COSTING THE CIRCLE: A FUSED INDUSTRIAL ENGINEERING–COST ACCOUNTING MODEL FOR SUSTAINABLE PRODUCTION

Sustainable and Circular Production Models

Abstract

Manufacturing faces mounting pressure to decouple growth from resource use while remaining cost-competitive. This article shows how converging Industrial Engineering (IE) and Cost and Management Accounting (CMA) accelerates the shift from linear, take-make-dispose production to sustainable and circular production models. IE tools — work measurement, process mapping, facility layout, DFMA, and statistical process control — generate the operational data that CMA techniques such as Material Flow Cost Accounting (MFCA), activity-based costing, target costing, and life cycle costing need to make material losses, energy waste, and end-of-life costs financially visible. This fusion turns circularity from an environmental aspiration into a cost-justified strategy. The article identifies key barriers — data infrastructure, organisational silos, valuation of externalities — and outlines future research directions.

CMA T D Baskaran
ERP Consultant & Researcher
Chennai
baskaran.be.cma@gmail.com

Introduction

Global manufacturing faces sustained pressure to reconcile profitability with planetary boundaries: resource extraction is projected to rise sharply under business-as-usual scenarios, and manufacturing accounts for a significant share of global emissions and material throughput. The circular economy paradigm — designing out waste, keeping materials in use, regenerating natural systems (Ellen MacArthur Foundation, 2015) — has moved into mainstream strategy. Yet shifting from linear "take–make–dispose" production to a circular model needs both operational tools to redesign processes and financial tools to make circularity's costs and benefits visible to decision-makers.

This is where Industrial Engineering (IE) and Cost and Management Accounting (CMA) become relevant. IE supplies methods — work measurement, method study, facility layout, production planning, quality control — to redesign processes and cut waste, energy, and material loss. CMA supplies methods — cost allocation, standard costing, variance analysis, budgeting, environmental management accounting — to translate those changes into decision-useful financial information. Long evolved separately, their fusion is now a practical necessity, since circularity decisions are simultaneously physical and financial. This article examines their foundations, integration mechanisms, barriers, and future research directions.

Conceptual Foundations

1. Industrial Engineering as an Enabler of Circularity

Industrial Engineering applies engineering analysis to design, improve, and control production systems. Its toolkit — work measurement, method analysis, facility layout, production planning, quality control — was built to raise throughput and cut cost; applied with a circularity lens it drives resource efficiency. Lean manufacturing targets waste — overproduction, waiting, transport, over-processing, inventory, motion, defects — much of which maps onto losses circular frameworks target (Ghaithan et al., 2023). DFMA and eco-design extend IE into design decisions governing disassembly, repair, and recycling (Discover Engineering, n.d.). IE thus both cuts waste at source and generates the granular data circularity's financial valuation requires.

2. Cost and Management Accounting for Sustainability

CMA provides the financial infrastructure for decision-making: cost allocation, budgeting, standard costing, variance analysis. Conventional practice has a blind spot for circularity — material losses are typically buried in overhead rather than isolated as their own cost (Christ & Burritt, 2015). Environmental management accounting corrects this: MFCA, standardised as ISO 14051, treats waste as a "negative product" with its own material, system, and delivery costs, making inefficiency financially visible (International Organization for Standardization, 2011; Christ & Burritt, 2015). Related tools — ABC, target costing, life cycle costing — extend this by tracing costs to specific activities and life-cycle stages. Melnyk and Semaniuk (2021) argue such accounting must move beyond compliance into routine pricing and investment decisions.

Rationale for Convergence

Circular decisions rarely fail for lack of intent; they fail because the physical case (IE) and financial case (CMA) are developed in isolation, often by different departments using different data. An engineer may show a redesign cuts scrap, but without cost separation that gain stays invisible to investment decision-makers. An accountant may see waste costs rising but, without IE process data, cannot pinpoint the cause. Nishitani et al. (2022) describe a triadic relationship linking MFCA, environmental performance, and economic performance, each depending on consistent measurement. Converging IE and CMA closes this gap, letting circular strategies — disassembly-friendly redesign, recycled-input substitution, shortened material travel — be evaluated with the rigour normally reserved for conventional cost-reduction projects.

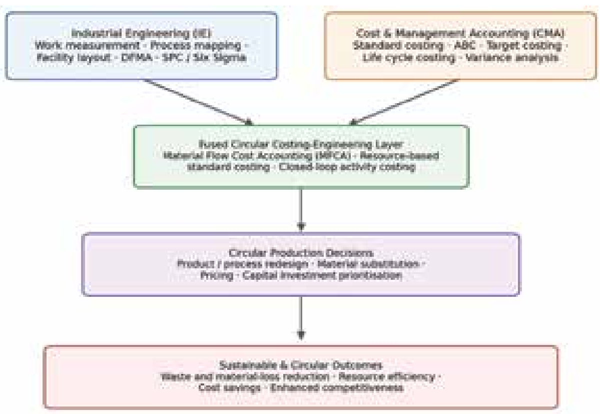

Figure 1. Conceptual framework for fusing Industrial Engineering and Cost & Management Accounting in sustainable and circular production.

Key Synergy Areas

Table 1 summarises the five synergy areas discussed below, mapping the IE tool that generates the physical/operational insight to the CMA tool that translates it into financial terms, and the circular production outcome each pairing supports.

Synergy Area	IE Tool(s)	CMA Tool(s)	Circular Production Outcome
Waste valuation	Process mapping, facility layout, material flow analysis	Material Flow Cost Accounting (MFCA)	Material losses costed and made visible for reduction
Resource-efficient standard costing	Work measurement, time studies, work sampling	Standard costing, variance analysis	Circular performance standards set and monitored

Synergy Area	IE Tool(s)	CMA Tool(s)	Circular Production Outcome
Design for circularity	DFMA, eco-design	Life cycle costing	Disassembly/remanufacturing value captured at design stage
Closed-loop process costing	Process mapping of reverse-logistics activities	Activity-based costing, target costing	Realistic costing of sorting, disassembly, remanufacturing
Operational excellence	Lean manufacturing, Six Sigma, SPC	Variance analysis	Waste and variability reduction prioritised by financial impact

1. Material Flow Cost Accounting and Waste Valuation

MFCA is the clearest fusion point. It needs a physical material-flow model — inputs, outputs, losses at each stage — which IE process mapping and facility layout analysis produce. CMA then attaches material, energy, system, and delivery costs to each flow, costing waste as rigorously as the finished product (Schmidt & Nakajima, 2013; International Organization for Standardization, 2011). Japanese manufacturer studies found MFCA associated with gains in both environmental and economic performance, supporting it as a genuine bridge rather than a trade-off (Nishitani et al., 2022). Zhou et al. (2017) extended MFCA for circular contexts to account for recovered materials re-entering production, depending on the closed-loop data IE flow analysis supplies.

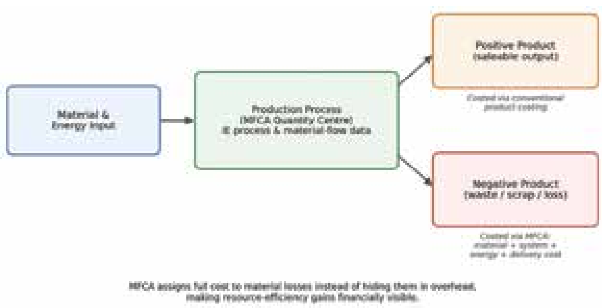

Figure 2. Simplified MFCA logic: production outputs are split into a positive (saleable) product and a negative product (waste), each carried at its full cost.

2. Work Measurement and Resource-Efficient Standard Costing

Work measurement — time studies, predetermined motion time systems, work sampling — standardises labour time but can equally standardise material and energy use per operation. Standard costs built on this data make variance analysis a circularity diagnostic: a material usage variance signals a resource-efficiency failure worth IE investigation. This lets organisations set circular performance standards — maximum scrap rates, target energy use — and monitor them with the discipline usually reserved for labour and material variances.

3. Life Cycle Costing and Design for Circularity

Circular decisions are made largely at the design stage, where material, fastener, and assembly choices determine whether a product can later be disassembled, repaired, or recycled. DFMA evaluates design choices for ease of production and disassembly; life cycle costing evaluates the same choices for total cost across acquisition, use, and end-of-life. Together they let a design team compare a conventional bonded assembly against a modular alternative in financial terms, capturing both the production-cost difference and value recoverable through remanufacturing — consistent with evidence that modular architectures, as in electric vehicles, cut cost and environmental impact by making disassembly economically viable (Frontiers in Sustainability, 2024).

4. Activity-Based Costing and Closed-Loop Process Mapping

Activity-based costing (ABC) traces overhead to the activities that consume resources rather than allocating it by volume. In a circular system this extends to sorting, disassembly, cleaning, and remanufacturing. IE process mapping sequences these activities; ABC costs them realistically, avoiding both understated reverse-logistics costs and overstated circular-strategy costs. Target costing complements this by setting a cost ceiling for a circular product at the design stage.

5. Lean, Six Sigma, and Environmental Cost Control

Lean manufacturing and Six Sigma reduce the waste and variability that generate the losses circular frameworks target. Ghaithan et al. (2023), studying Saudi manufacturers, found lean and Industry 4.0 technologies positively mediate the link between circular economy adoption and sustainability performance — operational excellence amplifies rather than substitutes for circular strategies. CMA variance analysis, applied to these cost categories, supplies the evidence to prioritise redesign and demonstrate return on circular investment.

Illustrative Applications Across Sectors

This synergy appears across sectors. In discrete manufacturing, modular design with life cycle costing lets component reuse be evaluated on the same footing as new production, notably in disassembly-friendly electric vehicles (Frontiers in Sustainability, 2024). In process industries, MFCA — developed in Germany, adopted widely in Japan — has costed material losses previously treated as unavoidable overhead, with documented gains in efficiency and profitability (Guenther et al., 2015; Nishitani et al., 2022). Firms combining engineering-led redesign with financial evaluation convert circular principles into practice more successfully than those pursuing either track alone (Ghaithan et al., 2023).

Challenges and Considerations

Fusing IE and CMA faces several barriers. Data infrastructure: MFCA and ABC need granular flow data many organisations lack, especially where legacy systems assume volume-based costing (Christ & Burritt, 2015). Organisational silos: IE and CMA report separately with little shared vocabulary. Valuation difficulty: benefits like reduced supply risk resist monetary valuation, biasing appraisal against circular alternatives. Short-term cost pressure: circular redesign needs upfront investment whose payback often exceeds conventional budgeting horizons. Overcoming these requires better tools and cross-functional collaboration between engineering and finance.

Table 2 summarises these barriers alongside practical mitigation approaches drawn from the literature.

Barrier	Description	Mitigation Approach
Data infrastructure	Granular material/ energy flow data required by MFCA and ABC is often not captured by legacy systems	Pilot MFCA on a single line; invest incrementally in metering and ERP integration
Organisational silos	IE and CMA functions report separately with limited shared vocabulary	Cross-functional project teams; joint accountability for circularity KPIs
Valuation difficulty	Benefits such as reduced supply risk resist conventional monetary valuation	Supplement costing with qualitative/ strategic criteria in investment appraisal
Short-term cost pressure	Circular redesign requires upfront investment with longer payback horizons	Extend capital budgeting horizons; phase investment around highest-value processes first

Future Research Directions

Comparative studies could clarify which IE-CMA tool combinations yield the largest circular-performance gains, and under what conditions. Longitudinal research is needed on whether MFCA produces durable gains or only short-term ones that fade once low-cost opportunities are exhausted. There is scope for standardised metrics combining physical circularity indicators with financial measures for benchmarking. As sensors, digital twins, and ERP systems make real-time flow data more accessible, research on how these lower the data-infrastructure barrier would have direct practical value.

Conclusion

Sustainable and circular production cannot be achieved by engineering redesign or financial reporting alone. IE supplies methods to reduce waste and generate flow data; CMA translates that data into information guiding pricing, investment, and design. Their fusion — through MFCA, life cycle costing, ABC, and resource-oriented work measurement — converts circularity from an aspiration into a measurable, cost-justified strategy. Realising this at scale requires shared data infrastructure, closer engineering-finance collaboration, and valuation approaches capturing the full economic case. Where these conditions are met, circular strategies can deliver environmental and financial gains simultaneously, not as a trade-off. MA

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Congratulations!!!

CMA Delzad Dinyar Tanaz Jivaasha

Heartiest congratulations to CMA Delzad Dinyar Tanaz Jivaasha on being bestowed the prestigious honour of Governance & Ethics Leader of the Year at the 2nd Edition Fraud & Credit Risk Management Summit & Awards 2026 organized by Krypton Group. The awards recognize the leadership, best practices implementation and noteworthy path breaking innovation by individuals. CMA Delzad Dinyar Tanaz Jivaasha's leadership, initiatives, innovations and consistent efforts to cement the importance and build a robust culture of Governance, Sustainability, Compliance, Risk Management and ESG has been appreciated with him being recognized as a leader.

We wish CMA Delzad Dinyar Tanaz Jivaasha the very best for all his future endeavours.