A Multiscale Modeling Framework for Organizational Resilience: Integrating Agent-Based, Discrete Event, and System Dynamics Approaches

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Abstract. Multiscale Modeling and Simulation (MMS) provides a robust approach to understanding organizational resilience in complex business systems. This paper presents a Micro-Meso-Macro framework integrating Agent-Based Modeling (ABM), Discrete Event Simulation (DES), and System Dynamics (SD). At the micro level, ABM captures individual behaviors and decision-making processes. DES at the meso level models how these individual behaviors aggregate into operational processes and efficiencies. At the macro level, SD explores systemic effects, strategic feedback loops, and policy implications over the long term. By explicitly linking these modeling techniques, the proposed conceptual framework enhances our understanding of how disruptions propagate across scales, influencing organizational resilience and adaptability. This study contributes to MMS literature by providing a scalable and structured methodology that integrates multiple simulation methods, enabling organizations to better navigate complexity and uncertainty.

Keywords: Discrete Event Simulation (DES), Agent-Based Modeling (ABM), System Dynamics (SD), Multiscale Modeling and Simulation (MMS), Organizational Resilience, Complex Systems, Simulation Integration

1 Background Research

The significance of Multiscale Modeling and Simulation (MMS) as a means of investigating complex, multi-level system interactions is continuously growing. Analysis of interactions and feedback across multiple hierarchical levels has enabled MMS to provide effective explanations for complex phenomena in a range of disciplines, encompassing materials science, biology, and environmental engineering, to name a few. Multiscale modeling has played a crucial role in materials science, helping researchers predict material properties by connecting atomic-level interactions to large-scale behavior. This approach has significantly contributed to the development of new and innovative materials [1]. In biological systems, it has provided deeper insights into processes ranging from molecular interactions to whole-organism functions, transforming fields like genomics and proteomics [2].

Notwithstanding clear evidence of its potential, the utilization of MMS within organizational and business settings, especially in relation to organizational resilience, is

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surprisingly constrained. Organizational resilience, defined as an organization's ability to foresee, adapt to, and effectively respond to disruptions and unexpected challenges [3] and is inherently shaped by interactions across multiple operational levels. Stability within organizations is often disrupted by cascading failures, where the breakdown of one component triggers further failures across interconnected systems. Fluctuating demand and operational disruptions at the micro level can amplify these effects, leading to widespread organizational instability [4].

While organizational resilience has been mostly studied through single-scale simulations and other methods [5], a comprehensive multiscale approach remains largely unexplored. Recently, a study applied MMS to a service desk in a UK-based telecommunications firm, introducing a strategic framework that leverages discrete event simulation (DES) to integrate multiscale modeling within organizational decision-making [6]. This gap highlights the need for a structured framework that integrates individual, operational, and strategic dimensions. In response, this paper introduces a new conceptual framework aimed specifically at applying MMS to enhance organizational resilience and sustainability. The proposed framework integrates Agent-Based Modeling (ABM) at the micro-level, capturing individual behavioral variations; Discrete Event Simulation (DES) at the meso-level, focused on operational processes and System Dynamics (SD) at the macro-level, addressing systemic and strategic interactions. By explicitly linking these modeling approaches, the framework enables organizations to understand more clearly how individual actions, operational practices, and long-term strategies collectively influence their resilience.

The paper is structured as follows: Section 1 provides an overview of literature on the existing state and limitations in MMS and organizational resilience studies. Section 2 presents the proposed multiscale framework, detailing the integration of ABM, DES, and SD. Section 3 explores potential real-world applications across various organizational contexts. Section 4 concludes by summarizing key findings and identifying opportunities for future research and practical application.

2 Conceptual Model Development

2.1 Understanding Organizational Complexity through Micro, Meso and Macro Perspectives

Organizations are complex, with interactions occurring across multiple levels. A multiscale approach clarifies how individual behaviors shape broader outcomes, how operational processes integrate these behaviors, and how strategic decisions drive resilience and performance [7].

At the micro level, individuals (i.e. employees, customers, or automated systems) make dynamic decisions influenced by personal preferences and external factors. In retail, purchasing habits differ between impulse buyers and planners. In airports, passenger responses to long queues affect terminal efficiency [8].

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The meso level focuses on organizational structures and workflows, showing how individual actions aggregate into patterns. In hospitals, patient flow through triage, consultation, and treatment highlights bottlenecks and inefficiencies [9].

At the macro level, organizations interact with external forces like markets and regulations, shaping long-term stability. For example, supply chain resilience depends on how disruptions like pandemics or trade barriers impact business continuity [10]. Figure 1 highlights the interplay among the three levels. In the following section, we illustrate our approach by referring to an airport scenario, which clearly demonstrates how ABS, DES, and SD can be integrated into a unified multiscale modeling framework.

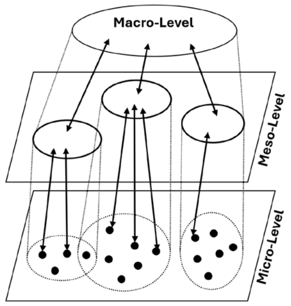

Fig. 1. Hierarchical Structure of Micro, Meso, and Macro Layers

2.2 Agent-Based Simulation (ABS) at the Micro Level

Agent-Based Simulation (ABS) is well-suited to the micro level as it models individual behaviors within a system, capturing diversity and adaptability. In business contexts, these actors affect organizational performance in distinct ways. Unlike traditional models, ABS acknowledges behavioral variability, making it ideal for scenarios where individual decisions influence system outcomes.

A key advantage of ABS is its ability to simulate interactions and decision-making. For example, in an airport check-in area, passengers (e.g. Business travelers, families, or first-time flyers) arrive at different times, select queues based on perceived waiting times, and may switch lines because of congestion. By modeling these choices, ABS identifies inefficiencies and behavioral patterns shaping system performance. However, ABS alone cannot optimize overall operations. To address this, its insights can be integrated into Discrete Event Simulation (DES) at the meso level, ensuring individual behavioral variations inform broader process decisions.

2.3 Discrete Event Simulation (DES) at the Meso Level

At the meso level, organizations comprise interconnected processes, departments, and workflows that shape overall performance. Unlike ABS, which focuses on individuals, Discrete Event Simulation (DES) models the sequence of events that drive operational efficiency. By representing business activities as discrete events occurring over time, DES captures how systems evolve in response to changing conditions.

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DES is widely used in service industries, production lines, logistics, and customer service. In an airport departure terminal, for example, a DES model can track passenger flow through check-in, security, immigration, and boarding. By simulating queue lengths, waiting times, and resource utilization, it allows decision-makers to test strategies for optimizing throughput. Adjusting staffing levels during peak hours or reconfiguring queues to reduce bottlenecks are just a few examples of insights gained from DES. Unlike ABS, which focuses on individual choices, DES provides a structured, process-oriented perspective. Incorporating ABS-generated data enhances realism by capturing behavioral variability at the micro level, leading to more adaptive meso-level simulations.

2.4 System Dynamics (SD) at the Macro Level

At the macro level, organizations function within broader systems where long-term trends, market forces, and feedback loops influence strategic decisions. System Dynamics (SD) is particularly effective in modeling these large-scale interactions over time, making it valuable for assessing resilience, sustainability, and adaptation to external change. A key advantage of System Dynamics (SD) is its ability to model long-term feedback loops that shape systemic behavior. In an airport context, SD helps assess how sustained passenger growth influences financial viability, infrastructure demand, and regulatory compliance. For example, if passenger volumes increase by 30% over five years, delaying investment in automation or terminal expansion could lead to chronic inefficiencies, higher operational costs, and revenue losses due to declining passenger satisfaction. Unlike DES, which focuses on workflow optimization, SD provides a high-level strategic perspective, guiding long-term decisions on capacity planning, policy implementation, and resource allocation to ensure long-term resilience and financial stability. Figure 2 demonstrates how ABS, DES, and SD are implemented at different organizational scales.

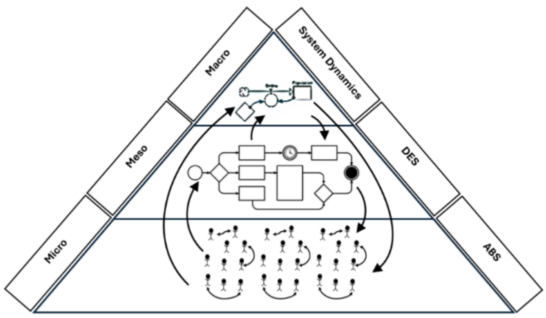

Fig. 2. Multiscale simulation framework for organizational resilience

2.5 A Layered Multiscale Framework: Integrating ABS, DES, and SD

Business operations require both immediate efficiency and long-term resilience, but no single modeling technique captures their full complexity. Linking individual behaviors to strategic outcomes is achieved by combining ABS at the micro level, DES at the

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meso level, and SD at the macro level. In the airport scenario, for instance, ABS simulates individual passenger behaviors at self-check-in kiosks. The efficiency of the check-in process is influenced by the type of passengers using the service. Business travelers, who are more familiar with self-check-in procedures, process their check-in 12% faster, reducing kiosk wait times. In contrast, first-time flyers, due to their unfamiliarity with the system, experience a 20% increase in check-in time. Additionally, 5% of passengers require staff assistance, leading to further slowdowns. These insights from ABS are used as input for DES to model queue dynamics at security checkpoints. (Fig. 3).

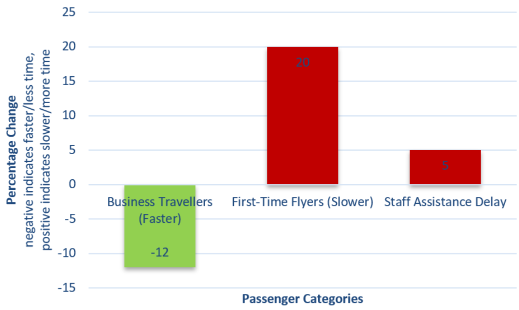

Fig. 3. Illustrative Check-In Efficiency Changes (ABS-Micro Level)

This granular behavioral data from ABS is then used at the meso level through DES, which focuses on operational workflows and resource allocation. At this level, DES models how variations in check-in flow influence queue formation and screening efficiency at security checkpoints. A 20% increase in check-in time leads to a 25% increase in security queue length, demonstrating the downstream impact of slow check-in processing. Introducing an additional security officer improves efficiency, reducing wait times by 18%. Furthermore, delays at security propagate to the boarding process, where a 10-minute delay in screening results in a 5% increase in boarding delays. These meso-level findings are used in SD to assess long-term congestion trends and resource allocation needs (Fig. 4).

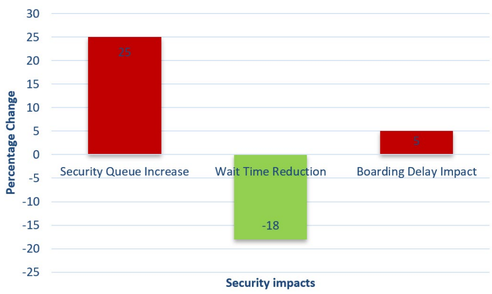

Fig. 4. Illustrative Security & Boarding Impacts (DES-Meso Level)

At the macro level, SD evaluates the long-term impact of operational efficiency, passenger volume growth, and infrastructure investment. Over five years, expanding automation in self-check-in processes results in a 10% reduction in staffing costs, saving

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the airport $5 million annually. If passenger volume increases by 20%, congestion at security and boarding areas could rise by 40% over the next decade if no infrastructure adjustments are made. Investing $50 million in an additional security terminal significantly enhances efficiency, reducing passenger delays by 25% and boosting overall airport revenue by 8%. Additionally, new government regulations could necessitate a 10% increase in security spending over the next 10 years to comply with evolving standards. These macro-level insights provide policymakers with a long-term perspective for sustainable airport planning (Fig. 5).

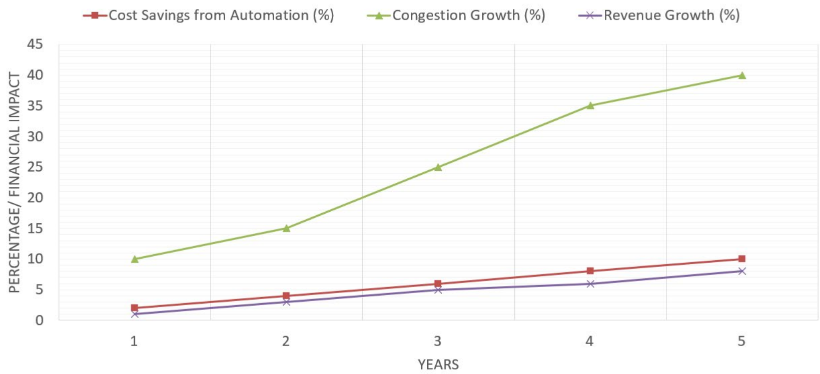

Fig. 5. Illustrative Strategic & Financial Implications Over Time

3 From Micro Dynamics to Macro Impact: Advancing Theory, Practice, and Digital Twins Integration

This study advances multiscale modeling and simulation (MMS) by proposing a novel micro-meso-macro framework that integrates ABS at the micro-level, DES at the meso-level, and SD at the macro-level. This integrated approach contributes significantly to the application of MMS within business contexts. By linking these three approaches, the framework enables a deeper understanding of how individual behaviors influence operational processes and how system-wide policies shape long-term strategic outcomes. Unlike traditional single-scale models, this integration provides a holistic perspective on organizational resilience, demonstrating how disruptions and adaptations propagate across multiple levels.

From a practical perspective, this framework offers business leaders, policymakers, and analysts a structured methodology for evaluating complex organizational systems. By connecting individual decision-making (ABS) to process efficiency (DES) and long-term systemic trends (SD), decision-makers can simulate different scenarios, test policies, and anticipate large-scale consequences before implementation. For example, in airport operations, the framework can predict how passenger behavior affects queuing and congestion at the micro level, how these delays affect security and boarding at the meso level, and how sustained inefficiencies influence long-term infrastructure and

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financial planning at the macro level. Similarly, in healthcare, it can model how patient decision-making affects emergency department congestion, how staffing adjustments alter hospital workflows, and how healthcare policies affect system-wide resilience over time.

3.1 From Supply Chains to Finance: Real-World Multiscale Use Cases

This framework has broad applications in industries where individual behaviors, structured workflows, and macro-level trends interact to shape system performance. In supply chain and logistics, ABS models capture supplier and consumer behavior, DES evaluates warehouse and transportation workflows, and SD predicts how long-term demand fluctuations and market disruptions influence supply chain resilience. Similarly, in smart manufacturing, the framework models worker efficiency and machine performance at the micro level, evaluates production flow at the meso level, and assesses long-term investment in automation and process optimization at the macro level.

By integrating System Dynamics, organizations can extend these insights to evaluate strategic decision-making under uncertainty. Financial institutions can use this approach to understand how individual trading behaviors impact short-term market fluctuations (ABS), how transaction flows and liquidity change across institutions (DES), and how regulatory policies shape long-term market stability (SD). The ability to bridge these levels provides a powerful tool for managing uncertainty and improving strategic planning.

3.2 Real-Time Evolution: Digital Twins in Multiscale Simulation

A natural evolution of this framework lies in Digital Twin (DT) technology, wherein multiscale simulations merge with real-time operational data to produce continuous decision-support. In manufacturing, for example, a DT might use ABS to model how individual machines or workers respond to sudden disruptions, DES to optimize production line scheduling and resource allocation, and SD to assess the long-term impact of iterative changes on overall system performance. Similarly, in supply chain management, a DT can incorporate ABS to capture variations in consumer demand or shipping conditions, DES to identify efficient distribution routes under fluctuating logistics constraints, and SD to forecast how these dynamics affect stock levels and lead times over prolonged periods.

By fusing Multiscale Modeling and Simulation (MMS) with live data, organizations can transcend static, one-off simulations to develop systems that self-correct and evolve as new information emerges. This approach not only enhances short-term efficiency through immediate operational adjustments but also underpins long-term resilience, enabling decision-makers to anticipate and mitigate future challenges before they manifest.

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4 Conclusion

This study introduces a Micro-Meso-Macro framework integrating ABS, DES, and SD to link individual behaviors, operational efficiency, and long-term resilience. This multiscale approach supports scenario testing, disruption management, and strategic decision-making by revealing how decisions propagate across levels. The framework remains conceptual and requires empirical validation. Scalability presents challenges, including data integration and computational demands. Immediate next steps include developing a prototype using publicly available datasets from airport and healthcare systems to assess feasibility under real-world constraints. We will conduct structured simulations, varying key variables with historical data, to test performance in controlled conditions. This supports assumption validation and parameter refinement. We are also exploring collaboration with industry partners to test scenarios using near-real-time data, particularly in logistics and emergency services. These efforts will ground the framework empirically and support future Digital Twin (DT) integration. Embedding real-time IoT data enables continuous monitoring and adaptive decision support, enhancing short-term responsiveness and long-term resilience. This framework provides a foundation for scalable, data-driven decisions in complex systems.

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