



Cost-Driven Design Exploration for a Pharmaceutical Rotary Filler Link Family

In this case study, we re-engineered a titanium nozzle actuation link from a high-speed rotary liquid filler, with the objective of confirming the **cost-optimal manufacturing route across a 16-variant product family** while reducing moving mass for long-term servo energy savings.

We evaluated investment casting, 5-axis CNC machining, and LPBF additive manufacturing in a single parallel exploration, and delivered CNC confirmed as cost-optimal route (-12% recurring cost), 14% mass reduction, and 4x faster full-family engineering lead time across 16 variants.

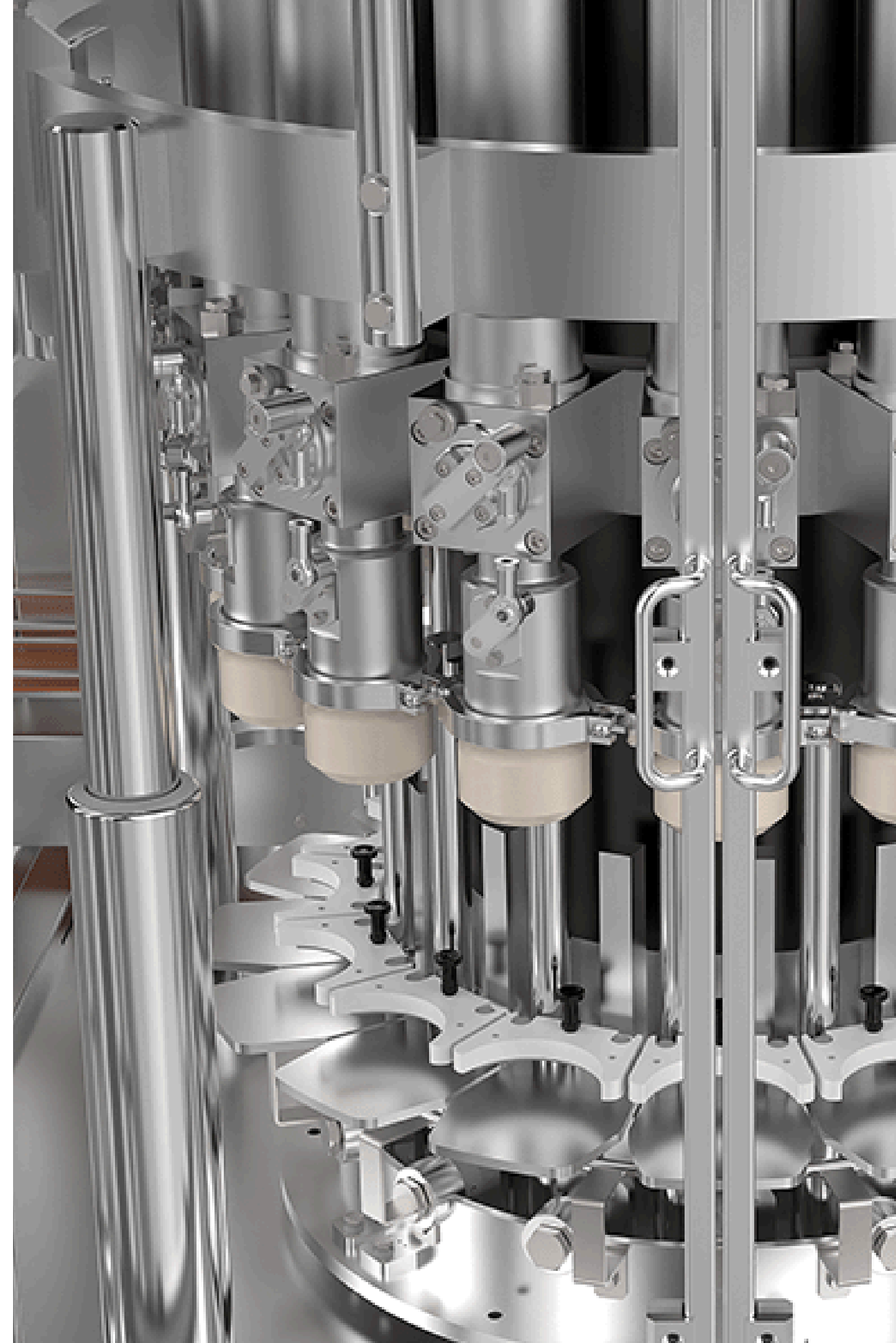
Engineering Challenge

The nozzle actuation link operates inside a rotary filler carousel, coupling a servo-driven cam to a reciprocating nozzle carrier for precise dosing. It cycles at 2–3 Hz over 10^8+ service cycles; Ti-6Al-4V is retained for CIP/SIP chemical resistance and very-high-cycle fatigue performance.

The legacy design functions, but two pressures drive redesign: procurement needs the cost-optimal manufacturing route validated early, and TCO (Total Cost of Ownership) targets push moving-mass reduction to cut long-term servo energy. **The solution must also scale across a 16-variant family, requiring a workflow that evaluates manufacturability, performance, and cost in parallel.**

Technical hurdles included:

1. **Multi-process route selection at concept stage** (casting vs CNC vs AM) with concurrent DFM + performance + cost.
2. **Joint cost + mass optimization** with mass tied to lifetime energy over 10^8+ cycles.
3. **Part family scalability** across 16 variants (4 platforms × 4 nozzle configs).
4. **Tooling amortization sensitivity** given 20–50 units/variant/year volumes.





The Solution: Cognitive Design Workflow

1. Design Space, Load Envelope, and Cost-Mass Baseline

We began by importing the legacy CAD and defining Preservation Zones at the cam interface, pivot bore, and CIP lubrication pocket. We applied load cases representative of carousel operation: 8 kN peak cam contact force at 2.3 Hz over 10^8 cycles, plus shock loading from emergency machine stops. Material was Ti-6Al-4V (yield 880 MPa). We set up a **dual-objective optimization**, cost as primary target, moving mass as secondary target driving long-term servo energy.

2. Parallel Multi-Process Exploration with Embedded MDD and SDD

Using the **Design Explorer** module, we generated 16 variants in parallel across three manufacturing routes, compared to the 2-3 concepts a conventional workflow allows. **Investment casting** contributed 4 candidates with embedded MDD constraints (draft angles $\geq 3^\circ$, wall thickness ≥ 2.5 mm, undercut removal). **5-axis CNC machining** contributed 6 candidates with tool accessibility envelopes enforced. **LPBF additive manufacturing** contributed 6 candidates with self-supporting geometry and overhang below 45° . Simulation-Driven Design ran meshless FEA on every variant, returning displacement and stress in real time. A cost model ran concurrently, scoring recurring cost and NRC exposure per batch size.

3. Route Selection, FEA Validation, and Cost Reconciliation

Ten of the 16 variants met the 0.4 mm displacement threshold. Cheapest compliant per route: €395 casting, €465 CNC, €1,150 AM. Applying NRC amortization for batch sizes of 20 to 50 units per variant per year, **effective casting cost rose above CNC**. The selected CNC variant delivered **14% mass reduction at 12% lower cost** than legacy. Final FEA confirmed max Von Mises 197 MPa, safety factor 4.8 versus 4.5 legacy.

4. Family Workflow Automation

We exported the full workflow as a parametric .cds template. Exposed inputs include machine platform, nozzle pitch, station count, and cam stroke. **Any remaining variant in the 16-part family regenerates end-to-end in 2 days**, MDD constraints, SDD validation, and cost scoring included. The engineering effort redistributes from per-variant redesign to one-time workflow construction, compressing full-family lead time 4x.

Key Metrics Comparison

Metric	CNC (Al-6061)	AM (Ti-6Al-4V)	Improvement
Mass	1.40 kg	1.20 kg	-14%
Recurring Cost per Part (Est.)	€530	€465	-12%
Concepts Explored per Part	2-3 (manual, sequential)	16 variants (parallel DoE)	~6x more design options
Lead Time, first variant	2 weeks	2 weeks	Workflow buildup
Lead Time, each subsequent variant	2 weeks	2 days	7x faster per variant
Lead Time, full 16-variant family	32 weeks	~8 weeks	4x faster

