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Activity-Based Costing in Industry 4.0: Resource Efficiency, Sustainability, and Digital Adaptation A Narrative Review (1990-2025)

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Abstract

Industry 4.0 has increased organizational cost complexity and challenged conventional resource allocation strategies. How ABC helps with resource efficiency, digitally integrated sustainability decisions and implementation across sectors is investigated in this study. Structured narrative review synthesizes a purposively assembled DOI verified evidence set of 29 substantive journal publications (plus two methodological sources). ABC and time-driven versions give activity-cost and capacity information; integrated models that link enterprise systems, digital twins, LCA and operational constraints can inform economic–environmental trade-offs but differences between calculated product costs and modelled production outcomes do not show savings or physical energy consumption reductions. Implementation depends on system requirements aligning with technology readiness, managerial capability and organisational complexity. The review provides a conceptual framework distinguishing between cost visibility, managerial intervention and realised operational or environmental outcome. Its implications are for managers to separate financial and physical results and researchers to test these relationships using longitudinal comparative designs.

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INTRODUCTION

Contains Digitalization of industry has not only expanded the potential of information but has also generated new challenges for organizations in terms of cost control. Organizations now utilize complex production systems which consist of many types of products, automated work stations, enterprise resource planning (ERP) software and operational monitoring software. Due to the diversity of activities associated with each product/service provided, using broad overhead allocation methods provides limited insights into the cost of producing each product/service. Activity-based costing (ABC)

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enables organizations to assign resource costs to specific activities and then to assign those costs to individual cost objects using appropriate allocation bases. However, if organizations cannot use the detailed cost data generated through ABC in making day-to-day business decisions, then how valuable is the increased level of detail provided by ABC? (Alsayegh, 2020; Vedernikova et al., 2020). Although there has been significant research conducted on the use of ABC in manufacturing, service organizations, and universities, there appears to be no clear consensus regarding whether or not ABC consistently delivers results. Studies comparing different applications of ABC have resulted in conflicting estimates of unit-cost; although ABC provides organizations with greater visibility into unutilized capacity, it does not necessarily result in reduced expenditures (Ghani et al., 2020; Zamrud & Abu, 2020); case studies from manufacturing demonstrate that activity-oriented costing can uncover differences that are hidden under more general allocation schemes (Firmandani et al., 2024); cross-country surveys show that barriers to implementing ABC vary based upon the organizational characteristics and decision-making processes used to adopt ABC (Pietrzak et al., 2020). Therefore, the question is not whether ABC is always the best approach, but rather when and how ABC provides information that managers can utilize. Industry 4.0 raises additional questions regarding how to calculate costs that extend beyond those associated with traditional cost calculation approaches. Digital twins and production information systems allow organizations to measure time and capacity requirements.

Furthermore, organizations are forced to examine environmental management costs including energy consumption, waste generation, and emissions more closely. Anderson (2021) discusses the relationship between time-driven activity-based costing (TDABC) and digital twins in additive manufacturing. Vărzaru (2022) examines the transformation of accounting tools used in healthcare. Jourdaine et al. (2021) propose an integration of ABC and life cycle assessment (LCA) which connects financial information with environmental information. These studies demonstrate that technology increases the scope of information available through costing systems but do not provide a unified implementation path for all organizations. Additionally, sustainability-focused modeling has further extended the application areas for ABC. Green production models incorporate changes in material prices, carbon-related costs, production bottlenecks, and alternative product mixes (Tsai & Jhong, 2018; Tsai et al., 2019). Examples of more recent applications of green production models include textile production, aluminum alloy wheels, and coffee roasting (Tsai, 2023; Tsai, Chang et al., 2024; Tsai, Chen et al., 2024; Tsai et al., 2025). However, optimized model outcomes should not be equated with physical energy savings or emissions reductions at operating firms. Research on environmental activity management indicates that management systems and organizational practices are also factors influencing the environmental performance of firms (Baird et al., 2021). A separate body of literature exists addressing why organizations implement, modify or reject ABC. Research conducted within universities indicates that factors such as information usefulness, technological capability, management characteristics, and system flexibility influence whether or not organizations decide to implement ABC (Abeysekera & Sharma, 2023; Kudanga et al., 2023). Research conducted in Tanzania and Vietnam expand the geographical and organizational context by examining institutional pressures and reported relationships between firm performance and ABC (Molela et al., 2023; Pham, 2021). These findings demonstrate that context is important, but they also suggest caution when applying relationships across countries, sectors, and study designs without consideration of qualification.

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There remains a research gap between the various bodies of literature discussing costing accuracy, unused capacity, environmental modeling research, and organizational adoption. Although reviews have described implementation patterns and sustainability applications internationally (Alsayegh, 2020; Ortiz-Cea et al., 2025), a more focused synthesis remains useful for identifying three connections: activity-level information, managerial interventions, and achieved results. Therefore, this study seeks to answer three questions: (1) how can ABC contribute to improving raw-material and operational resource efficiency?; (2) how can digitally integrated ABC assist in managing costs, time, and energy in a sustainable manner?; and (3) what organizational and sector-specific characteristics influence the effectiveness of implementing ABC? Utilizing Contingency Theory as its primary theoretical framework and supplementing it with Theory of Constraints (TOC) and literature related to management-accounting change, this study will develop an integrated interpretive framework. Its contribution is to consider ABC as a context-dependent informational capability rather than as a standalone source of savings; it separates improvements in cost visibility from managerial interventions necessary to produce operational results and cost reductions from empirical evidence demonstrating improvements in physical environmental performance.

LITERATURE REVIEW

Activity-Based Costing **(**ABC) allocates costs based upon the activities that consume resources. In organizations with many different types of processes, ABC may allow for the identification of differences in costs for products and services that would otherwise be obscured by the allocation of costs based on volume. Additionally, ABC is a tool for ABM (Activity Based Management), where the information generated through ABC is used to prioritize areas for improvement. Although an accounting allocation is not a change in the inputs into production, Time Driven ABC generates resource consumption based on practical capacity and time requirements. Studies examining automotive manufacturing and assembly have shown how time-driven ABC can provide insight into the value of analyzing capacity; however, these studies also note that Time Driven ABC relies heavily on accurate estimates of time (Ghani et al., 2020; Vedernikova et al., 2020; Zamrud & Abu, 2020). Costing system operational versatility is being demonstrated through more recent uses. The complexity of assigning costs during the manufacturing process has been investigated in a study with CV XYZ (Firmandani et al., 2024). Additionally, a bank internal audit department showed how time-based costing could be applied to professional services (Burak et al., 2022). Research on university and dental school costs illustrated that educational processes are valid cost objects; however, they require alternative cost drivers and capacity assumptions than what is commonly used in manufacturing (Zaini & Abu, 2023; Zamandi & Raei, 2025). Therefore, the variations among sectors provide motivation to clearly explain why a particular costing system would be appropriate for each sector.

Contingency Theory serves as the primary perspective for this study. The reason why Contingency Theory is relevant is because it is possible that the effectiveness of a costing system will depend upon the environmental and organizational context in which it operates as well as its technical sophistication. Survey results regarding ABC implementation in Polish and Lithuanian companies suggest that there are differences between those who have implemented ABC and those who have not implemented ABC in terms of what they perceive to be barriers to implementing ABC (Pietrzak et al., 2020). Research conducted at universities in South Africa and Australia suggests that

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organizational strategies, adaptability of systems, institutional characteristics and whether or not organizations continue to use systems over time are all factors that influence how organizations implement ABC systems (Kudanga et al., 2023; Abeysekera & Sharma, 2023). Additionally, research conducted on Tanzanian manufacturers suggests that an additional factor influencing how organizations implement ABC systems is an organization's pressure to conform to industry standards or other institutional norms that go beyond evaluating the cost/benefit trade-offs associated with implementing an ABC system (Molela et al., 2023). The organizational change dimension is consistent with contingency theory. Giannetti et al.'s (2024) model of management accounting change provides guidance regarding pressures for change, facilitating conditions, and triggering events. For example, growing product complexity and increased demand for environmental reporting can provide the impetus for changing an existing costing system within an ABC environment. Integrated databases and management capabilities can facilitate this process. Technological advances or modifications in control procedures can stimulate the implementation of a new system. These examples represent analytical descriptions as opposed to empirically validated classifications that apply to all organizations.

TOC provides direction to constraints that limit the amount of output a system produces; whereas ABC provides information about the cost of activities. Using both together will provide guidance to avoid making "local" improvements to efficiencies that do not address the bottleneck of the production process. Tsai, Chen, et al. (2024) developed a model for a digitally supported textile system utilizing ABC, TOC, ERP and environmental constraints. Mathematical approaches have also been developed for making decisions regarding footwear and aluminum-alloy wheels (Tsai, 2024; Tsai, Chang, et al., 2024). These studies demonstrate the ability to utilize multiple models for optimizing results within specific assumptions of each model, but do not show that multiple models are always superior to using one model in practice. Environmental applications also need to be made more clear with regard to how visible expenditures are versus how well an organization does environmentally. Integration of ABC and LCA could provide a link from what was spent for financial activities to the environmental burden created by each of those financial activities during the production process (Jourdaine et al., 2021). Surveys of environmental activity management look at connections among management practices, environmental systems, and organizational performance (Baird et al., 2021). Research on green ABC in Iraq, as well as on unused energy costs, provide sector-specific examples of why environmental costing is relevant managerially (Al-Mashkoor et al., 2023; Mahmoud & Hanoon, 2025). However, there is no way to determine if environmental benefits exist based only on reallocating money to different cost categories (Ortiz-Cea et al., 2025).

These three arguments lead to three analytical propositions. Proposition 1: ABC provides the opportunity to improve raw materials and operational resource efficiency through the improvement of activity level cost transparency and the availability of information used for management intervention. Proposition 2: When ABC is integrated with Industry 4.0 technology, it can provide support for making sustainable operational decisions by providing connections among cost, time, energy and environmental resource information. Proposition 3: How successful ABC implementations are, will be determined by context-specific factors; these factors include, but are not limited to: information system readiness, management support, activity complexity, and implementation costs. These propositions help interpret findings and do not represent statistical hypotheses.

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Table 1. Conceptual Propositions and Evidence Anchors

Proposition	Analytical claim	Representative studies
P1	Activity cost transparency can support decisions on material, capacity, and operational efficiency.	Ghani et al. (2020); Vedernikova et al. (2020)
P2	Digital ABC integration can make cost–time–energy trade-offs more visible.	Jourdaine et al. (2021); Tsai, Chen, et al. (2024)
P3	Implementation usefulness depends on technology, organizational fit, and managerial capabilities.	Kudanga et al. (2023); Pietrzak et al. (2020)

Source: From Various Sources That Have Been Processed by AI-Assisted Authors

The Table 1. lists three propositions in order of most fundamental benefits to conditions for successful Activity Based Costing (ABC) implementations. First (P1), the ABCs allow for transparency of the costs associated with each activity, allowing managers to make more informed decisions about material usage, capacity, and operational efficiency, as identified in Ghani et al. (2020) and Vedernikova et al. (2020). Second (P2), when ABCs are combined with digital technologies, the trade-off between cost, time and energy will be more readily visible, enabling managers to consider all three variables when making decisions, as suggested in Jourdaine et al. (2021) and Tsai, Chen, et al. (2024). Third (P3), while there are numerous benefits to ABC, they will not occur simply through implementation; rather, the benefits of implementing ABC depend upon the level of technological readiness, organizational compatibility and managerial ability, as identified in Kudanga et al. (2023) and Pietrzak et al. (2020). In summary, the flow of information is that cost transparency forms the foundation for decision-making (P1), digitalization extends the focus from cost alone to include time and energy as well (P2), and the success of both is dependent upon technology, organization and manager capability factors (P3).

METHODS

This article uses a structured narrative literature review (SNR) with theory-informed thematic synthesis. The design is appropriate because the evidence includes heterogeneous surveys, organizational case studies, capacity analyses, mathematical programming models, and prior reviews. It does not estimate pooled causal effects or test statistical hypotheses. Following narrative-review quality principles, the study makes its review questions, evidence types, inclusion logic, and interpretive limitations explicit (Baethge et al., 2019). Thematic synthesis is used to group reported findings and develop interpretations spanning different study designs (Thomas & Harden, 2008).

The working evidence set was assembled from ten user-supplied journal PDFs and targeted scite literature searches, supplemented by verified methodological publications. Search concepts included 'activity-based costing', 'time-driven activity-based costing', 'Industry 4.0', 'ERP', 'digital twin', 'resource efficiency', 'environmental activity management', 'life-cycle assessment', 'implementation barriers', and 'sustainability'. Searches used combinations of these concepts and were restricted to bibliographic records available at the time of preparation (12 November 2026). Historical contributions were included when relevant to costing foundations; targeted additions emphasized 2021–2025 publications. The phrase '1990–2025' in the working title indicates the intended historical scope, not a claim that every publication or year in that interval was systematically screened.

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The transparently identifiable corpus for this manuscript consists of 31 DOI-verified journal publications: 29 substantive papers and two methodological references. Sources were selected purposively for direct relevance to at least one research question, publication identity, and accessible evidence concerning methods or findings. The review does not claim exhaustive database retrieval. Because comprehensive search exports, dated query logs, and item-level exclusion decisions were not retained, a reliable initial retrieval count, duplicate count, or full screening funnel cannot be reconstructed retrospectively. These missing quantities are not manufactured. The corpus is therefore reported as a purposively assembled, DOI-verified narrative evidence set rather than a PRISMA-screened systematic review.

Evidence extraction considered publication year, country or organizational setting when stated, sector, design, ABC variant, type of cost or operational measure, implementation factors, and limitations. Findings were additionally coded by evidentiary status: observed case or survey data, modeled or scenario-based outcomes, and secondary synthesis. Coding aligned with P1 (cost and resource visibility), P2 (digital and environmental integration), and P3 (organizational contingencies), while allowing cross-cutting themes such as capacity measurement and change management. Numerical findings were not pooled because units, study designs, and operational contexts were noncomparable.

A descriptive manufacturing illustration is provided through published cases of assembly, textile production, and other sectors. No primary interviews or proprietary company-level data were used. The earlier draft's inconsistent references to Nestlé Indonesia and Nestlé Bangladesh are excluded as unverified empirical evidence. Cross-study conclusions are interpreted with attention to theoretical plausibility, source-specific limitations, and the distinction between improved cost allocation and realized operational savings.

Table 2. Review protocol and evidence classification

Element	Implementation	Boundary
Evidence sources	10 user-provided journal PDFs, plus targeted scite-retrieved DOI-verified papers	Selected evidence, not exhaustive retrieval
Time boundary	Intended historical range 1990–2025; included publication years verified individually	No false claim of complete coverage
Selection	Direct thematic relevance, DOI verified, study characteristics inspected	No reconstructed screening funnel
Extraction	Sector, approach, method, outcomes, limitations, study type	Noncomparable outcomes not pooled
Synthesis	Theory-informed coding across RQ1–RQ3 / P1–P3	Interpretive, not causal effect estimation

Source: From Various Sources That Have Been Processed by AI-Assisted Authors

This review in Table 2. was compiled selectively and transparently, rather than as a thorough literature search. The source of evidence was 10 PDF journal articles provided by the researchers, plus several papers taken through scite and DOI verified, so the scope was limited to selected evidence and did not claim to be complete. The intended time range was 1990–2025, but the year of publication of each article was examined individually, so that there were no false claims about the completeness of the period. Articles were selected based on their immediate thematic relevance, valid DOIs, and examination of study characteristics, and therefore the authors did not display a

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reconstructed screening funnel chart after the event. From each article, data were extracted regarding the sector, approach, method, outcome, limitations, and type of study; the disproportionate results were not aggregated or calculated in aggregate. Finally, the synthesis was carried out by theory-based coding of the RQ1–RQ3 research questions and the P1–P3 proposition, so that the findings were interpretive and not intended to estimate causal effects.

RESULT AND DISCUSSION

Evidence Characteristics and Thematic Findings

The research sample includes cost-related studies from manufacturing, education, professional service organizations, environmental management, and health care. The wide variety of methods employed in these studies provides an analytical advantage for comparative purposes; however, it limits the extent to which each study can be treated as a treatment effect of the same intervention. Manufacturing studies typically focus on cost-differentiation of products, utilization of manufacturing capacity, and optimization of manufacturing processes. University-based studies and professional service studies generally examine the cost-accounting system being used by an organization, the amount of time employees spend performing non-productive tasks, and the fit between an organization's structure/culture and its cost-accounting systems (Vedernikova et al., 2020; Kudanga et al., 2023; Burak et al., 2022).

As part of P1, there is a good amount of direct evidence regarding capacity and cost visibility. For example, Ghani et al. (2020) determined both utilized and unutilized workstation capacity within the context of automotive manufacturing. Vedernikova et al. (2020) identified differences in how products are allocated costs based upon the type of assembly setting used. Finally, Zaini and Abu (2023) identified unused time and the costs associated with that time in university operations. Additionally, Anderson (2021) linked time-driven costing with digital twins in additive manufacturing. He indicated that it would be possible to connect cost and capacity models to actual operational models. While these studies show the usefulness of information provided by identifying idle resources, they do not provide consistent evidence that identifying such idle resources will lead to less cash outflow or fewer raw material inputs.

A related manufacturing research stream focuses on the use of detailed activity data for product costing. Firmandani et al. (2024) explore how production complexity can affect the use of detailed activity data within a manufacturing case study, and Zamrud and Abu (2020) compare Activity Based Costing (ABC) with Time Driven Activity Based Costing (TDABC) within the electronics manufacturing sector. Evidence suggests that the type of costing method chosen impacts the way indirect costs are allocated and interpreted. Thus, the conclusion that there are differing unit costs among various costing systems must be presented separately from any assertions regarding decreases in actual production costs.

In addition to integrating cost models with environmental concerns under P2, there is an increase in literature focusing on the integration of environmental concerns with cost modeling. For example, Jourdaine et al. (2021) developed a method for integrating ABC and LCA calculations. Baird et al. (2021) examined relationships between environmental activity management, environmental management systems, and company performance. Green ABC has been applied to report on the use of sustainability-oriented practices in Iraq (Al-Mashkoor et al., 2023) and analyze energy-related unused capacity (Mahmoud & Hanoon, 2025). Carbon-cost models in manufacturing have been used to evaluate

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alternative policy and product mix scenarios for several products including aluminum wheels (Tsai et al., 2019), textiles (Tsai, 2023), footwear (Tsai, 2024), and coffee roasting (Tsai et al., 2025). It can be said that these studies provide evidence of modeled economic-environmental trade-offs, rather than demonstrating universally reduced emissions.

The survey and case-based evidence under P3 supports that organizational context matters. Different ABC implementation barriers were found by Pietrzak et al. (2020) based upon the adoption group. In addition, Kudanga et al. (2023) identified both organizational and technology-related aspects within a university located in South Africa, while Abeysekera and Sharma (2023) explored differences in how universities in Australia adopted ABC. Finally, Molela et al. (2023) expanded on this finding through examining institutional pressure within manufacturing in Tanzania. Additional support for the relationship between firm performance and management accounting systems as related to organizational ambidexterity provides possible mechanisms that could explain the differences in adoption of ABC, however, there is need for caution regarding causal relationships (Pham, 2021; Al-Dhubaibi, 2025).

There appears to be strong support for the proposition that the benefit of activity-cost information is more often perceived as informational rather than in terms of tangible resources saved (or environmental impacts reduced). Regardless of the industry sector being studied, the process by which activity-cost information is used to improve performance includes decision-making regarding processes, identifying bottlenecks, making commitments about capacity, or taking action to minimize environmental impact. Thus, the evidence patterns are supportive of the use of the three propositions as interpretations, but do not provide formal validation for each.

Table 3. Evidence matrix across selected sectors

Source	Study Setting / Evidence Type	Main Contribution and Limit
Ghani et al. (2020)	Automotive manufacturing; time/capacity analysis	Identifies underused and overused capacity, not verified avoided expenditure
Vedernikova et al. (2020)	Assembly; multiple-case costing comparison	Different product-cost assignments, not cash savings
Anderson (2021)	Additive manufacturing; digital twin / TDABC	Conceptual/applied connection between digital production representation and time costing
Firmandani et al. (2024)	Manufacturing case	Examines activity-based cost assignment in complex production
Burak et al. (2022)	Bank internal audit; TDABC application	Shows applicability to professional service workflows
Kudanga et al. (2023)	South African university; mixed methods	Organizational and technological adoption conditions
Molela et al. (2023)	Tanzanian manufacturing; survey	Institutional influences on adoption
Jourdaine et al. (2021)	ABC–LCA model	Connects financial cost accounting with environmental assessment
Tsai, Chen, et al. (2024)	Textile; ERP–ABC–TOC optimization	Modeled product-mix decisions under constraints
Tsai et al. (2025)	Coffee roasting; ABC environmental modeling	Modeled energy and carbon trade-offs

Source: From Various Sources That Have Been Processed by AI-Assisted Authors

Table 3. illustrates that the evidence reviewed here is from many different industry segments and is presented in four separate stages. Initially, research conducted on automotive manufacturing and assembly indicates the basic advantages of ABC.

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Specifically, Ghani et al. (2020) demonstrated how ABC can help identify whether there was a surplus or deficit in capacity; however, Vedernikova et al. (2020) demonstrated how ABC provides more detailed information about product costing allocations. Neither study provided evidence of actual cost reductions. Next, Anderson (2021) and Firmandani et al. (2024) broaden the scope of discussion beyond traditional manufacturing processes to include more advanced manufacturing techniques such as additive manufacturing using digital twin technology, TDABC, and activity-based costing for complex manufacturing operations. Additionally, Burak et al. (2022) illustrate that TDABC can be used for professional service workflows, including internal audit functions within banks. Then, Kudanga et al. (2023) at a university in South Africa and Molela et al. (2023) in manufacturing in Tanzania emphasize that successful implementation relies on organizational features, technology used, and institutional support. Finally, Jourdaine et al. (2021), Tsai, Chen, et al. (2024), and Tsai et al. (2025) demonstrate that ABC can assist organizations in assessing the environmental impacts of their activities, optimizing their product mix under constrained conditions, and evaluating trade-offs between energy consumption and carbon emissions. However, most of these studies rely heavily on models. Since the types of evidence collected and the findings generated vary greatly across each study, the results from each study should be viewed as providing a collective view of patterns of behavior across industries rather than as providing direct comparisons or quantitative combinations of data.

Table 4. Synthesis by research question

Question	Most defensible finding	Remaining evidence limitation
RQ1 / P1	ABC improves cost and capacity visibility	Actual material reduction not consistently demonstrated
RQ2 / P2	Digital/environmental integration supports scenario evaluation	Modeled savings are not longitudinal observed outcomes
RQ3 / P3	Context affects feasibility and adoption	Relative factor importance varies by setting

Source: From Various Sources That Have Been Processed by AI-Assisted Authors

Table 4 presents the strongest results for each of the four research questions and their limitations. RQ1/P1 showed that the best supported conclusion was that ABC provided increased visibility of cost and capacity to allow managers to better understand resource utilization and cost within each activity; however, no consistent evidence of reduced use of materials has been found across studies. RQ2/P2 showed that integrating ABC with digital tools and environmental assessments could assist with evaluating scenarios (e.g., comparing alternatives based on cost, time and energy) prior to making decisions; however, most reported savings are model based rather than results obtained through long-term observation. RQ3/P3 showed that organization-specific characteristics affected both the ability to implement and the overall success of ABC, therefore, the degree of success will vary among organizations; however, the relative importance of the different factors (i.e., technological, organizational, or institutional) varied based upon the setting in which the study took place. In summary, although ABC can be used effectively to clarify information and support decision-making, there remains little evidence regarding the measurable impact of ABC and the factors that determine its effectiveness across different types of organizations; therefore, additional research using long-term observational data and cross-contextual comparisons is required.

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Interpreting the Information–Intervention–Outcome Mechanism

The research suggests that the primary use of ABC should be viewed as an information capability. By using activity-level tracking, managers can examine their consumption of resources in greater detail than they would be able to do so through the use of generalized allocation systems. However, the financial implications of identifying an inefficient activity depend upon whether there are alternative ways for the organization to respond to the identification of such activities. For instance, estimating unused-capacity is helpful when attempting to identify a problem with a workflow; however, estimating unused-capacity does not result in a cash savings until such time as resources can be re-allocated, avoided costs can be eliminated, or future commitments to capacity can be modified. Viewing the research results in this manner supports both the information benefits related to ABC found in assembly and automotive study results, and the lack of support regarding the actual reduction in materials (Ghani et al., 2020; Vedernikova et al., 2020).

A distinction should be made since cost-system comparisons could otherwise exaggerate their management significance. A lower calculated cost using TDABC might indicate a different method of treating idle capacity, but not a productive change. Similarly, a better cost driver may redistribute overhead costs across products, however it will not change total spending. To make use of diagnostic information to guide decisions in procurement, production scheduling, process design, or product/service portfolio management, managers must relate this information to actions taken to improve operations. TOC offers a supplementary framework to help prioritize these types of improvements based on identifying constraints that restrict the amount of output that can be produced by the organization (Tsai, Chen, et al., 2024). Therefore, P1 is conceptually supported as well as descriptively as related to cost visibility; however, any realized resource savings are conditional on being directly measured.

Interpretation of the sustainability evidence is similarly demanding. ABC-LCA and green costing models develop a language to link the cost of activities to the use of materials, energy, waste, and carbon emissions (Jourdaine et al., 2021; Ortiz-Cea et al., 2025). This language can be enhanced through the development of more detailed information about the operation of the process through the use of digital monitoring, and integrated mathematical models can provide insight into the implications of different alternatives (Tsai, 2023; Tsai, Chang, et al., 2024). A model-based estimate of what is considered to be the most appropriate product mix will reflect specific prices, technical parameters, and environmental constraints. Therefore, it is important that this estimate is not represented as an empirically verified field outcome until the organization has used the model and evaluated the results after using it.

The purpose of this review is to treat sustainability as a multi-dimensional construct. Cost effectiveness, energy used per unit of output, waste material generated and greenhouse gas emissions are related yet distinct constructs. An increase in throughput can decrease the unit cost of production while increasing overall energy use. Conversely, investments that improve environmental performance can result in higher activity costs in the short run. Therefore, the managerially relevant issue is not whether ABC will inherently lead to reduced environmental impacts, but if an activity-based information architecture will allow for explicit trade-offs to be made. There is evidence that supports the qualified interpretation of ABC as an integrated decision support tool (Baird et al., 2021; Al-Mashkoor et al., 2023) through the study of environmental activity management and sustainability-oriented accounting.

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Implementation variability can be attributed to the match between the costing system used and the organization's institutional and technological environments. Company and university studies have shown significant variations in how costing systems are adopted, their adaptability, their technological capabilities, and their managers' information requirements (Pietrzak et al., 2020; Kudanga et al., 2023; Abeysekera & Sharma, 2023). Institutional pressures can also influence the decision to adopt costing systems; however, adopting a costing system does not mean it is being utilized effectively (Molela et al., 2023). Based on research conducted in manufacturing, banking, health care, and higher education, it is no longer appropriate to make recommendations regarding the same cost driver structure for each organization (Burak et al., 2022; Vărzaru, 2022; Zamandi & Raei, 2025).

The process interpretation is an extension of the contingency interpretation. Changes in management accounting can occur due to pressures, conditions, and triggers. However, the continuation of these changes depends upon whether the users within the organization perceive them as credible and workable (Giannetti et al., 2024). The implementation of an Enterprise Resource Planning (ERP) system can enhance activity measurement while at the same time creating additional requirements for skill development, data governance, and departmental coordination. If there is no corresponding adjustment in the organization, then the implementation of advanced digital technology can result in high-cost data sets that will never be used to make decisions. Therefore, the P3 statement is supported as a contextual explanation; however, the relative importance of each determinant does not imply uniformity across different industries.

The theoretical contribution made by this review is to provide an integrated explanation for how information, interventions, and outcomes are related. ABC (and its various forms) creates more visibility for what is happening within organizations; the decision-making process used by managers will determine whether or not that visibility can be converted into changes in operations; and the organizational context in which organizations operate will affect the likelihood of implementing ABC, and taking subsequent action based on its results. TOC adds a systems-level constraint view, and research on change explains why organizations adopt and adapt new technologies. This framework prevents us from assuming that costing accuracy alone can serve as a measure of an organization's competitiveness or sustainability. In addition, this framework offers an empirical research agenda: future researchers should be able to separate the measurement of costing accuracy, the utilization of information generated by ABC, operational changes implemented as a result of ABC, and physical outcomes associated with those changes, preferably using longitudinal multi-site research methods.

For the purpose of developing practice, the synthesis recommends that organizations start by identifying a need for a decision prior to implementing a technology. Pilot projects will be used to determine the availability and quality of activity-based data; estimate the administrative cost required to sustain the model; and link outputs to specific management actions. Evaluations will be conducted to separately document changes in cost allocation; avoided expenses; utilization/throughput; and other appropriate environmental indicators. Comparative implementation studies across different industry sectors may assist in determining what organizational factors lead to the creation of long-term value from these types of initiatives.

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CONCLUSION

This structured narrative review examined the role of Activity-Based Costing (ABC) in improving resource efficiency, enabling decision making for sustainability, and adapting to digitization within Industry 4.0. The literature reviewed suggests that ABC and its time-driven variants provide a more complete view of activity cost and capacity utilization. This allows organizations to understand where they are experiencing operational inefficiencies; however, providing such views does not necessarily indicate a decrease in raw material use or cash outflows. Organizations must take actions based on the improved costing data to achieve tangible resource savings.

The development of digitally integrated ABC (Activity Based Costing) systems, such as those that are combined with enterprise systems, Life Cycle Assessment (LCA) and the Theory of Constraints (TOC), offers a way to analyze both production costs and other factors including time, energy, materials, and environmental constraints. Although most of the literature on sustainability is based upon scenario and optimization modeling; this cannot be equated to long term emission and/or energy reduction as seen in actual practice. The literature also supports the view that the suitability of the system is dependent upon the organization's level of technological readiness, management's commitment to the use of the system, the complexity of the activities being analyzed, the accuracy of the data collected, and the cost of implementing the system.

This study makes a conceptual distinction between cost visibility, management action and performance achieved; as well as identifying how organizational factors influence the relationships between these variables. This study has practical implications in terms of assessing ABC implementations relative to decision making requirements, and separately measuring financial and physical outcomes. The limitations of this study include using a non-randomized, purposive sample of studies, having heterogeneous study design, lack of documentation for all studies retrieved via search, and the absence of independent verification of the interview data collected from organizations. Additional studies are needed to examine the validity of the proposed relationships using longitudinal studies across multiple sectors, and include measures of cost, capacity and environmental performance.

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