Sa 2.5 Near-White delivers the lowest cost per year of protection — the single best-value specification on the preparation spectrum.

EXECUTIVE SUMMARY

Every coating specification answers one question, whether explicitly or by default: how well should the surface be prepared before the first coat goes on? The answer spans a spectrum from no preparation at all to Sa 3 white metal — and each step up the spectrum costs more in time, abrasive, labour, and equipment. This paper asks the question every asset owner ultimately cares about: **is there a preparation grade that delivers the best coating service life per dollar invested — a sweet spot — and where is it?**

Using a controlled comparison framework — a single reference substrate (hot-rolled structural steel, initial rust grade C per ISO 8501-1), a single constant coating system (a generic 3-coat epoxy system at ~280 µm nominal dry film thickness, ISO 12944 C4-High durability class), and a single service environment (C4 industrial/coastal atmosphere) — this paper synthesises published service-life data, international standards, and blast production data to model the full cost-per-year-of-protection curve across seven preparation grades.

The headline findings:

- Coating service life rises steeply and non-linearly with preparation grade. Moving from Sa 2 (Commercial) to Sa 2.5 (Near-White) adds approximately 57% more service life for roughly a 30–65% increase in preparation cost — the single best value step on the entire spectrum.
- Moving from Sa 2.5 to Sa 3 (White Metal) adds only ~9% more service life in atmospheric exposure for a 25–30% preparation cost premium. In direct-cost terms, Sa 2.5 is the minimum-cost-per-year grade — the sweet spot.
- When access and indirect costs (scaffolding, containment, downtime, mobilisation) are included, Sa 3 statistically ties Sa 2.5. The higher the cost of getting to the surface, the more the balance tips toward maximum preparation — because the dominant cost becomes the intervention itself, not the preparation grade.
- Below Sa 2, cost-efficiency collapses. A no-preparation approach costs approximately 5 times more per year of protection than Sa 2.5 over a 25-year horizon. Hand and power tool preparation (St 2 / St 3) are never cost-optimal for full-area work and are economically justified only for spot repair or where blasting is genuinely impossible.
- Over a 25-year asset horizon, the Sa 2.5 path costs approximately $91/m² (all-in, model values) versus $465/m² for the no-preparation path and $129/m² for Sa 2 — the preparation decision alone drives a 5:1 spread in life-cycle cost.

The conclusion for specifiers is direct: **specify Sa 2.5 as the default minimum for full-area atmospheric coating work; specify Sa 3 where access costs are very high, where service is immersion or severe (C5/CX/Im), or where the consequence of failure is unacceptable.** Money saved by specifying below Sa 2 is not saved — it is borrowed from the maintenance budget at a punishing interest rate.

1. THE RESEARCH QUESTION

1.1 Objective

This paper sets out to answer a deceptively simple question: for a given substrate and a given coating system, which surface preparation grade delivers the longest coating service life for the total money, time, and effort invested? In other words, where on the preparation spectrum — from doing nothing at all to achieving a perfect Sa 3 white metal finish — does each additional dollar of preparation stop paying for itself?

The question matters because surface preparation is simultaneously the largest controllable driver of coating performance and a significant, highly variable cost line. Industry literature consistently attributes the majority of premature coating failures — commonly cited figures range from 60% to 80% — to inadequate surface preparation rather than to coating material deficiencies. At the same time, preparation can represent 30–50% of the total cost of a painting project. Both under-specifying and over-specifying preparation destroy value: the former through early failure and repeated repaints, the latter through cost premiums that purchase little additional life.

1.2 Why a Controlled Comparison

Published coating-life data is abundant but heterogeneous: different substrates, coating systems, film builds, environments, and failure definitions make direct comparison unreliable. To isolate the effect of preparation grade alone, this analysis holds every other variable constant and varies only the preparation. The framework mirrors a controlled laboratory exposure programme — the approach used in the classic public studies this paper draws on — while remaining transparent about being a literature-based model rather than a new physical test programme.

2. CONTROL FRAMEWORK & METHODOLOGY

2.1 The Control Sample Definition

Controlled Variable	Specification	Rationale
Substrate	Hot-rolled structural steel plate (S275/S355 class), 6–10 mm	The most common industrial coating substrate worldwide
Initial condition	Rust grade C per ISO 8501-1 (mill scale rusted away; light pitting visible)	Representative of maintenance and fabrication backlog steel
Surface profile (blasted grades)	50–75 µm angular profile per ISO 8503-2 (garnet / grade to suit)	Matched to the coating system's DFT; held constant
Soluble salts	< 50 mg/m² chloride per ISO 8502-6/-9 before coating	Removes salt contamination as a confounding variable
Coating system	3-coat epoxy system: zinc-rich epoxy primer 60–80 µm / epoxy MIO intermediate 120–160 µm / polyurethane topcoat 50–80 µm; ~280 µm NDFT	Archetypal ISO 12944-5 C4-High system; equivalents available from all major coating manufacturers
Application	Airless spray, qualified applicators, per manufacturer PDS; environmental conditions compliant (substrate ≥ 3°C above dew point, RH ≤ 85%)	Removes application quality as a variable
Environment	ISO 12944-2 category C4 (industrial / coastal atmosphere)	The most common severity class for specified protective coatings

Controlled Variable	Specification	Rationale
Failure criterion	Practical service life: time to first major maintenance at ~Ri 3 rust rating (ISO 4628-3), ≈ 5–10% surface breakdown	The industry-standard economic repaint trigger used in published service-life studies

A note on coating brand: the analysis is deliberately brand-agnostic. The modelled 3-coat system corresponds to qualified C4-High systems available from every major manufacturer (e.g., equivalent product families from Jotun, Hempel, PPG, AkzoNobel International, Sherwin-Williams, Nippon Paint). Published durability data across these brands for equivalent generic systems is closely clustered, and the effect of preparation grade dominates brand-to-brand variation — which is precisely the point of this paper.

2.2 The Preparation Spectrum Under Test

Seven preparation levels are compared, spanning the full practical spectrum. Each is defined by its ISO 8501-1 / SSPC-AMPP standard:

#	Grade	Standard (ISO / SSPC)	What Is Achieved
1	None (degrease only)	SSPC-SP-1 only	Oil and grease removed with solvent; rust, mill scale and old coating remain
2	Hand tool	St 2 / SSPC-SP-2	Loose rust, scale and coating removed by wire brush and scraper; adherent material remains; polished rather than profiled
3	Power tool	St 3 / SSPC-SP-3	As St 2 but more thorough by power wire brush/disc; slight sheen; minimal profile
4	Brush-off blast	Sa 1 / SSPC-SP-7	Loose material blasted away; tightly adherent mill scale and rust remain
5	Commercial blast	Sa 2 / SSPC-SP-6	Most contamination removed; ≤ 33% staining per unit area; full profile
6	Near-white blast	Sa 2.5 / SSPC-SP-10	All visible contamination removed; ≤ 5% staining; full profile
7	White metal blast	Sa 3 / SSPC-SP-5	Uniformly clean grey-white metal; zero staining; full profile

2.3 Data Sources

Service-life inputs are synthesised from the most widely cited publicly available sources: the SSPC/JPCL expected-service-life and cost studies (the Brevoort–Roebuck line of papers and their periodic updates by Helsel et al., published in the Journal of Protective Coatings & Linings), ISO 12944-1/-5 durability classes, US Federal Highway Administration bridge coating research, offshore qualification regimes (NORSOK M-501, IMO PSPC — both of which mandate Sa 2.5 minimum for critical service), and the corrosion economics baseline established by the NACE IMPACT study (global corrosion cost US$2.5 trillion, ~3.4% of global GDP). Production-rate and abrasive-consumption inputs are drawn from PanBlast blast cleaning rate data for garnet abrasive across surface conditions and nozzle sizes. Cost figures are stated as illustrative mid-2020s model values in USD per square metre and must be calibrated to local labour and material rates before use in bids or budgets; the paper's conclusions rest on the ratios between grades, which are far more stable across markets than absolute prices.

3. WHAT THE PUBLISHED EVIDENCE SHOWS: LIFE VS. GRADE

3.1 The Service-Life Table

The table below presents the modelled practical service life — time to first major maintenance at approximately Ri 3 breakdown — for the constant 3-coat system over each preparation grade in C4 atmospheric service. Ranges reflect the spread across published studies; mid-points are used in all subsequent cost modelling.

Preparation Grade	Service Life Range (yr)	Mid-Point (yr)	Life Index (Sa 2.5 = 100)
None (SP-1 only)	1.5 – 3.5	2.5	15
St 2 Hand Tool	4 – 6	5.0	30
St 3 Power Tool	5 – 8	6.5	39
Sa 1 Brush-Off	6 – 9	7.5	45
Sa 2 Commercial	9 – 12	10.5	64
Sa 2.5 Near-White	15 – 18	16.5	100
Sa 3 White Metal	16 – 20	18.0	109

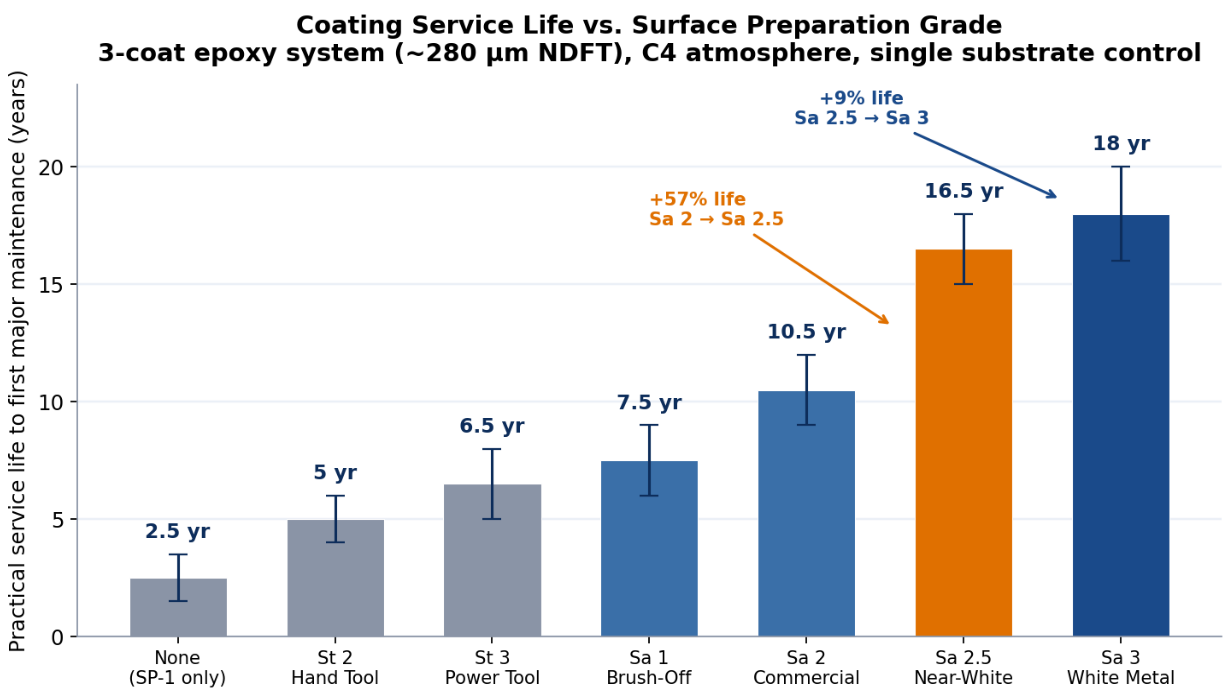

Figure 1 — Coating service life vs. preparation grade. Error bars show published ranges; bar values are model mid-points.

3.2 Why the Curve Has This Shape

The life-vs-grade curve is steep in the middle and flat at the top, and the failure mechanisms explain why:

- At the bottom of the spectrum (none, St 2, St 3), failure is driven by what remains on the surface. Residual rust holds hygroscopic ferrous salts that draw moisture through the coating and initiate under-film corrosion; residual mill scale is cathodic to steel and creates galvanic cells at every break; and hand/power tool methods polish rather than profile the surface, so mechanical adhesion is poor. The coating fails from beneath regardless of its own quality.
- Sa 1 removes loose material but leaves adherent scale and rust — better, but the same mechanisms operate at reduced intensity.
- The decisive jump is Sa 2 to Sa 2.5. At Sa 2, up to a third of each unit area may still carry staining and residues; at Sa 2.5 that falls to 5%. This disproportionately extends life because failure is seeded at the residual contamination sites — reduce the seeds by a factor of six and the time to reach the Ri 3 breakdown threshold extends dramatically. This is why virtually every high-performance specification (NORSOK M-501, IMO PSPC, ISO 12944 C4-H/C5 systems, zinc-rich primer PDS requirements) sets Sa 2.5 as the minimum.
- Sa 2.5 to Sa 3 removes the last 5% of staining. In atmospheric service the marginal life gain is small (~9% in this model) because at this level the life-limiting factors shift to the coating system itself — UV degradation of the topcoat, film ageing, mechanical damage — rather than the substrate. In immersion or chemically severe service, however, residual contamination remains the life-limiter, which is why Sa 3 is specified for tank linings and critical immersion work.

> **THE CENTRAL MECHANISM**
> *Coating failure in atmospheric service is seeded at residual surface contamination. Each step up the preparation spectrum removes seeds; the Sa 2 → Sa 2.5 step removes the most seeds per dollar spent, and beyond Sa 2.5 the coating itself — not the surface — becomes the life-limiting factor.*

4. THE COST MODEL

4.1 Direct Preparation Costs

Preparation cost per square metre is built from three components: labour and equipment time (driven by production rate), abrasive consumption, and consumables/setup. The production-rate foundation comes from blast cleaning rate data for garnet abrasive: with a #6 nozzle (200 cfm) on rust grade C steel, indicative rates are 66.9 m²/hr to Sa 1, 16.7 m²/hr to Sa 2, 7.2 m²/hr to Sa 2.5, and 6.7 m²/hr to Sa 3 — with garnet throughput of approximately 499 kg/hr at that nozzle size. Two structural facts follow directly from this data:

- The Sa 2 → Sa 2.5 step roughly halves the production rate (and roughly doubles labour and abrasive cost per m²) — this is the price of the biggest life gain on the curve.
- The Sa 2.5 → Sa 3 step reduces the production rate by only ~7% on the same surface — but the true Sa 3 premium in the field is larger (typically 25–30% all-in) because it adds stricter environmental control, higher rejection/re-blast risk of flash-rusted or stained areas, tighter lighting and inspection requirements, and hold-point time.

The model's direct preparation costs (illustrative USD/m², rust grade B–C steel, field blasting with partially recycled garnet, all-in including labour, equipment amortisation, abrasive, and consumables):

Grade	Prep Cost ($/m²)	Basis
None (SP-1 only)	1.50	Solvent/degreaser and rags; minimal labour
St 2 Hand Tool	6.00	2–4 m²/hr per person; negligible equipment; high labour share
St 3 Power Tool	11.00	3–5 m²/hr; power tools, discs/brushes, higher consumables
Sa 1 Brush-Off	5.00	High production rate (~67 m²/hr at #6); low abrasive per m²
Sa 2 Commercial	9.00	~17 m²/hr; moderate abrasive consumption
Sa 2.5 Near-White	15.00	~7 m²/hr; roughly double the abrasive of Sa 2 per m²
Sa 3 White Metal	19.00	~7% slower than Sa 2.5 plus environmental control, inspection and re-blast risk premium

4.2 Coating and Application Costs (Held Constant)

Because the coating system is the control variable, its cost is identical across all grades: materials approximately $10/m² (3 coats at ~280 µm NDFT, typical net consumption including losses) plus application labour and equipment approximately $10/m² — a constant **$20/m² per full application**. In reality a specifier facing a hand-tool-only scenario would select a surface-tolerant coating rather than a zinc-rich system (zinc-rich primers require Sa 2.5 minimum to function); the model notes this as a controlled-variable simplification and observes that published data for surface-tolerant systems shows the same directional life-vs-grade pattern, merely shifted.

4.3 Access and Indirect Costs — The Multiplier Most Analyses Ignore

On real structures, the cost of an intervention is dominated not by preparation or paint but by getting to the surface: scaffolding or rope access, containment and environmental compliance, plant mobilisation, inspection and QA hold points, and — often largest of all — production downtime or outage windows. The model uses a deliberately conservative **$25/m² per intervention** for accessible onshore structures; for elevated bridges, process plant requiring shutdown, or offshore assets, real figures of $50–300/m² are routinely reported. Every repaint incurs this cost again in full. This is the single most important economic fact in the analysis: **the fewer times you must return to the surface over the asset's life, the less the asset costs to protect — almost regardless of what each visit costs in preparation.**

5. RESULTS: COST PER YEAR OF PROTECTION

5.1 Annualized Cost — The Sweet Spot Curve

Dividing the total cost of one full protection cycle (preparation + coating, with and without access costs) by the service life it purchases yields the decisive metric: **dollars per square metre per year of protection**. The results:

Grade	Life (yr)	Direct Cost/Cycle ($/m²)	Direct $/m²/yr	Total incl. Access ($/m²)	Total $/m²/yr
None	2.5	21.50	8.60	46.50	18.60
St 2	5.0	26.00	5.20	51.00	10.20
St 3	6.5	31.00	4.77	56.00	8.62
Sa 1	7.5	25.00	3.33	50.00	6.67
Sa 2	10.5	29.00	2.76	54.00	5.14
Sa 2.5	16.5	35.00	2.12	60.00	3.64
Sa 3	18.0	39.00	2.17	64.00	3.56

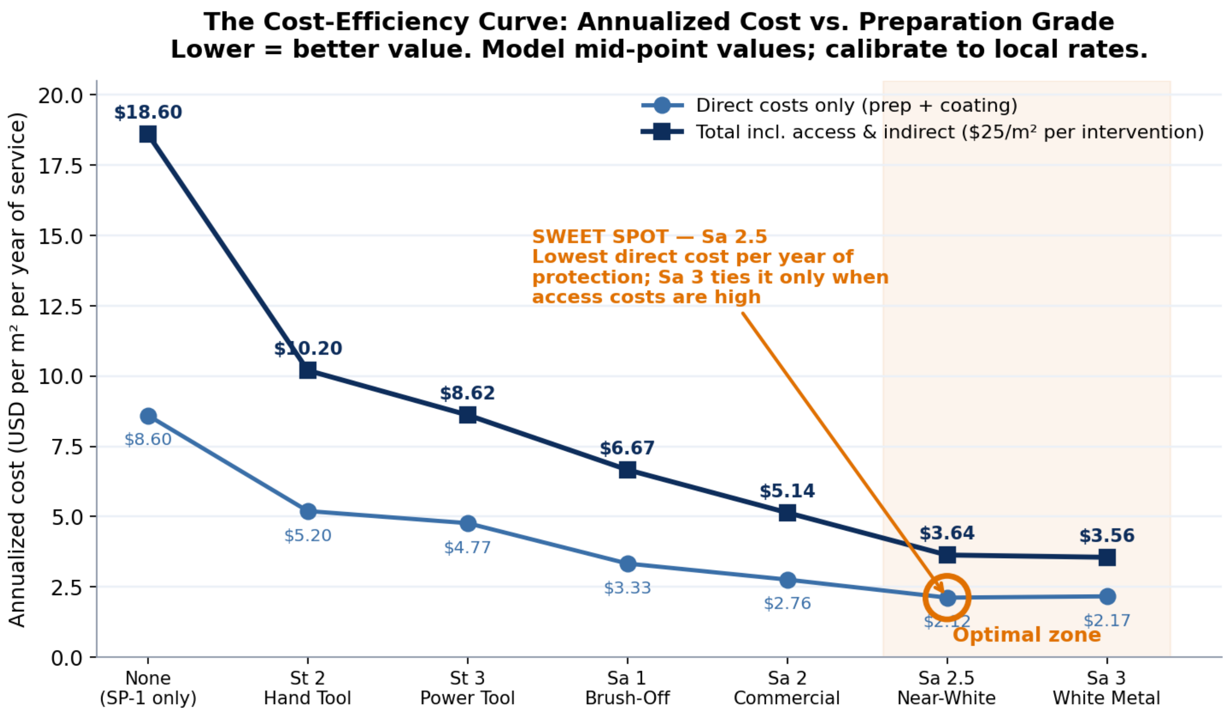

Figure 2 — The cost-efficiency curve. Sa 2.5 is the direct-cost minimum; including access costs, Sa 2.5 and Sa 3 are statistically tied within model precision.

5.2 Reading the Curve

- On direct costs alone, Sa 2.5 is the minimum: $2.12/m²/yr — the sweet spot. Sa 3 costs $2.17 (2% more per year); Sa 2 costs $2.76 (30% more); Sa 1 costs $3.33 (57% more); doing nothing costs $8.60 — over four times the Sa 2.5 rate.
- Including access and indirect costs, Sa 3 edges to $3.56 vs. Sa 2.5 at $3.64 — a 2% difference well inside model uncertainty. The practical reading: Sa 2.5 and Sa 3 tie at the optimum, and the tiebreaker is context (Section 7).

- St 3 power tool preparation is a notable trap: it costs more per m² than Sa 1 or Sa 2 blasting ($11 vs. $5–9) while delivering less life than either. Wherever blast access is possible, power tooling full areas is economically dominated — its legitimate role is spot repair and blast-inaccessible details.

5.3 The 25-Year Horizon

Annualized figures compound over an asset's life. Over a 25-year horizon (fractional repaint cycles, undiscounted for clarity — discounting narrows but does not reorder the gaps):

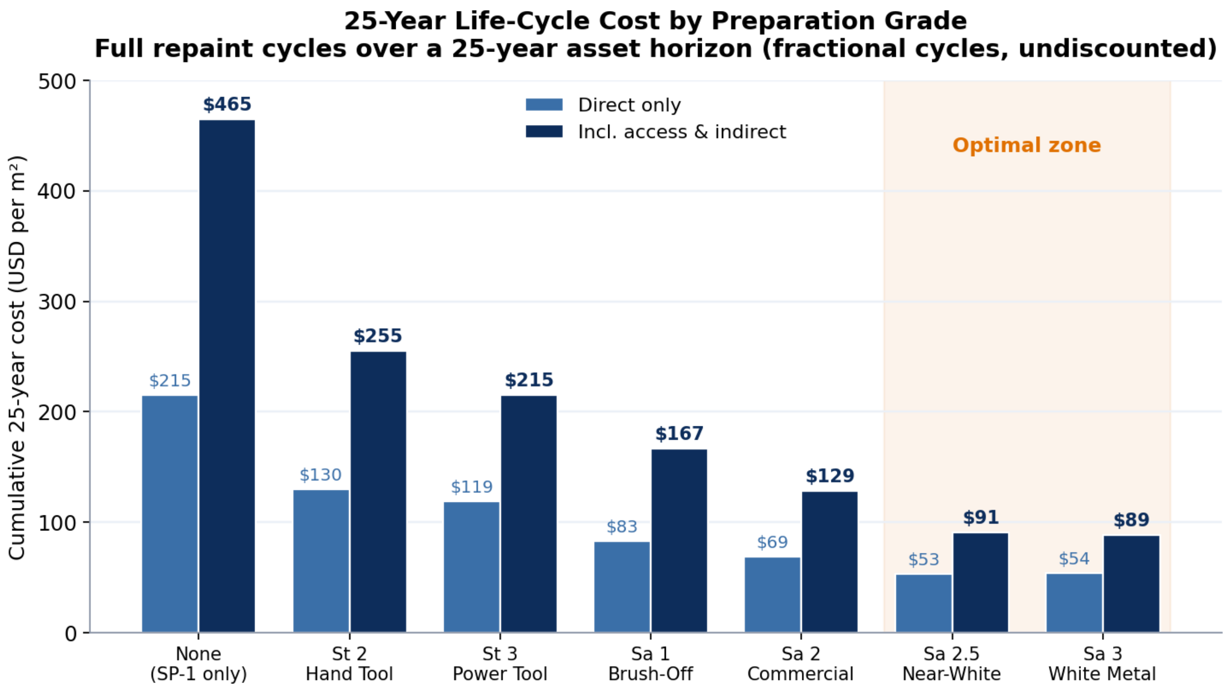

Figure 3 — Cumulative 25-year protection cost per m². The preparation decision alone drives a ~5:1 spread.

Grade	Repaint Cycles in 25 yr	25-yr Direct ($/m²)	25-yr Total incl. Access ($/m²)	vs. Sa 2.5
None	10.0	215	465	+411%
St 2	5.0	130	255	+180%
St 3	3.8	119	215	+136%
Sa 1	3.3	83	167	+84%
Sa 2	2.4	69	129	+42%
Sa 2.5	1.5	53	91	—
Sa 3	1.4	54	89	−2%

The 25-year view makes the economics unambiguous. The no-preparation path requires roughly ten full interventions and costs five times the Sa 2.5 path. Even the respectable-sounding Sa 2 specification costs 42% more over the asset life than stepping up to Sa 2.5 — a step that adds only ~$6/m² at the moment of first application. There is no horizon length at which under-preparation wins.

6. SENSITIVITY: WHAT MOVES THE SWEET SPOT

6.1 Access Cost

As the per-intervention access cost rises from the model's $25/m² toward the $50–300/m² typical of elevated, contained, offshore, or outage-bound work, the optimum shifts decisively toward Sa 3: when each visit is expensive, buying the longest possible interval between visits is worth almost any preparation premium. Conversely, for shop-primed new steel with trivial access cost, Sa 2.5 wins outright.

6.2 Environment Severity

In milder environments (C2/C3) the life differences between Sa 2 and Sa 2.5 narrow and Sa 2 can be defensible for budget-constrained, easily accessible work. In severe environments (C5, CX, Im1–Im4 immersion), the curve steepens: residual contamination is attacked harder, low grades fail faster, and Sa 2.5 becomes mandatory (as NORSOK M-501 and IMO PSPC codify) with Sa 3 frequently justified. For tank linings and immersion service, Sa 3's life advantage widens well beyond the atmospheric ~9% and it becomes the rational specification.

6.3 Spot Maintenance vs. Full Repaint

The analysis above models full-area work. For maintenance painting where breakdown is localised (< 10–20% of area), spot power-tool preparation (SP-11 to bare metal with profile) plus surface-tolerant coating of spots, followed by a full overcoat, is a legitimate and often optimal strategy — it defers the full blast-and-repaint intervention and stretches the asset's maintenance calendar. The sweet-spot logic still applies at the next full intervention.

6.4 What Does Not Move the Answer

Reasonable variation in coating price, labour rates, abrasive type, or discount rate changes the absolute numbers but not the ordering: across all tested sensitivity ranges, Sa 2.5 remains the direct-cost optimum, the Sa 2.5/Sa 3 pair remains the total-cost optimum, and everything below Sa 2 remains dominated. The conclusion is robust because it is driven by the shape of the life curve — steep through Sa 2.5, flat after — which is a physical property of failure mechanisms, not a price assumption.

7. LIMITATIONS

- This is a literature-based controlled model, not a new laboratory exposure programme. Service-life inputs are mid-points of published ranges; individual projects will vary with execution quality, salt contamination control, film build achieved, and micro-environment.
- Cost figures are illustrative mid-2020s USD values for a representative field-blasting context; local labour rates, abrasive logistics, and recycling practice shift absolute numbers (though not the between-grade ratios on which the conclusions rest).
- The constant-coating-system control means the low-grade scenarios are modelled with a system that would not, in practice, be specified over hand-tooled rust; surface-tolerant alternatives extend the low-

grade lives somewhat but published data confirms the directional pattern and the location of the sweet spot are unchanged.

- The model treats each repaint as a full-cost, full-scope intervention; sophisticated maintenance strategies (overcoating windows, spot repair programmes) can defer interventions and improve every grade's economics — proportionately.

8. CONCLUSIONS & RECOMMENDATIONS

8.1 Conclusions

- A sweet spot exists, and it is Sa 2.5 (Near-White Metal, SSPC-SP-10). It is the direct-cost minimum per year of protection and is statistically tied with Sa 3 once access costs are included.
- The single best-value step on the entire preparation spectrum is Sa 2 → Sa 2.5: approximately +57% service life for a preparation cost increase that adds only a few dollars per square metre to a full application cycle.
- Sa 3 is not wasted money — it is insurance whose premium is justified when access is expensive, when service is immersion or severe, or when failure consequence is high. In routine atmospheric work it buys little additional life over Sa 2.5.
- Preparation below Sa 2 is never life-cycle-cost-optimal for full-area coating work. Its apparent savings are consumed several times over by shortened repaint cycles — the no-preparation path costs roughly five times the Sa 2.5 path over 25 years.
- Because access and indirect costs dominate real intervention economics, the most powerful cost lever available to an asset owner is not cheaper preparation — it is fewer interventions, which is precisely what better preparation purchases.

8.2 Recommendations for Specifiers and Asset Owners

- Specify Sa 2.5 (ISO 8501-1) / SSPC-SP-10 as the default minimum preparation for all full-area protective coating work in C3–C5 atmospheric environments, with a defined surface profile (e.g., 50–75 µm, ISO 8503) and a soluble-salt limit (e.g., < 50 mg/m² chloride, ISO 8502).
- Step up to Sa 3 / SSPC-SP-5 for immersion service, tank linings, high-access-cost structures, and assets where the cost of unplanned intervention is severe.
- Reserve St 2/St 3 hand and power tool preparation for spot maintenance (< 10–20% breakdown) and blast-inaccessible details — never as the primary method for full areas where blasting is feasible.
- Evaluate coating proposals on annualized cost per m² per year of protection — not on first cost. Require bidders to state the preparation grade, profile, and salt limits their life projections assume.
- Protect the preparation investment: enforce the 3°C-above-dew-point rule from blast completion through first coat, verify cleanliness with ISO 8501-1 comparators and profile with ISO 8503 methods, and control the blast-to-coat interval to prevent flash rusting — a failed hold here converts Sa 2.5 money into Sa 1 performance.

REFERENCES

Standards:

- ISO 8501-1 — Visual assessment of surface cleanliness (rust grades A–D; Sa/St preparation grades)
- ISO 8502 (series) — Tests for the assessment of surface cleanliness (soluble salts)
- ISO 8503 (series) — Surface roughness characteristics of blast-cleaned steel substrates
- ISO 12944-1/-2/-5 — Corrosion protection of steel structures by protective paint systems: durability classes, environment categories C1–CX and Im1–Im4, and paint systems
- ISO 4628-3 — Assessment of degree of rusting (Ri ratings)
- SSPC-SP / NACE (AMPP) joint surface preparation standards SP-1, SP-2, SP-3, SP-5, SP-6, SP-7, SP-10, SP-11
- NORSOK M-501 — Surface preparation and protective coating (offshore; Sa 2.5 minimum for critical systems)
- IMO Resolution MSC.215(82) — Performance Standard for Protective Coatings (PSPC) for ballast tanks (Sa 2.5)

Published studies and industry data:

- Brevoort, G., Roebuck, A., et al. — 'Expected Service Life and Cost Considerations for Maintenance and New Construction Protective Coating Work', Journal of Protective Coatings & Linings (JPCL); with subsequent periodic updates by Helsel, J., Lanterman, R., et al. — the primary public source for coating service life vs. preparation grade and cost estimating
- NACE International — IMPACT: International Measures of Prevention, Application, and Economics of Corrosion Technologies (2016): global corrosion cost US$2.5 trillion (~3.4% of global GDP); 15–35% savings available through corrosion management
- US Federal Highway Administration — bridge coating performance and life-cycle cost research programmes
- SSPC/AMPP technical guidance on painting cost structure (surface preparation typically 30–50% of project cost) and failure attribution (majority of premature failures traced to surface preparation deficiencies)

PanBlast technical data:

- PanBlast Open Blasting Technical Guide — blast cleaning rates vs. surface cleanliness and condition; garnet consumption by nozzle size
- PanBlast / Pan Abrasives Abrasive Media Guide — EnviroGrit™ garnet properties, recyclability, and consumption characteristics
- PanBlast Introduction to Surface Preparation (Rev. 2) and Surface Preparation Standards Reference

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