Proceedings of the 11th North American International Conference on Industrial Engineering and Operations Management, Milwaukee, Wisconsin, USA, June 9-11, 2026

Proceedings of the International Conference on Industrial Engineering and Operations Management

Publisher: IEOM Society International, USA DOI: 10.46254/NA11.20260085
Published: June 9, 2026

CNC Machine Selection Using Annual Cash Flow Analysis for a Medical Device Machine Shop

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Abstract

Medical device manufacturers operate under strict regulatory requirements and high expectations for quality and cost performance. The present work deals with such a medical device machine shop that needs to decide between a new 3-axis vertical machining center and a more automated 5-axis CNC to expand capacity for precision housings. The research problem is to determine which CNC alternative provides superior economic performance and strategic value under realistic shop conditions. Engineering-economy method of annual cash-flow analysis and capital recovery has been applied at a minimum attractive rate of return (MARR) of 18%. Data on purchase price, salvage, production rates, availability, scrap, labor, maintenance, tooling, consumables, energy, and overhead were collected from company records and vendor quotations. The study estimates total cost of ownership (TCO), machine cost per good part, annual net cash flows, and a simple annual return on investment (ROI) for each CNC option. Results show that although the 5-axis machine has higher ownership and operating costs, its higher throughput and lower scrap rate yield a lower cost per finished part, significantly higher annual net cash flow, and a higher ROI than the 3-axis alternative. Theoretically, the case illustrates how classical engineering-economy tools can structure CNC investment decisions alongside more complex multi-criteria selection approaches. Practically, it demonstrates that purchase price alone can be misleading; in a regulated medical device environment where the cost of quality is substantial, managers should evaluate CNC alternatives on lifecycle economics, cost per good part, and alignment with capacity and quality objectives.

Keywords
CNC, Machine Shop, Medical Devices, annual cash flow analysis

1. Introduction
Medical device manufacturers operate in a high-stakes environment where product failures can directly affect patient safety, and regulators enforce stringent quality system requirements through ISO 13485 and the U.S. Food and Drug Administration's Quality System Regulation and the new Quality Management System Regulation (QMSR) (ISO 2016, FDA 2026). Analyses estimate that the direct cost of quality in the medical device industry can reach between

6.8% and 9.4% of sales, amounting to tens of billions of dollars annually, which makes equipment and process choices economically critical (Fuhr et al. 2017). Within this context, a medical device machine shop that produces precision stainless-steel housings faces a capital investment decision: purchase a 3-axis vertical machining center (CNC A) or a more automated 5-axis machining center with a pallet changer (CNC B) to relieve a capacity bottleneck and support anticipated demand. The choice will influence unit cost, throughput, scrap, and compliance capability over many years (Groover 2020). The research problem addressed in this paper is to determine which of the two CNC alternatives provides superior economic performance and strategic value for a medical device machine shop, given the shop's demand, contribution margin, and operating assumptions. The shop's finance policy specifies a minimum attractive rate of return (MARR) of 18%, making an engineering-economy–based cash-flow analysis a natural tool for evaluating mutually exclusive alternatives (Eschenbach 2011). The specific research questions are: (a) What are the expected annual net cash flows for each CNC alternative, considering contribution margins and all operating costs? (b) What simple annual return on investment (ROI) does each alternative deliver relative to its initial investment? and (c) How do cash-flow and ROI results relate to total cost of ownership (TCO) and cost per good part, which are key metrics for machining operations in regulated manufacturing (Cauchick-Miguel and Coppini 1996)?

2. Literature Review

Engineering economy provides core methods for analyzing capital investments, including present worth, annual worth, and internal rate of return (Eschenbach 2011, Park 2016, DeGarmo et al. 1997, Song et al. 2015, Al-Odeh et al. 2012). Annual cash-flow analysis and capital recovery factors allow first cost and salvage to be expressed as equivalent annual costs, facilitating comparison of alternatives with different lives and cost structures. In practice, companies often complement discounted-cash-flow metrics with simpler indicators such as payback and ROI to communicate results to non-finance stakeholders (Badiru 2014). In infrastructure projects, benefit-cost analysis can be used (Sahay et al. 2025) whereas Badar et al. (2020) used net present value method. Townsend and Badar (2018) used internal rate of return and payback period to evaluate economic benefits of condition monitoring of equipment. In machining environments, cost per part and annual cash flow are particularly intuitive because they link financial performance to throughput, scrap, and utilization. Cauchick-Miguel and Coppini (1996) provide a structured method for determining cost per piece in machining processes. Modern manufacturing emphasizes that CNC machines must be evaluated over their full lifecycle, considering not only acquisition cost but also energy, maintenance, and process capability (Groover 2020). Götze et al. (2012) propose an integrated methodology for measuring the energy and cost-effectiveness of machine tools, linking energy flows to life-cycle costing. Feng and Huang (2020) review key technologies for sustainable machine-tool design, emphasizing energy, material efficiency, and maintainability. Scrap and rework are central to both cost and sustainability; Lemon et al. (2025) and Enache et al. (2023) show how Lean Six Sigma can reduce scrap rates in a metal forming process, directly increasing effective capacity and profitability. A substantial body of research addresses machine-tool selection using multi-criteria decision-making (MCDM) frameworks. Yurdakul (2004) proposes an analytic hierarchy process approach that links machine tools to manufacturing strategy, demonstrating that AHP can model both quantitative criteria (such as cost and productivity) and qualitative strategic factors. Alberti et al. (2011) develop a decision support system for high-speed milling machine selection that integrates machine characteristics, performance tests, dimensional accuracy, cycle time, and cost. Arslan et al. (2004) apply multi-criteria weighted average methods with sensitivity analysis to identify critical performance criteria in machine selection decisions. When decision criteria involve both quantitative and qualitative factors, fuzzy multi-criteria approaches have proven effective. Ayağ (2006) applies fuzzy AHP to handle imprecise judgments in CNC machine selection, while Dawal et al. (2012) combine fuzzy AHP with benefit-cost ratio analysis for flexible manufacturing systems. These studies demonstrate that technical and qualitative factors such as flexibility and precision are critical, while still relying on underlying cost and performance data generated through engineering-economy calculations. In medical device manufacturing, quality management standards such as ISO 13485:2016 and the FDA's QMSR define expectations for design, production, and process control (ISO 2016, FDA 2026). McKinsey & Company and others highlight that the direct cost of quality, including prevention, appraisal, internal failures, and external failures, can materially affect profitability and competitiveness (Fuhr et al. 2017). For a machine shop supplying precision components into such a system, CNC investments must therefore be evaluated not only in terms of throughput and cost, but also their impact on scrap, rework, and process capability.

3. Case Description and Assumptions

The analysis considers a medical device machine shop that produces stainless-steel precision housings for regulated applications. The shop operates on two shifts for 250 days per year, with a baseline demand that keeps available capacity fully utilized. Management has approved capital funding for one additional CNC machining center to support anticipated product demand. The decision is mutually exclusive: either a 3-axis vertical machining center (CNC A) or a more advanced 5-axis machine (CNC B). Global parameters include 4,000 scheduled hours per year (2 × 8 hr over 250 days), a selling price of USD 80 per finished part, non-machine costs of USD 50 per part, a resulting contribution margin of USD 30 per good part, and a MARR of 18%. This hurdle rate reflects both the weighted average cost of capital and a risk premium typical for manufacturing capital projects in the 15%–20% range (Park 2016). Table 1 presents the technical and economic parameters for each CNC alternative.

Table 1. CNC alternative technical and economic parameters

Parameter	CNC A (VMC-500) – 3 Axis	CNC B (VMC-700) – 5 Axis
Purchase price (USD)	$350,000	$520,000
Salvage value (USD)	$35,000	$75,000
Economic life (years)	7	10
Nominal rate (parts/hr)	10	14
Availability (%)	92%	96%
Scrap rate (%)	3%	2%
Power (kW)	35	45
Annual maintenance (USD)	$18,000	$24,000
Tooling (USD/good part)	$1.10	$1.30
Consumables (USD/yr)	$4,000	$5,500
Labor	1 op/shift @ $28/hr	0.7 op/shift @ $28/hr

These values align with contemporary manufacturing engineering practice and CNC specifications described in modern references (Groover 2020, Kalpakjian and Schmid 2018).

4. Methodology

This study uses quantitative single-case analysis. Data were drawn from three sources: (a) internal company records (labor rates, overhead, production days, utilization); (b) vendor quotations and technical datasheets (purchase price, salvage, power rating, parts per hour); and (c) engineering estimates (scrap, tooling, consumables, contribution margin). The analysis proceeds in three steps consistent with standard engineering-economy practice (Eschenbach 2011, Park 2016, DeGarmo et al. 1997):

- **Step 1:** Capital Recovery. For each machine, capital recovery (CR) is calculated using the standard formula:
  $$CR = P(A/P,i,n) - S(A/F,i,n)$$
  where P is purchase price in present, S is salvage value in future, i is MARR, n is economic life in years, A/P is factor to convert P to annual equal payment, and A/F is factor to convert F to A .
- **Step 2:** Annual Operating Costs. Annual operating and maintenance (O&M) cost is the sum of energy, maintenance, tooling, consumables, direct labor, and allocated overhead.
- **Step 3:** Net Cash Flow and ROI. Annual contribution (good parts per year × contribution margin) minus total annual O&M cost yields annual net cash flow. Simple ROI is net cash flow divided by initial investment. This approach aligns with cost-per-piece and lifecycle evaluations in the machining and CNC investment literature (Cauchick-Miguel and Coppini 1996, Götze et al. 2012).

5. Results

The financial and operational analysis proceeds by calculating production capacity, annualized ownership costs, and unit economics for each alternative. These metrics directly inform the cash flow and return-on-investment calculations that drive the investment decision. Table 2 summarizes the key performance and economic outcomes for both CNC alternatives.

Table 2. Summary of annual performance and economic metrics for CNC alternatives

Metric	CNC A (VMC-500) – 3 Axis	CNC B (VMC-700) – 5 Axis
Effective hours per year	3,680	3,840
Good parts per year	35,696	52,685
Annual capital recovery (USD)	$88,944	$112,519
Annual O&M costs (USD)	$206,666	$218,190
Total annual cost (USD)	$295,610	$330,709
Machine cost per good part (USD)	$8.25	$6.26
Total cost per finished part (USD)	$58.25	$56.26
Annual contribution (USD)	$1,070,880	$1,580,544
Annual net cash flow (USD)	$864,214	$1,362,354
Simple ROI (% per year)	246.9%	262.0%

As shown in Table 2, CNC B produces 52,685 good parts per year with nearly 48% more than CNC A (35,696). Despite higher capital recovery charges (USD 112,519 vs. USD 88,944), CNC B achieves a lower machine cost per good part (USD 6.26 vs. USD 8.25) and a lower total cost per finished part (USD 56.26 vs. USD 58.25), a 3.4% reduction, due to its higher throughput, better availability, and lower scrap rate (Cauchick-Miguel and Coppini 1996). The cost-per-part advantage arises because CNC B's productivity gains more than offset its higher ownership costs. In terms of cash generation, CNC B's higher output yields an annual contribution of USD 1,580,544 vs. USD 1,070,880 for CNC A. After subtracting O&M costs, annual net cash flows are approximately USD 1,362,354 for CNC B and USD 864,214 for CNC A, which represents a difference of nearly USD 498,000 per year. Simple ROI further confirms CNC B's superiority: 262.0% per year versus 246.9% for CNC A. Both alternatives offer very high returns, but CNC B's ROI is higher, and its absolute net cash flow advantage is substantial.

6. Concluding Remarks

6.1 Economic and Strategic Analysis

Economically, CNC B is preferred because it delivers lower cost per finished part, generates significantly higher annual net cash flow, and yields a higher simple ROI despite its higher first cost. These outcomes reflect classic engineering-economy principles: investments with higher capital cost can be superior when they generate sufficiently higher benefits or reduce unit costs (Eschenbach 2011). Beyond the numeric results, CNC B offers higher throughput and better utilization of the available 4,000 hours per year, a lower scrap rate, and improved capability for complex geometries and reduced setups, aligning with trends toward advanced machining and manufacturing capability (Groover 2020). These features support strategic goals such as reducing cost of quality in a heavily regulated environment and creating headroom for new product introductions without immediately hitting capacity constraints (ISO 2016, Fuhr et al. 2017).

6.2 Risk Considerations

The analysis assumes sufficient demand to keep either machine busy for 4,000 scheduled hours per year. If demand were substantially lower, the higher fixed cost of CNC B could become a disadvantage. Similarly, if the product mix shifted away from parts leveraging 5-axis capabilities, CNC B’s advantage would shrink. On the risk side, CNC B introduces more complex controls and automation, requiring more training and specialized maintenance (Badiru 2014). Technology obsolescence risk is somewhat higher, although this is mitigated by its flexibility and alignment with sustainable and energy-aware machine-tool design trends (Götze et al. 2012, Feng and Huang 2020). From a quality and regulatory standpoint, CNC B’s lower scrap and improved repeatability contribute to lowering the direct cost of poor quality, a factor McKinsey and others have quantified as substantial in medical device manufacturing (Fuhr et al. 2017).

6.3 Conclusions and Recommendations

This paper applied an engineering-economy annual cash-flow framework to CNC selection in a medical device machine shop. Using industrially realistic data and a MARR of 18%, the study compared a 3-axis vertical machining center (CNC A) to a more automated 5-axis machine (CNC B). Key conclusions are:

- CNC B has higher total cost of ownership but lower cost per finished part
- CNC B generates significantly higher annual net cash flow (approximately USD 498,000 more annually)
- CNC B yields higher simple ROI (262.0% vs. 246.9%)

- In a medical device context where the cost of quality is substantial and regulatory requirements are strict, CNC decisions should consider cost per good part, scrap, and capacity, not just purchase price.

For the company in this case, CNC B (VMC-700) is the economically preferred alternative under the base assumptions, provided that demand remains strong and the organization manages technology and training risks appropriately. Future work could extend the analysis by adding net present value and equivalent annual worth metrics, incorporating tax and depreciation effects, performing structured sensitivity analysis, combining the cash-flow model with multi-criteria decision-making methods as demonstrated in the literature (Yurdakul 2004, Alberti et al. 2011, Ayağ 2006, Arslan et al. 2004, Dawal et al. 2012), and addressing uncertainty through fuzzy set approaches or Monte Carlo simulation.

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Biographies

Alexander Collado-Méndez is a PhD student in Technology Management at Indiana State University, specializing in Manufacturing Systems. He is also a Senior Engineering Supervisor at Medtronic in Juncos, Puerto Rico, bringing over 10 years of professional experience in the pharmaceutical and medical device industries. Alexander holds a Bachelor of Science in Chemical Engineering from the University of Puerto Rico, Mayagüez Campus, and a Master of Science in Technology Management with a Manufacturing Concentration from Indiana State University. Throughout his career, Alexander has developed expertise in new product introductions, product transfers, capacity increase initiatives, and remediation activities, with a strong technical focus on electroplating and coating technologies. He has proven proficiency in Computerized Software Validation Lifecycles and Process Development, ensuring compliance with industry standards while driving operational efficiency. Alexander is skilled in leading cross-functional teams, mentoring colleagues, and implementing continuous improvement initiatives to enhance productivity and quality outcomes.

Michaela Faith Williams is a PhD student in Technology Management at Indiana State University, specializing in Quality Systems. She has over a decade of professional experience in the consumer packaging goods industry, with demonstrated expertise in analytics, finance, strategic planning, supply chain management, and organizational communication. Her research and professional practice are informed by strong business acumen applied to the systematic identification and resolution of complex operational and managerial problems. Michaela has a Bachelor of Science in International Trade and Marketing from the Fashion Institute of Technology and a Master of Business Administration in Technology Management from SUNY Polytechnic Institute.

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M. Affan Badar, PhD, CPEM, IEOM Fellow is a professor, former department chair, and current director of the consortium-based PhD in Technology Management program in Bailey College of Engineering & Technology at Indiana State University (USA). While on leave from 2016 to 2018, he was Professor and Chair of the Industrial Engineering & Engineering Management Department at University of Sharjah (UAE). He earned his PhD in industrial engineering (IE) from University of Oklahoma (USA), MS in mechanical engineering (ME) from King Fahd University of Petroleum and Minerals (Saudi Arabia), and MSc in IE and BSc (Hons) in ME from Aligarh Muslim University (India). Prof. Badar has published two edited books, seven book chapters, and over 100 articles in refereed journals and proceedings in the areas of lean six sigma, design, reliability, quality, engineering economy, healthcare, and supply chains.