OWNER
0	Approval; purchase order issued (30% payment)	Purchasing
1–8	Supplier lead time; network drop and OT zone prepared; alarm routing configured in the CMMS	Vendor B · Controls · IT/OT
8–10	Installation in sanitation windows; commissioning; QA sign-off on device placement (50% payment)	Vendor B · QA
10–14	Site acceptance and 30-day performance period; final payment on pass (20%)	Reliability Engineer
Month 12	Benefit review within the ROI-2026-005 verification	Reliability · Controller

APPROVAL ROUTING

Recommended by
Lead Reliability Engineer, Apex Reliability Engineering
Signature _____ Date _____

Technical acceptance
Maintenance & Engineering Manager
Signature _____ Date _____

Security review
IT/OT Security Lead
Signature _____ Date _____

Food safety review
Food Safety & QA Manager
Signature _____ Date _____

Financial approval
Plant Controller
Signature _____ Date _____

Capital approval
Plant Manager
Signature _____ Date _____

SAMPLE — FICTIONAL D

A Scoring Rubric and References

TABLE A.1 — SCORING RUBRIC

SCORE	MEANING
5	Exceeds the requirement with demonstrated evidence (test, reference, or site inspection)
4	Fully meets the requirement with evidence
3	Meets the requirement on the supplier's statement, without independent evidence
2	Partially meets the requirement; gap closable in contracting
1	Does not meet the requirement

TABLE A.2 — BIDDER PROFILES (ANONYMIZED)

BIDDER	OFFER	LEAD TIME
Vendor A	Cloud-hosted wireless monitoring (subscription)	4 weeks
Vendor B	Wireless sensors with on-premise edge gateway	8 weeks
Vendor C	Low-cost cloud-only sensors	3 weeks

TABLE A.3 — STANDARDS AND REFERENCES

REFERENCE	TITLE AND USE
IEC 62443-3-3	Security for industrial automation and control systems — Part 3-3: System security requirements and security levels. Basis of the IT/OT security gate.
IEC 60300-3-3:2017	Dependability management — Part 3-3: Application guide — Life cycle costing. TCO structure.
21 CFR 117.40	Equipment and utensils. Food-safe device requirements over the product zone.
ROI-2026-005 · MA-2026-006	Prior Apex analyses at Plant 2. Approved business case and maintainability requirements.

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