

Value-of-Information Methods for Prioritising Photopolymer Research: Uncertainty, Decision Impact and Experimental Choice

Choosing the next experiment by how much it can improve a decision, not by novelty, convenience or the size of the current uncertainty alone

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Abstract

Photopolymer research portfolios often contain many uncertain questions but limited experimental capacity. Value-of-information methods provide a decision-theoretic way to rank information by the improvement it could produce in a downstream decision. This review translates expected value of information, expected value of perfect information and expected value of sample information into photopolymer engineering terms. It defines the required decision model, distinguishes reducible from irreducible uncertainty, and shows how experiment cost, feasibility and time modify priority. The method is proposed as a research-allocation tool, not as a universal economic monetisation of scientific knowledge.

Keywords: value of information; research prioritisation; photopolymer; uncertainty; experimental design; decision analysis; EVSI

1. Uncertainty alone does not set research priority

A poorly known parameter may have little effect on an engineering choice, while a moderately uncertain parameter near a qualification boundary can control the decision. Value-of-information analysis formalises this distinction by asking how much better the expected decision could become if uncertainty were reduced [1].

2. Start from a decision and loss function

The method requires explicit alternatives, uncertain states and consequences. In photopolymer development, alternatives may be formulation routes, cure protocols, material selections or qualification actions. Consequences can combine failure risk, performance, cost, schedule and rework. Without a defined decision, information value is undefined.

Table 1. Value-of-information quantities in engineering language.

Quantity	Question answered	Use
EVPI	what is the value of eliminating all decision-relevant uncertainty?	upper bound
EVPPi	which uncertainty block matters most?	target selection
EVSI	what is the expected value of a proposed finite study?	design comparison
net VOI	EVSI minus experiment/resource cost	go/no-go research decision

3. EVPI defines the ceiling

Expected value of perfect information asks how much decision performance could improve if uncertainty were removed completely. It is an upper bound on what any experiment about that uncertainty can be worth. A high-uncertainty parameter with negligible EVPI should not dominate the research queue.

4. Partial and sample information identify practical experiments

Expected value of partial perfect information isolates a subset of uncertainties. Expected value of sample information estimates the benefit of a realistic finite experiment and can therefore compare candidate study designs [2]. The experiment is worthwhile only if its expected decision improvement exceeds its resource, time and opportunity cost under the chosen utility model.

Table 2. Photopolymer experiment prioritisation inputs.

Input	Example
decision	select cure protocol for service requirement
uncertainty	dose-response slope and part-to-part variation
consequence	failure risk, cycle time, dimensional loss
experiment	dose-temperature factorial study
cost/time	machine hours, specimens, decision delay

5. Engineering experiments rarely update one parameter only

A cure experiment may inform kinetics, conversion variability and process robustness simultaneously. Information models should therefore represent correlated updates rather than assign independent value to every measured quantity. Conversely, a measurement can have low value if downstream decisions remain dominated by another unresolved uncertainty.

6. Time and obsolescence change information value

Information delivered after a design freeze or technology transition can have little operational value. Research priority should therefore discount slow experiments when a decision is imminent and recognise options that preserve flexibility. Recent decision-analysis work emphasises that information value depends on the decision problem in which the information will be used [3].

Table 3. Reasons high uncertainty may have low value.

Reason	Interpretation
decision insensitive	all plausible values select same action
not reducible	experiment cannot resolve dominant variability
too late	result arrives after decision
dominated	another uncertainty controls outcome
too costly	information benefit below resource cost

7. Portfolio use and stopping rules

At portfolio level, candidate experiments can be ranked by net expected information value per constrained resource, while preserving mandatory safety or regulatory work as non-discretionary. Research stops when remaining reducible uncertainty no longer changes the preferred decision enough to justify further information cost. This creates an auditable alternative to research-by-habit. FAIR metadata and persistent identifiers [4] are therefore operational requirements when research-priority decisions must be revisited after new experiments or model revisions.

8. Scope boundary and neighbouring reviews

ER-399 owns value-of-information methods for choosing among candidate research actions. ER-398 owns whether benchmark data are fit for modelling, while ER-400 owns corpus-level dependency mapping and research-priority synthesis. ER-399 supplies the decision-analysis method; it does not define the corpus architecture that applies it.

9. Preposterior analysis connects a proposed experiment to a future decision

Value-of-information analysis is prospective. The experiment is evaluated before its result is known by integrating over the possible data it may produce and the decisions that would follow from each possible outcome. Structural-engineering applications use this preposterior logic to determine whether inspection or monitoring information is worth its cost and to compare candidate information-gathering schemes [5]. In photopolymer R&D the same structure can compare, for example, an additional cure-kinetics study, a long-term ageing programme or a machine-transfer experiment. The analysis asks not which experiment is most interesting, but which can most improve the downstream decision under the current uncertainty model.

10. Decision models should expose the action boundary

Information has high value when plausible experimental outcomes can change the preferred action. This makes the decision boundary central. Suppose two formulations have similar expected performance, but one has large uncertainty near a minimum toughness requirement. An experiment that resolves that uncertainty can have high value. By contrast, if one formulation dominates under every plausible state, reducing uncertainty may have little decision value even when the parameter itself is poorly known. ER-399 therefore requires a sensitivity map showing which uncertain quantities can actually change the selected action before research priority is assigned.

11. Correlated observations and shared experiments

A single experiment can update several uncertain quantities at once. A temperature sweep may inform cure kinetics, conversion variability, modulus and dimensional drift; an ageing campaign may inform several failure modes with correlated outcomes. Treating each observation as an independent information source double-counts value. The preposterior model should therefore represent shared latent variables and correlated measurement error where they materially affect the decision. Conversely, two nominally different experiments may be redundant if both update the same dominant uncertainty. Portfolio ranking must be based on incremental information value conditional on experiments already selected.

12. Constraints, irreversibility and mandatory work

Not every research action is discretionary. Safety, regulatory or contractual qualification may be mandatory even when its calculated net information value is low. Other experiments may be impossible within schedule, sample or equipment constraints. The portfolio therefore separates mandatory evidence from discretionary information acquisition and optimises only within the latter. Irreversible decisions also increase the value of early information, whereas flexible decisions can sometimes be deferred until more data arrive. Time-to-information, decision deadline and option to delay should therefore appear explicitly in the model rather than being hidden inside a generic cost term.

13. Worked prioritisation logic

Consider three candidate studies before choosing a production cure protocol: a short conversion study, a mechanical-replicate study and a six-month ageing study. The conversion study may be inexpensive but have low value if both candidate protocols already exceed the conversion level needed for the decision. The replicate study may have high value if current scatter leaves a meaningful probability of selecting the wrong protocol. The ageing study may have the largest potential impact but arrive after the production freeze, reducing operational value unless the decision can be delayed. The correct priority therefore emerges from decision impact, uncertainty reduction, timing and cost together. This worked logic is the core engineering contribution of ER-399: uncertainty is a research input, not the priority score itself.

14. EVPI, EVPPI and EVSI answer different portfolio questions

Expected value of perfect information (EVPI) is the ceiling: it asks how much would be gained if all relevant uncertainty vanished. Expected value of partial perfect information (EVPPI) asks which subset of uncertainties is worth resolving. Expected value of sample information (EVSI) asks what a realistic study with finite sample size and measurement error is expected to contribute. These quantities should not be conflated. A high EVPI can coexist with low EVSI when available experiments are weak, slow or noisy. Conversely, a modest uncertainty can have high EVSI if a cheap measurement reliably resolves a decision boundary. [1,2,5]

15. Net value requires explicit study cost and consequence scale

The benefit side of information value is measured in the same utility or loss scale as the decision. The cost side includes direct experimental cost, consumed material, machine time, analyst time, delay and opportunity cost. Where consequences include safety or compliance, monetary conversion may be inappropriate; a multi-attribute utility or constrained decision rule can be used instead. What matters is that the trade-off is explicit and that mandatory constraints are not treated as optional costs. The resulting ranking is conditional on the chosen decision model and should be sensitivity-tested to plausible alternative weights.

16. Portfolio sequencing and adaptive research

Research projects are rarely independent. The result of one experiment can change the value of the next. A rational portfolio therefore supports adaptive sequencing: perform the first high-value experiment, update the decision model, then recompute the value of remaining studies. This can terminate a programme early when the preferred action becomes robust or redirect effort when a surprising result exposes a new dominant uncertainty. The audit trail should preserve each prior model and ranking so that changes in research priority can be explained rather than appearing arbitrary.

17. Worked decision threshold example

Suppose two formulations are candidates for a component and the preferred action depends on whether aged elongation remains above a functional threshold. Existing evidence places one formulation clearly above the boundary and the other close to it with substantial batch uncertainty. Measuring the already-safe formulation has low information value because the action is unlikely to change. A targeted ageing study on the boundary formulation can have high EVSI because a realistic result may reverse the selection. The example illustrates the central point: research priority follows probability of changing the decision multiplied by the consequence of that change, not the visual size of an error bar alone. [1,2]

18. Sensitivity of value-of-information rankings

Information-value rankings depend on the decision model, priors, loss function and proposed experiment. A robust portfolio should therefore test whether the ranking changes across plausible assumptions. If one experiment is top-ranked only under a narrow cost estimate or prior, that fragility should be reported. If the same study remains valuable across a wide range of assumptions, the case for prioritisation is stronger. Sensitivity analysis also exposes parameters whose uncertainty affects the research ranking itself, which can justify a low-cost scoping measurement before committing to an expensive qualification programme. [1-3,5]

19. Governance of research stopping

Stopping is part of experimental design. A programme may stop when one action has high posterior probability of being optimal, when residual EVPI falls below the cost of further work, when no feasible experiment has positive expected net value, or when an external deadline makes new information unusable. The stopping criterion should be written before the final result is known and recorded with the decision. Continuing experimentation after the decision is already robust wastes resources; stopping too early can lock in avoidable uncertainty. Explicit stopping governance therefore links statistical learning to engineering programme control.

20. Imperfect information and correlated uncertainty

Experiments rarely resolve one uncertainty independently. A cure study may inform conversion, modulus and ageing response simultaneously; a chemical analysis may update both composition identity and residual-content risk. EVSI calculations should therefore account for correlated parameters and shared observations where those correlations affect the decision. Double-counting the same information across separate project proposals can otherwise make a portfolio appear more valuable than it is. The decision model should identify which uncertainties each experiment can update and whether multiple proposed studies are redundant or complementary. [2,3,5]

21. Value of information under constrained feasibility

The highest theoretical information value may belong to an experiment that cannot be executed safely, quickly or at the required scale. Feasibility constraints should therefore enter before final ranking. Candidate studies can be screened for available equipment, specimen count, material consumption, regulatory limits, destructive testing requirements and lead time. The ranking then compares only feasible actions or explicitly values investment needed to make a high-value study feasible. This prevents the portfolio from repeatedly selecting an ideal but inaccessible experiment.

22. Reporting a value-of-information analysis

A reproducible VoI report should state the decision alternatives, uncertain quantities, probability model, loss or utility function, baseline preferred action, candidate experiments, assumed sampling distributions, study costs and stopping rule. It should report EVPI as the ceiling and the expected net value of each realistic study, with sensitivity analysis for influential assumptions. The report should also identify which experiment would be selected next after each major possible result where adaptive sequencing is intended. This makes the research priority an auditable engineering decision rather than an expert ranking presented without its assumptions. [1-3,5]

23. Limitations and research priorities

Value-of-information analysis is only as credible as the decision model and the experiments considered feasible. Photopolymer applications often have sparse probability data, correlated properties and hard safety or compliance constraints, so apparently precise VoI estimates can overstate certainty. Priorities are worked case studies in which predicted information value is compared with the actual

decision change after an experiment, sensitivity analysis for elicited priors and loss weights, and portfolio methods that update after shared experiments. Another useful direction is linking VoI to qualification gates so that mandatory evidence is separated from discretionary research optimisation. ER-399 therefore recommends VoI as a transparent prioritisation framework, not as an automatic numerical ranking detached from engineering judgement. [1-5]

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Competing interests

The author is Founder, CEO and CTO of 3Dresyns by Resyner Technologies S.L.; ER-399 is a methodological engineering review and does not provide a comparative commercial recommendation.

Data availability

ER-399 is a literature-based engineering review; no new experimental dataset was generated.