

Process-Failure-Mode-and-Effects Analysis for Vat Photopolymerisation: State Variables, Detection and Control Priority

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Abstract

Process-Failure-Mode-and-Effects Analysis for Vat Photopolymerisation is evaluated as the bounded decision of which VPP process failure modes deserve prevention, detection or containment based on function, causality and control effectiveness. The controlled state comprises process step, intended function, state variables, failure mode, local/end effect, cause mechanism, existing prevention/detection and residual action. For ER-295, both cited sources are confined to their stated point-of-use evidence roles. ER-295 defines measurements, transfer logic, failure modes and release gates specific to this subject; no universal process window, product recipe or compliance conclusion is inferred.

Keywords: FMEA; PFMEA; vat photopolymerisation; state variables; failure modes; detection; control priority

1. Significance, scope and ownership

ER-295 owns which VPP process failure modes deserve prevention, detection or containment based on function, causality and control effectiveness. The review is organised around the decision-specific evidence chain and leaves neighbouring ownership intact.

1.1. Corpus boundary

PFMEA is the causal risk model, not the monitoring or calibration system. ER-293 retains requalification, ER-296 statistical process monitoring, and ER-297 measurement validity. ER-295 owns the chain from function to failure mode, effect, cause, detection and preventive or detective control priority.

2. Subject-specific state model and causal chain

For ER-295, causal interpretation begins by freezing process step, intended function, state variables, failure mode, local/end effect, cause mechanism, existing prevention/detection and residual action. Severity, occurrence and detection are only useful when they are tied to a specific failure mechanism and to controls that can actually prevent or reveal it.

3. Direct evidence and point-of-use source map

IEC 60812:2018 defines a generic FMEA/FMECA framework applicable to processes and supports prioritisation without mandating one risk-priority-number formula. ISO/ASTM 52920:2023 supplies AM production context. ER-295 applies that logic to VPP state variables rather than building a universal numerical scorecard. Reference [1] is used for FMEA/FMECA method architecture. In ER-295, reference [2] supplies the production-qualification context relevant to this control problem.

4. Measurement architecture

The measurement architecture for ER-295 is built around failure-mode specificity, causal evidence, severity basis, occurrence evidence where available, detection capability, control ownership and post-action residual risk. The PFMEA record is checked for causal completeness from effect to cause and for whether each proposed control changes occurrence, detection or both.

5. Qualification and transfer

PFMEA transfer requires the functions, operating envelope and controls to remain comparable. A new machine, resin or workflow can create different causes or detection opportunities even when the top-level failure label is unchanged.

6. Failure modes and interpretation traps

The central interpretation trap in ER-295 is that generic labels such as print failure replace physical failure modes; arbitrary RPN multiplication hides high-severity cases; detection controls are credited without demonstrated sensitivity. Function, failure mode, effect, cause, detection and residual-risk gates prevent scoring arithmetic from replacing a causal explanation of how the process can fail.

7. Non-compensatory release gates

Gate	Minimum evidence	Blocking failure
Function	Process step and intended function defined	Generic print failure
Failure mode	Physical deviation specific and observable	Effect written as failure mode
Effect/severity	Local/end effect and severity basis	Unexplained score
Cause	Mechanism or credible cause linked	Cause list without linkage
Occurrence	Evidence or declared qualitative basis	Invented frequency
Detection	Method sensitivity/coverage demonstrated	Detection credited nominally
Control	Prevention/containment ownership verified	Control existence assumed effective
Residual risk	Action effectiveness retested	RPN reduction by arithmetic only

8. Minimum verification experiment

Map one VPP process from resin receipt through release, define functions and state variables, construct failure modes from observed or physically credible deviations, score/prioritise under a declared method, then test at least one detection or prevention control against a deliberately introduced bounded deviation.

9. Knowledge boundary

PFMEA prioritisation is sensitive to scoring method and evidence quality. No universal RPN or severity/occurrence/detection scale is justified for VPP, and rare high-consequence modes cannot be safely averaged away.

10. Conclusions

ER-295 uses PFMEA to expose causal process failure paths and the effectiveness of their controls; priority numbers cannot replace that causal record.

References

1. International Electrotechnical Commission. IEC 60812:2018 Failure modes and effects analysis (FMEA and FMECA). Geneva: IEC; 2018.
2. International Organization for Standardization and ASTM International. ISO/ASTM 52920:2023 Additive manufacturing — Qualification principles — Requirements for industrial additive manufacturing processes and production sites. 2023.

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