University of Tehran Press

Industrial Management Journal

Online ISSN: 3115 - 7386

Homepage: https://imj.ut.ac.ir

The Rise of Dynamic Modeling Approaches for Sustainable Decision-Making in Complex Management Systems

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Cite this article: Safari, H., (2025). The rise of dynamic modeling approaches for sustainable decision-making in complex management systems. ***Industrial Management Journal***, 17(3), 1-5. https://doi.org/10.22059/imj.2025.108482

Publisher: University of Tehran Press.

DOI: https://doi.org/10.22059/imj.2025.108482

Document Type: Editor's Note

Introduction

The growing complexity of contemporary management systems has fundamentally transformed the nature of organizational decision-making. Modern production networks, healthcare systems, energy infrastructures, and supply chains are characterized by nonlinear interactions, feedback mechanisms, multiple stakeholders, and persistent uncertainty. In such environments, conventional optimization techniques that rely on static assumptions often fail to capture the dynamic behavior of real-world systems and their long-term consequences. As organizations increasingly pursue economic performance alongside environmental stewardship and social responsibility, decision-makers require analytical approaches capable of representing system evolution over time while accounting for the interdependencies among operational, economic, environmental, and behavioral dimensions. Consequently, dynamic modeling has emerged as a promising paradigm for supporting sustainable decision-making in complex management systems.

The transition toward sustainability has further accelerated the adoption of dynamic analytical methods. Sustainable development requires balancing competing objectives across economic, environmental, and social dimensions while considering delayed effects, policy feedbacks, and adaptive behaviors of system participants. Recent research demonstrates that dynamic modeling techniques particularly System Dynamics (SD), Agent-Based Modeling (ABM), discrete-event simulation, and hybrid simulation-optimization approaches provide an effective means of understanding these complexities. Rather than identifying a single optimal solution under fixed assumptions, these methods allow researchers and practitioners to evaluate alternative scenarios, explore policy interventions, and anticipate unintended consequences before implementation, thereby improving the quality and resilience of managerial decisions.

Among these approaches, System Dynamics has gained particular prominence as a framework for analyzing sustainability challenges. Francis and Thomas (2023) showed that integrating System Dynamics with Multi-Criteria Decision-Making (MCDM) provides a comprehensive mechanism for evaluating sustainability policies by simultaneously capturing dynamic interactions among environmental, economic, and social indicators. Similarly, Naeem et al. (2023), in their comprehensive review of sustainable water supply and demand management, concluded that System Dynamics is highly effective in modeling complex socio-environmental systems, while emphasizing that future research should increasingly integrate SD with optimization methods, Agent-Based Modeling, and other quantitative techniques to enhance decision support. These studies collectively indicate that sustainability assessment is progressively moving from isolated analytical methods toward integrated dynamic decision-support frameworks. The evolution of dynamic modeling extends beyond individual methodologies toward comprehensive decision intelligence frameworks. Selin et al. (2023) argued that recent advances in dynamic systems modeling have significantly improved the ability of researchers to analyze nature–society interactions, evaluate policy interventions, and inform sustainable development strategies across multiple sectors. Likewise, Hashemizadeh et al. (2024) demonstrated how System Dynamics can support renewable energy policy design by incorporating economic, political, technological, and environmental variables within a unified causal structure, enabling policymakers to compare alternative intervention scenarios. At the organizational level, Debnath et al. (2024) further illustrated how advanced quantitative decision-making techniques can identify the underlying drivers and interdependencies that hinder sustainable production practices, thereby facilitating more effective strategic planning. Together, these studies highlight a broader shift from descriptive analysis toward predictive, scenario-based, and policy-oriented decision support.

This thematic issue reflects these emerging developments by presenting studies that employ diverse dynamic modeling techniques, including simulation-optimization, System Dynamics, Agent-Based Modeling, mathematical optimization, and hybrid decision-making approaches to address sustainability challenges across healthcare, energy systems, manufacturing, supply chains, and public policy. Although the application domains vary considerably, the contributions collectively emphasize a common research direction: the movement from static optimization toward dynamic, data-informed, and systems-oriented decision-making. They demonstrate that sustainable management increasingly depends not only on identifying efficient solutions but also on understanding how complex systems evolve over time, respond to interventions, and generate long-term outcomes. In this context, the articles included in this issue contribute to the growing body of knowledge advocating dynamic modeling as a foundational approach for designing resilient, adaptive, and sustainable management systems.

Insights from This Issue

The articles featured in this issue collectively demonstrate that sustainable decision-making is no longer confined to the pursuit of optimal solutions under static assumptions. Instead, they embrace a dynamic systems perspective in which managerial decisions are evaluated through their long-term interactions, feedback mechanisms, and responses to uncertainty. Whether addressing healthcare inventory management, renewable energy development, pharmaceutical operations, manufacturing systems, or public policy, the studies consistently recognize that complex management problems require analytical approaches capable of representing system evolution over time rather than isolated decision points. This shared perspective reflects an important shift in operations and industrial management research from optimization-centric thinking toward dynamic decision intelligence. A second notable insight concerns the increasing methodological integration observed across the contributions. Rather than relying on a single analytical technique, several studies combine simulation, mathematical optimization, multi-criteria decision-making, system dynamics, and agent-based modeling to exploit the complementary strengths of each approach. This trend aligns with recent developments in sustainability research, which advocate hybrid modeling frameworks capable of incorporating operational constraints, stakeholder behavior, policy interventions, and environmental considerations within a unified decision-support system. The convergence of these methodologies enhances both the realism of analytical models and the practical relevance of their recommendations for decision-makers operating in uncertain environments.

Another common theme emerging from this issue is the broadening scope of sustainability itself. The published studies demonstrate that sustainability should not be interpreted solely through environmental performance, but rather as a multidimensional objective encompassing economic efficiency, operational resilience, social welfare, and responsible resource utilization. Whether optimizing healthcare supply chains through big data analytics and lean principles, modeling behavioral patterns of energy consumption, designing biofuel supply chains, or evaluating extended producer responsibility in the apparel industry, the contributions consistently illustrate that sustainable performance depends on balancing multiple objectives across interconnected systems. Such an integrated perspective reinforces the need for management research that explicitly captures the trade-offs and synergies among economic, environmental, and social outcomes. Finally, this collection of articles points toward an emerging research agenda in which dynamic modeling serves as the foundation for more adaptive and evidence-based management systems. Future advances are likely to arise from tighter integration between dynamic simulation, artificial intelligence, digital twins, real-time analytics, and optimization algorithms, enabling organizations to anticipate system behavior, evaluate alternative policies proactively, and continuously adapt to changing conditions. By showcasing diverse applications of advanced modeling techniques across multiple industrial contexts, this issue contributes to the growing body of knowledge that positions dynamic modeling not merely as a methodological alternative, but as a strategic capability for designing resilient, intelligent, and sustainable management systems in an increasingly complex world.

Future Research Agenda

The rapid evolution of dynamic modeling creates significant opportunities for advancing both theory and practice in sustainable management research. One promising direction lies in the development of integrated modeling frameworks that combine System Dynamics, Agent-Based Modeling, discrete-event simulation, mathematical optimization, and Multi-Criteria Decision-Making within a unified analytical environment. Although each methodology provides valuable insights independently, their integration can better capture the structural complexity, behavioral heterogeneity, and operational constraints that characterize modern industrial systems. Future studies should therefore focus on developing standardized hybrid modeling architectures capable of supporting comprehensive sustainability assessments while remaining computationally efficient and practically applicable. A second avenue for future research concerns the incorporation of emerging digital technologies into dynamic decision-support systems. The increasing availability of real-time operational data through Internet of Things (IoT) devices, cyber-physical systems, and enterprise information platforms creates new opportunities for constructing adaptive simulation models that evolve alongside the systems they represent. The integration of Artificial Intelligence, machine learning, and Digital Twin technologies with dynamic modeling could substantially improve forecasting accuracy, scenario generation, anomaly detection, and policy evaluation. Such intelligent decision-support systems would enable organizations to move beyond periodic planning toward continuous, data-driven decision-making under rapidly changing operational conditions.

Another important research direction involves strengthening the behavioral and institutional dimensions of dynamic models. Many sustainability challenges arise not only from technical or operational factors but also from the interactions among governments, firms, consumers, regulators, and other stakeholders whose decisions evolve over time. Future research should therefore place greater emphasis on modeling human behavior, organizational learning, policy adaptation, and stakeholder collaboration. Integrating behavioral economics, social network analysis, and participatory modeling into existing simulation frameworks would provide a more realistic representation of complex socio-technical systems and improve the effectiveness of sustainability-oriented policies. Finally, future studies should expand the application of dynamic modeling across emerging sustainability challenges while improving model validation and generalizability. Critical research domains such as circular economy systems, climate adaptation, carbon-neutral supply chains, smart manufacturing, resilient healthcare systems, and sustainable urban development present ideal contexts for applying advanced dynamic modeling techniques. At the same time, greater attention should be devoted to transparent model validation, uncertainty analysis, sensitivity assessment, and cross-sector comparative studies to enhance the credibility, reproducibility, and practical adoption of dynamic decision-support models. Such efforts will contribute to establishing dynamic modeling as a mature scientific foundation for sustainable management research.

Conclusion

The studies presented in this issue collectively demonstrate that sustainable decision-making increasingly depends on understanding the dynamic behavior of complex management systems rather than optimizing isolated decisions. Across diverse application domains, including healthcare, energy, manufacturing, supply chains, and public policy the contributions illustrate how advanced modeling approaches can reveal feedback structures, evaluate alternative scenarios, and support more resilient and informed managerial decisions. Together, these articles reflect the continuing evolution of industrial management research toward systems thinking, methodological integration, and evidence-based policy design. As organizations face growing uncertainty arising from technological transformation, environmental challenges, and socio-economic change, the need for dynamic, adaptive, and sustainability-oriented decision-support tools will continue to expand. We hope that the research presented in this issue not only contributes to the advancement of dynamic modeling methodologies but also inspires future interdisciplinary collaborations that bridge operations management, systems science, artificial intelligence, and sustainability research. By fostering such integration, the management research community can play a pivotal role in designing intelligent, resilient, and sustainable systems capable of addressing the complex challenges of the decades ahead.

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