

Cost of Quality in Photopolymer Manufacturing: A General Prevention-Appraisal-Failure Framework, and the Photopolymer-Specific Cost Evidence Still Required

Engineering review

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ER-472 · Engineering Review · Version 0.1 · 12 October 2026

Abstract

General cost-of-quality categories can organise expenditure in photopolymer manufacturing, but they cannot establish sector-specific costs, savings or an optimum allocation. This review develops a proposed accounting framework using prevention, appraisal and failure as organising categories. The literature basis is a general review of cost-of-quality models consulted at publisher-abstract depth. No photopolymer cost dataset is analysed. The proposed contribution is a traceable connection between a quality activity or event, its accounting boundary, the resources attributed to it and the product or observation period used for comparison. Special attention is given to shared resources, rework, delayed returns and double counting. The framework treats investment comparisons as hypotheses requiring local measurement and a credible comparison. It preserves the separate roles of failure classification and returned-product investigation rather than replacing them with cost categories. A synthetic reconciled account and a restricted break-even calculation demonstrate intervention cost, delayed returns and the consequences of the chosen accounting boundary.

Keywords: cost of quality; photopolymer manufacturing; prevention; appraisal; failure cost; accounting boundary; evidence investment

1. Scope and literature basis

Schiffauerova and Thomson review general approaches to quality costing. Their publisher abstract identifies the prevention-appraisal-failure model as a commonly implemented approach and emphasises that model choice depends on organisational context [1]. That supports a framework-level discussion. It does not establish a photopolymer cost distribution, a saving from a particular intervention or a preferred inspection policy.

The following accounting structure is proposed engineering analysis. It is intended to organise local evidence, not to report observed industrial performance. ER-472 owns the cost consequences of prevention, appraisal and failure. ER-484 retains failure taxonomy and minimum failure records. ER-483 retains warranty and returned-product evidence and exposure reconstruction. A cost entry can refer to those records without substituting an accounting label for a failure mechanism.

2. Define the accounting object

A cost comparison requires a declared object. Possible objects include a manufactured batch, an accepted component, a defined production interval or a bounded quality intervention. The framework proposes choosing the object before aggregating costs and retaining the rule used to assign shared expenditure.

For example, an inspection activity serving several products could be recorded once at the resource level and allocated using an explicitly stated rule. This is an illustrative accounting design, not evidence that a particular allocation basis is economically correct. The appropriate basis would need to reflect the local purpose and available measurements.

The reporting record would distinguish booked expenditure from an estimate and both from a hypothetical opportunity cost. Without that separation, apparent precision in a total can conceal very different levels of evidential support.

3. Map activities to categories without changing their identity

The proposed framework would assign a quality-related activity to prevention, appraisal or failure according to its declared purpose and trigger. Candidate prevention activities could include work intended to avoid a defined defect. Candidate appraisal activities could include work intended to assess conformity. Candidate failure costs could include resources consumed because a specified nonconformity occurred. These are examples of intended categorisation, not measured photopolymer sector practices.

An activity can have more than one purpose. If it is divided between categories, the division would need an explicit rule. If it is left in a combined category, that limitation would need to remain visible. The framework favours a reproducible assignment over forcing every activity into a category that the records cannot support.

4. Preserve the event-to-cost connection

A failure-cost entry could point to the underlying event identifier, the affected item or batch, the disposition and the resource record. The event would remain an observation to be investigated through its own evidence. Its financial consequence would be a separate attribute.

A high-cost event is not automatically the most frequent event, and a frequent category is not automatically the largest expenditure. A proposed review would therefore retain count, severity description and cost as different fields. It would also preserve the interval over which each was observed.

Returned-product costs can arrive after the manufacturing period. The framework proposes declaring whether they are assigned to the return period, the originating production cohort or another stated basis. Mixing these treatments without disclosure could make periods incomparable even if every individual invoice were correct.

5. Control rework and double counting

A proposed local record would follow material or parts through their disposition. Rework could consume additional resources while leaving a usable output. Scrap could remove output while generating other costs or recoveries. The accounting treatment would need to state whether the initial resource use, additional processing and recovery are already represented elsewhere in the total.

The same principle applies to labour and equipment. A resource should not silently enter the calculation through both a fully burdened activity rate and a separately added overhead covering the same resource. This is a proposed consistency check, not a sector-specific costing rule.

A transparent total could therefore retain its component entries, allocation rules and exclusions. The objective is to make another analyst able to reproduce the total under the same rules and identify how it changes under a different declared boundary.

6. Compare investments as testable propositions

An intervention might increase prevention or appraisal expenditure while changing failure-related expenditure. Whether that improves an outcome is an empirical question. The proposed analysis would record the intervention, the intended effect, the comparison period or group, changes in production conditions and the cost components expected to respond.

A before-and-after reduction alone would not establish the intervention as its cause if product mix, output, observation duration or reporting practice also changed. The framework proposes making such changes explicit rather than converting a temporal association into a saving attributed to the intervention.

Decision use also depends on uncertainty. Where an amount is estimated, a range or sensitivity analysis could show whether the preferred action changes under plausible assumptions. This review supplies no numerical ranges, probability model or universal investment threshold; these would have to be justified from local evidence.

7. Photopolymer-specific evidence still required

Applying the framework requires records linking quality-related activities to the particular material, process and product under study. Potentially relevant activities could arise during formulation handling, manufacture, cleaning, post-processing or inspection, but their inclusion must follow the declared accounting question. Their mere presence in a workflow does not make all their costs quality costs.

A useful dataset would preserve the activity definition, timing, resource quantity, valuation basis, allocation rule, product denominator and uncertainty. It would also identify omissions and delayed observations. Comparison across sites would require examination of these definitions before the resulting totals could be treated as comparable.

8. A reconciled illustrative cost-of-quality account

The following example is synthetic and uses monetary units without representing a company or production dataset. For a defined period, suppose prevention activities cost 600, appraisal costs 400, recorded internal failures cost 500 and recorded external failures cost 200. The total cost of quality under this boundary is 1700. If the period produces 1000 accepted parts, the descriptive ratio is 1.70 per accepted part. This denominator must accompany the ratio; it is not a price, margin or total manufacturing cost.

Now suppose a proposed intervention adds 200 to prevention and the next period records internal-failure expenditure of 250, with the other categories and accepted output unchanged. The new total is 1650, a reduction of 50. Reporting only the 250 reduction in internal failures would overstate the net change because it omits the intervention expenditure. These figures illustrate reconciliation. They do not establish causation, and the comparison would need to consider changed product mix, observation time and event capture before attributing any saving.

An individual rework event should retain its resource entries. If the original manufacturing cost is already included in the production account, a cost-of-quality view can identify that amount by reference without adding it again to a combined total. The reporting question determines whether the account is a reclassification of existing expenditure or a calculation of additional expenditure. Mixing those two interpretations creates double counting even when each entry has a valid invoice.

9. Delayed returns and an intervention decision

A return received this month may belong to an earlier production cohort. A period-based account can answer what expenditure occurred now; a cohort-based account can answer what observed expenditure has accumulated for the relevant products. Neither is inherently sufficient for the other question. A comparison of young and old cohorts should state the available follow-up, because the younger cohort has had less time to generate recorded external failures.

For a proposed intervention with additional cost I , avoided-event count A and avoidable cost per event c , the simple net expenditure change is $I - Ac$. The break-even condition $Ac = I$ is an arithmetic property of this deliberately restricted model. It does not include unmeasured safety, service, capacity or opportunity effects. Where c is estimated, varying it can reveal whether the decision depends on a poorly supported valuation.

The accounting analysis should preserve the underlying technical event and investigation identifiers. It can establish the resources associated with an event without establishing the event's root cause. That separation allows the quality-cost record to be corrected when the technical interpretation changes, while keeping the original expenditure traceable.

10. Evidence hierarchy and transferability of additive-manufacturing cost models

The literature provides distinct evidence tiers that should not be collapsed. Schiffauerova and Thomson [1] survey cost-of-quality models across industrial settings and report that the prevention-appraisal-failure model is commonly implemented. Their synthesis concerns the organisation of quality expenditure, not measured cost coefficients for photopolymer manufacturing. It supports the account structure, but does not support an expected rejection rate, inspection return on investment or optimum prevention budget for any resin-printing operation.

Sartini, Favi and Mandolini [2] develop a techno-economic analysis for vat photopolymerisation within rapid investment casting. Their manufacturing-cost boundary includes machine time, materials, labour, energy and post-processing operations. It demonstrates why washing, support removal and utilisation cannot be omitted from a process cost model. However, these normal process steps are not automatically quality costs. They become prevention, appraisal or failure entries only when their purpose or triggering nonconformity

meets the declared accounting classification. Using all post-processing expenditure as an internal failure category would be a category error.

Colosimo, Cavalli and Grasso [3] model the economic consequences of defects, scrap and in-situ monitoring in metal powder-bed additive manufacturing. This is a useful methodological comparator for linking inspection decisions to failure consequences. It is not direct empirical evidence for vat photopolymerisation: sensing approaches, defect frequencies, process economics and corrective actions differ. Transfer should therefore be restricted to the structure of the decision problem, not its numerical parameters.

11. Accepted-output denominators, yield and uncertainty

Cost per accepted component is sensitive to the denominator. A batch may include initially accepted parts, parts accepted following rework, rejected parts and work in progress. A proposed cost-of-quality rate should state whether the denominator is final accepted output, first-pass accepted output, saleable output or a physical production quantity. Switching denominator definitions across reporting periods can create an apparent improvement even when underlying expenditure is unchanged.

To illustrate the arithmetic rather than assert industrial performance, consider an entirely synthetic batch of 120 starts, 90 accepted first pass, 10 subsequently accepted after rework and 20 rejected. First-pass yield is $90/120 = 75\%$; final accepted yield is $100/120 = 83.3\%$. If identified quality expenditure is 900 currency units, the descriptive quality-cost intensity is $900/100 = 9.0$ per final accepted part, whereas dividing by 120 starts yields 7.5 per start. These are different indicators, not conflicting observations. Neither should be interpreted as the fully loaded manufacturing cost.

Uncertainty should be disclosed separately for measurement uncertainty, allocation uncertainty and observation incompleteness. For example, recorded rework minutes may be directly observed while equipment overhead is allocated from a monthly pool. An external-return estimate can remain censored when cohort follow-up is incomplete. Reporting one precise total without these distinctions disguises the evidence quality of its inputs. An auditable comparison should retain both the baseline assumptions and scenarios for plausible allocation or late-return changes.

12. Quality investment appraisal and decision thresholds

A prospective inspection investment should be evaluated using incremental rather than gross expenditure. Under a stated horizon, the incremental cost comprises implementation, operating and maintenance costs, including time displaced from other activities. The potential benefit comprises avoided resource loss or other outcomes actually linked to the intervention. An illustrative break-even condition is: incremental prevention and appraisal cost less than or equal to the expected reduction in failure-related cost, adjusted to a common observation window. This is a decision identity, not a finding that increased inspection will save money.

Inspection can also shift the point at which a nonconformity is discovered rather than change its physical incidence. Earlier detection may reduce the resources added to a defective item before its rejection, while increasing recorded internal failures and reducing later external failures. A superficially worse internal-failure count can therefore coexist with an improved cost outcome. Evaluating the intervention requires an event definition held stable across periods, a consistent valuation basis, comparable case mix and explicit treatment of displaced capacity.

Where production volumes vary, a sensitivity analysis should distinguish fixed inspection expenditure from variable per-part activity, and distinguish avoidable from sunk costs. Expected savings obtained by multiplying a historical rejection rate by an assumed unit cost must disclose uncertainty in both terms, particularly when the rate is estimated from few observations. Neither this review nor the available photopolymer source [2] establishes a universal monitoring investment threshold.

13. Reproducibility protocol for a photopolymer cost-of-quality study

A future empirical application should predefine its manufacturing population, observation window, unit of analysis and inclusion boundary. It should register an activity identifier, quality purpose or triggering event, timestamp, resource quantity, unit valuation, allocation rule and acceptance disposition. The quality-cost record should link to a source record rather than replace it: physical failure mechanisms and minimum failure evidence belong to ER-484, while returned-product evidence and exposure reconstruction belong to ER-483. ER-472 interprets only the cost consequences of those observations.

The analysis should report totals by prevention, appraisal, internal failure and external failure; first-pass and final acceptance denominators; delayed-cost treatment; shared-cost allocation; and the proportion of entries estimated rather than directly booked. Site-to-site comparisons require matched accounting boundaries before interpreting rates. A sensitivity appendix should test alternative overhead allocations, follow-up horizons and rework valuations. These are proposed reporting requirements, not an established sector standard.

The strongest future validation would use traceable production and finance records collected prospectively, with a documented intervention and matched comparison where feasible. Where causal identification is unavailable, the conclusion should be confined to descriptive cost patterns and explicit scenarios. A convincing review must keep the distinction between general cost-of-quality theory [1], process-specific manufacturing economics [2] and transferable but technologically distinct quality-investment models [3].

Avoiding category errors in the cost of quality

Prevention, appraisal and failure costs should be recorded at the same unit of analysis and over a defined observation period. A quality engineer must not count the same rejected build both as scrapped resin and as the entire invoice value of a subsequent replacement, unless the separate cost elements and their allocation are explicitly disclosed. Internal failure is attributable before acceptance; external failure begins when an accepted article generates a return, warranty action or field correction. The technical coding of the underlying failure belongs to ER-484, and returned-product exposure reconstruction belongs to ER-483. The present article evaluates the financial consequences of those records, not their technical diagnosis.

For photopolymer operations, the useful economic denominator may be accepted parts, conforming build volume or qualified manufacturing hours, depending on the process. Sampling-only appraisal cannot be compared with comprehensive inspection without

accounting for unobserved defects. Likewise, a fall in recorded warranty cost might indicate improved quality, a shorter observation window or incomplete capture of external failure. Cross-site comparisons should disclose product mix, warranty horizon, acceptance thresholds and the treatment of rework. These recommendations are proposed reporting controls, not measured outcomes of the sources cited.

Linking failure costs to accepted output without duplicate counting

The prevention-appraisal-failure taxonomy becomes useful only after each event is assigned a unique accounting path. A resin batch that fails incoming inspection may generate material disposal and test costs; counting its replacement purchase as both an internal-failure cost and a second consumption of the same material would inflate the ledger. The review should identify event identifiers, decision dates and cost ownership so that an audit can reproduce each allocation.

Yield denominators require special care. Cost per printed build can decline while cost per accepted article rises if rework or rejection is omitted. A production review should reconcile resin charged, recoverable inventory, rejects, accepted output and return events before publishing a unit-cost comparison. This is an accounting proposal, not an empirical claim that any particular defect rate is typical of vat photopolymerisation.

The value of prevention must be stated as a counterfactual with uncertainty. An intervention is economically supported only if measured changes in accepted yield or avoided rework are distinguished from concurrent changes in demand, machine utilisation and product complexity. Classification of defect mechanisms remains the remit of ER-484; investigation of returns and exposure reconstruction remains within ER-483.

14. Limitations and conclusions

This review is a proposed cost-of-quality framework, not a photopolymer industry cost survey. The literature includes a general synthesis of quality costing [1], a relevant vat-photopolymerisation techno-economic model [2] and a transferable monitoring-economics comparator from metal additive manufacturing [3]. None provides a measured photopolymer cost-of-quality distribution, an intervention-specific causal saving or an optimal prevention-appraisal allocation. The contribution is an auditable link from bounded activities and verified events to financial consequences, explicit accepted-output denominators and uncertainty-sensitive investment decisions. Its industrial utility requires prospective validation with matched accounting boundaries and traceable local records.

Competing interests

The author is Founder, CEO and CTO of 3Dresyns by Resyner Technologies S.L. The company develops and supplies photoresins and related process materials. No proprietary formulation, manufacturing sequence, process window or comparative product recommendation is disclosed.

Data availability

No experimental or financial dataset was generated. Numerical examples are synthetic and are not derived from company records. The literature supports the stated general and process-cost frameworks; all proposed reporting rules and decision identities are engineering analysis.

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