

# Manufacturing-Process Data and Digital Twins in Additive Manufacturing: Limits of Transfer to Field Performance of Photopolymer Products

*Lifecycle assurance and responsible innovation*

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## Abstract

Additive-manufacturing data systems and digital twins can organise process and quality information, but process-side data are not equivalent to field-performance evidence. The two sources available to this review address AM data, monitoring, machine learning, digital twins and quality-centric data synchronisation at manufacturing level [1,2]. They do not establish post-deployment performance for photopolymer products, and they do not supply a privacy framework for such field data. This review therefore treats field performance as a transfer boundary rather than an evidenced property. It identifies the minimum post-deployment evidence that would be needed before manufacturing-process data could support field-performance updating for a photopolymer product. A proposed prediction record and validation design separate the intended transfer unit, information available at decision time and the consequences of model use.

**Keywords:** manufacturing-process data · digital twins · additive manufacturing · field performance · photopolymer products · transfer limits · privacy

## 1. Scope and ownership

ER-482 asks what manufacturing-process data and AM digital-twin architectures can and cannot support when the target claim concerns field performance of a photopolymer product. The article makes no field-performance claim for any photopolymer product and no privacy claim.

## 2. Controlled evidence base

Source [1] reviews big data, machine learning and digital twins in additive manufacturing and is manufacturing/process oriented [1]. Source [2] reviews quality-centric digital twins in AM, including data synchronisation and model updating, also at the process and quality layer [2]. Both are AM-general rather than photopolymer-specific field-use evidence.

## 3. Manufacturing-process data are upstream evidence

Machine settings, monitoring signals, process histories, inspection results and quality records can describe how a part was made. They can support traceability and model updating at the manufacturing layer. They do not, by themselves, establish what happened after deployment in a real service environment.

## 4. Field performance is a different evidence layer

A field-performance claim requires observations after the product enters its intended environment. The target evidence must therefore identify the deployed article or cohort, the use context, elapsed service, relevant exposures, measured outcome, failure or censoring state where applicable, and the relation back to the manufactured state. Neither controlled source provides that photopolymer product evidence [1,2].

## 5. The transfer problem

A process-side model may be useful without being a field model. Transfer becomes defensible only if the variables used upstream are linked to outcomes observed downstream and that linkage is tested rather than assumed. This review therefore treats the relation between manufacturing-process data and field performance as a hypothesis to be validated for the intended photopolymer product.

## 6. Minimum post-deployment evidence needed to close the gap

At minimum, a future field-performance evidence set should contain: a persistent product or cohort identity; the corresponding manufacturing and post-processing state; deployment context; service duration; relevant environmental or loading history; defined outcome or failure criteria; measurement method; observation time; and a link between the field observation and the process record used for model updating. Without those elements, the field layer cannot be reconstructed reliably.

## 7. Bias and representativeness

Field observations can be selectively observed because products that remain in service, are returned, are monitored or are reported may not represent the whole deployed population. The present two-source evidence set does not quantify that bias for photopolymer products. Any future update model should therefore expose the sampling route and missingness rather than treating incoming field records as an unbiased stream.

## 8. Privacy remains an unevidenced requirement

If future field records contain information that can identify a person, organisation, site or usage pattern, privacy governance may become necessary. The controlled evidence for this article does not establish a privacy method, so no procedure is asserted here. Privacy is retained only as a requirement to be resolved before such data are collected or reused.

## 9. Model updating

Digital-twin and quality-centric AM literature supports the general concept of updating models with new information [1,2]. For field performance, however, an update should occur only after the incoming data are shown to correspond to the product state and outcome of interest. An update based on unmatched process and field populations can create apparent learning without validated transportability.

## 10. Specify the prediction before assessing the twin

The proposed validation record identifies the predicted quantity, prediction time, information available at that time and decision supported by the prediction. Predicting a measured process response during manufacture is a different task from predicting a field failure months later. A model should not inherit the stronger task merely because both are represented in the same software environment.

A useful test separates development data from data representing the intended future use. If observations from the same build or material batch appear in both sets, the evaluation may exploit shared conditions that are not available in a genuinely new production event. The split should therefore follow the unit of intended transfer, such as a new build, lot, machine or time period. This is a proposed validation principle, not a claim that one split is sufficient for every model.

The record should also identify variables measured after the decision. A model used to decide whether to continue a build cannot legitimately depend on a final inspection result that becomes available only after completion. Apparent prediction performance with that information would not represent the operational task.

## 11. Evaluate calibration and decision consequences

An expanded evaluation would compare predicted and observed quantities under a declared endpoint and retain uncertainty. For a probabilistic output, ranking higher-risk cases and accurately estimating their probabilities are different properties. For a numerical prediction, low average error can coexist with poor performance in a critical region. Reporting only one global fit statistic can therefore conceal the part of the prediction relevant to the decision.

A proposed deployment exercise would compare the decision made with the model against a defined baseline, recording both errors and cases where the system declines to decide. A model that flags unfamiliar inputs should be evaluated on that behaviour rather than scored only on the cases it accepts. The conditions defining unfamiliarity must be declared before the operational assessment.

Following a process change, the validation question is whether the previous evidence still represents the new inputs and outcomes. Retraining is not automatically proof that it does. A new model version should preserve its training scope, evaluation set and decision boundary. These controls make a process twin testable while keeping field-performance claims dependent on appropriately linked field observations.

**Additional critical synthesis: evidence, applicability and qualification: Model outputs need an explicit domain of validity:** A digital twin may describe the printer, a process step, an inspection outcome or the product in service. These are different models with different observations and validation obligations. Machine telemetry can support inference about exposure or process stability, yet it does not directly measure monomer conversion, residual extractables, mechanical properties or environmental durability. A predictive model must identify its inputs, observable targets, confounders and the conditions under which a prediction is valid. Combining unmatched machine logs with downstream field outcomes risks constructing apparent correlations that do not survive deployment.

**Data leakage and independent evaluation:** Validation should separate training from evaluation by more than a random row split when data include repeated parts from the same build, printer or lot. Otherwise the model may recognise shared production conditions rather than generalise to an unseen manufacturing setting. Holdouts by batch, machine, material family and time period test distinct generalisation questions. Reporting should include error distribution, uncertainty, failure-to-predict cases and the effect of missing data. High average accuracy can hide unacceptable false acceptance in rare but important product states.

**Closing the manufacturing-to-service evidence chain:** A process-to-performance model becomes more useful when each observation has traceable links to source material, curing history, inspection state and service exposure. The linkage must preserve failed parts and missing outcomes rather than preferentially recording successful products. Calibration and drift monitoring are essential when software, resin or hardware revisions change the data-generating process. Literature on digital twins in additive manufacturing provides the methodological starting point, but photopolymer-specific field-life predictions require independent datasets not supplied simply by machine telemetry.

**Critical evidence synthesis: Digital-twin evidence: calibration, observability and external validity:** A manufacturing data stream can support state monitoring without establishing that a digital twin predicts performance in service. The intermediate causal links must be demonstrated: sensor readings to material state, material state to part properties and part properties to application-specific outcomes. The first link may be estimable from production measurements, while the final link often requires independent physical testing and environmental exposure records. Combining these links into one predictive score risks hiding which component has actually been validated.

External validity requires testing on manufacturing lots, machines or service environments that were excluded from model development. Splitting correlated layer records at random between training and testing sets inflates apparent predictive ability when those records originate from the same build. A scientifically useful review should distinguish interpolation within a qualified process window, transfer between machines and extrapolation to new formulations. For each, calibration drift, missing data and the decision consequences of false reassurance must be reported separately.

## 12. External validation of a manufacturing-to-field model

A process digital twin can be useful for monitoring exposure, geometry or quality indicators while remaining unvalidated for long-term in-service response. Those are different predictive tasks. A field-performance claim requires a defined output, time horizon, target population, operating conditions and a ground-truth measurement procedure. Predictions of printer faults or cure proxies should not be relabelled as forecasts of service life.

Temporal and site separation are essential validation safeguards. Randomly partitioning observations from the same machine, build or material lot between training and test sets may inflate performance estimates because shared conditions leak into both sets. A stronger evaluation holds out later production periods, independent lots or receiving sites and documents how process drift is detected. Where use environments vary, validation must stratify or model those differences rather than assuming a single exposure distribution.

Model quality has at least three layers: measurement validity, predictive calibration and utility for a prespecified engineering decision. Low average numerical error may coexist with poor predictions for rare high-consequence failures. A useful report should provide residual distributions, uncertainty intervals, out-of-distribution criteria and the operating point at which the system withholds a prediction. Model updating must maintain versioned training data and prospective performance checks.

A 2025 systematic review of 65 additive-manufacturing digital-twin studies identifies gaps in integration of material behavior and structural analysis. That AM-general observation supports caution, not a quantitative claim about field reliability of printed photopolymers. The missing evidence is a linked dataset from manufacturing state to measured field exposure and outcomes, evaluated without leakage.

### **13. Limitations**

The evidence base is AM-general and process-side. It does not establish field performance, privacy governance or photopolymer-specific deployment behaviour. This article therefore defines a transfer test and minimum evidence set rather than reporting field reliability.

### **14. Conclusions**

Manufacturing-process data and digital twins can structure upstream evidence, but they do not automatically become field-performance evidence. For photopolymer products, the missing bridge is a traceable post-deployment dataset linked back to the manufactured state. Until that bridge is demonstrated, field performance remains outside the supported claim set.

### **References**

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### **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 new experimental dataset was generated.

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