

RESILIENCE ENGINEERING IN STRATEGIC OPERATIONS MANAGEMENT

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ИНЖЕНЕРИЯ УСТОЙЧИВОСТИ В СТРАТЕГИЧЕСКОМ УПРАВЛЕНИИ ОПЕРАЦИЯМИ

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Abstract

This article explores the integration of resilience engineering into strategic operations management, focusing on the increasing importance of adaptability, robustness, and learning in volatile business environments. Drawing from cross-sectoral evidence, the paper contrasts traditional risk-centric models with resilience-oriented frameworks that prioritize system elasticity, real-time responsiveness, and autonomous decision-making. Through detailed tables and a graphical typology of resilience strategies, the study examines how organizations across manufacturing, logistics, healthcare, and information and communication technology sectors operationalize resilience dimensions such as modularity, predictive analytics, and procedural agility. The findings underscore the need for sector-specific, metrics-based approaches that embed resilience into core operational systems.

Keywords: Resilience engineering, strategic operations management, system robustness, adaptability, organizational learning, digital transformation, performance metrics, supply chain resilience, sectoral benchmarking, uncertainty management.

Аннотация

Статья посвящена интеграции инженерии устойчивости в стратегическое управление операциями в условиях нестабильной внешней среды. Анализируются отличия традиционных моделей, ориентированных на управление рисками, от современных подходов, акцентирующих внимание на адаптивности, отказоустойчивости и организационном обучении. На основе отраслевых примеров и сравнительных таблиц рассматриваются ключевые измерения устойчивости, такие как модульность, предиктивная аналитика и децентрализованное принятие решений. Представлена графическая типология стратегий устойчивости для секторов производства, логистики, здравоохранения и информационно-коммуникационных технологий. Сделан вывод о необходимости метрико-ориентированных, контекстно-зависимых решений в построении операционной устойчивости.

Ключевые слова: Инженерия устойчивости, стратегическое управление операциями, системная устойчивость, адаптивность, организационное обучение, цифровая трансформация, метрики эффективности, устойчивость цепочек поставок, отраслевое сравнение, управление неопределенностью.

Introduction

In an era marked by increasing complexity, uncertainty, and systemic volatility, resilience engineering has emerged as a critical paradigm in strategic operations management. Traditional operational models, which emphasized stability and efficiency under predictable conditions, are no longer sufficient to navigate the multifaceted disruptions caused by digital transformation, global

supply chain fragility, climate-related risks, and geopolitical tensions. As organizations strive for sustained competitiveness, their capacity to anticipate, absorb, and adapt to disturbances becomes a core strategic asset.

Resilience engineering in the context of operations management focuses on designing systems and processes that are not only robust but also adaptive and reconfigurable. Unlike risk management, which primarily addresses known threats, resilience engineering aims to enhance a system's capability to cope with unknown and unforeseen events without compromising its essential functions. This includes embedding flexibility in supply networks, decentralizing decision-making structures, and implementing feedback-driven mechanisms for real-time learning and correction. The engineering of resilience thus intersects with systems thinking, digital technologies, and organizational behavior [1].

The objective of this article is to examine the integration of resilience engineering principles into strategic operations management frameworks. Emphasis is placed on identifying key dimensions of resilience—such as redundancy, modularity, interoperability, and agility—and analyzing how these can be operationalized within manufacturing, logistics, and service-based environments. Through comparative analysis, graphical models, and case-based evidence from European firms, the article aims to present practical guidelines for embedding resilience into core operational strategies.

Integrating resilience engineering into operations management: foundational concepts and practical implications

The concept of resilience engineering in strategic operations management centers on an organization's ability to anticipate, absorb, adapt to, and recover from disruptions while maintaining core functions and operational continuity [2]. Unlike traditional risk management, which is often reactive and probabilistic, resilience engineering adopts a systems-thinking approach and emphasizes proactive capacity building, adaptive design, and continuous feedback mechanisms. In modern global supply chains and high-stakes production environments, the need for resilience is amplified by digital complexity, geopolitical instability, and increasing customer expectations.

Table 1 offers a comparative overview of core elements distinguishing traditional operations management frameworks from those grounded in resilience engineering principles. The comparison highlights changes in decision-making logic, design philosophy, and response strategy across operational systems.

Table 1

Comparison of traditional operations management and resilience engineering approaches

| Operational dimension | Traditional operations management | Resilience engineering perspective |
|------------------------------|--|--|
| Risk management | Focus on risk identification, quantification, and avoidance based on historical data | Emphasis on uncertainty tolerance, adaptive responses, and early warning signal detection |
| System design | Optimized for efficiency, cost reduction, and predictability | Designed for flexibility, redundancy, and robustness under variable conditions |
| Decision-making logic | Deterministic models assuming steady-state conditions | Scenario-based, dynamic modeling considering cascading effects and systemic shocks |
| Failure handling | Root cause analysis followed by corrective action | Emphasis on learning from near misses and building fault-tolerant processes |
| Performance measurement | Key performance indicators (KPIs) based on throughput and cost efficiency | Inclusion of resilience metrics such as time-to-recovery, elasticity, and operational continuity |

As illustrated, resilience engineering requires organizations to rethink optimization in favor of adaptability. This shift also demands structural and cultural changes, including the development of cross-functional response teams, the integration of digital monitoring technologies, and the adoption of real-time simulation models. By redefining success as the ability to "fail gracefully and recover

rapidly", resilience engineering introduces a paradigm well-suited for volatile and uncertain operational environments [3, 4].

Resilience components in strategic operations: a systems-oriented framework

In the context of strategic operations management, resilience engineering provides a structured approach for enhancing an organization's capacity to sustain performance under volatile conditions [5]. This approach requires more than contingency planning—it necessitates a reconfiguration of core operational components across organizational, technical, and behavioral domains.

The table 2 below outlines five key dimensions of resilient operations: infrastructure robustness, human-system integration, adaptive supply networks, predictive analytics, and decision-making decentralization. Each dimension is further detailed in terms of specific strategies, implementation examples, and measurable outcomes, enabling practitioners to embed resilience principles into operational systems [6].

Table 2

Key components of resilience engineering in strategic operations management

| Resilience dimension | Strategic approach | Implementation example | Expected outcome | Measurement metric |
|-----------------------------|---|---|---|--|
| Infrastructure robustness | Design for modularity and failover mechanisms | Use of microgrid energy systems in critical manufacturing plants | Increased system uptime during grid failure | Downtime hours avoided per incident |
| Human-system integration | Enhance interface design and empower operator autonomy | Digital twin interfaces with real-time override capabilities for control room operators | Faster human response to system anomalies | Operator decision latency (seconds) |
| Adaptive supply networks | Build multi-tier, geo-diverse supply ecosystems | Distributed sourcing of critical components across continents | Reduced dependency on single suppliers | Number of tier-1 and tier-2 suppliers per component |
| Predictive analytics | Use of AI/ML for early disruption detection and trend forecasting | Machine learning models forecasting equipment failure or demand fluctuations | Proactive asset maintenance and inventory balancing | Forecast accuracy rate; reduction in emergency maintenance events |
| Decision decentralization | Enable local units to take autonomous decisions during operational shocks | Granting authority to regional warehouses during logistics disruptions | Faster localized recovery and reduced burden on central command | Recovery time deviation between centralized and decentralized response |

This framework illustrates the interplay between technology, human factors, and system design in fostering operational resilience. Notably, each dimension serves as both a functional and strategic lever—contributing to the overall elasticity of the system and its ability to regenerate after stress events.

Evaluating resilience: sectoral benchmarks and performance indicators

To translate the theoretical principles of resilience engineering into actionable practice, organizations require a structured approach to measurement and benchmarking. This involves the identification of key performance indicators (KPIs) that capture both proactive and reactive

capabilities across sectors [7]. Unlike conventional KPIs focused on throughput or efficiency, resilience indicators must reflect system elasticity, recovery time, failure containment, and adaptability under duress.

Table 3 below presents a cross-sectoral comparison of resilience performance indicators in manufacturing, logistics, healthcare, and ICT. The indicators are grouped into four categories—response time, adaptive capacity, system robustness, and learning mechanisms—offering a multidimensional perspective on organizational resilience across industries.

Table 3

Cross-sectoral benchmarks for operational resilience

| Sector | Response time indicator | Adaptive capacity metric | System robustness metric | Organizational learning mechanism |
|--------------------|--|---|--|--|
| Manufacturing | Mean Time to Recovery (MTTR) after equipment failure | Reconfiguration time for production lines in crisis | Availability of backup systems and redundancies | Post-incident review frequency and integration |
| Logistics | Lead time restoration after disruption | Flexibility in route planning and dynamic fleet allocation | % of critical suppliers with dual sourcing | Scenario-based simulation and contingency protocol updates |
| Healthcare | Emergency service recovery time post-outage | Capacity to shift personnel and resources between departments | Infrastructure redundancy in energy and IT systems | Root cause analysis of near misses integrated into SOPs |
| ICT infrastructure | Downtime duration after cyber or system breach | Load balancing and traffic rerouting speed | Failover readiness and system compartmentalization | Continuous red-teaming and incident learning loops |

These benchmarks highlight that resilience is inherently sector-specific, shaped by operational constraints and service criticality. For instance, while manufacturing focuses heavily on hardware redundancies, ICT environments emphasize cyber-resilience and rapid traffic rerouting. Similarly, healthcare systems prioritize resource adaptability and error learning, especially under surge conditions [8].

By institutionalizing such indicators into their performance evaluation systems, organizations not only quantify resilience but also expose operational blind spots and underperforming areas. Sectoral benchmarks also facilitate inter-organizational learning and regulatory alignment, especially in ecosystems such as critical infrastructure, where collective robustness is essential.

Typology of resilience strategies across industries

While the core principles of resilience engineering—redundancy, adaptability, feedback, and modularity—are shared across domains, their operationalization varies significantly depending on the sectoral context. Industries differ in their risk exposure, regulatory constraints, technological dependencies, and tolerance for downtime, all of which shape the selection and implementation of resilience strategies [9].

For instance, the manufacturing sector prioritizes physical redundancy and predictive maintenance, whereas the logistics domain leans heavily on route flexibility and decentralized decision-making. Healthcare institutions, given their life-critical functions, rely on layered contingency protocols and personnel adaptability. ICT firms, by contrast, emphasize cybersecurity layers, real-time failover systems, and continuous red-teaming [10].

Figure 1 illustrates a typology of resilience strategies across four critical industries—manufacturing, logistics, healthcare, and ICT. Each bar represents the relative prevalence of five

distinct strategy types: structural redundancy, procedural agility, real-time monitoring, autonomous decision frameworks, and learning-oriented protocols. The data are drawn from a meta-analysis of 56 industry reports and academic studies published between 2018 and 2024.

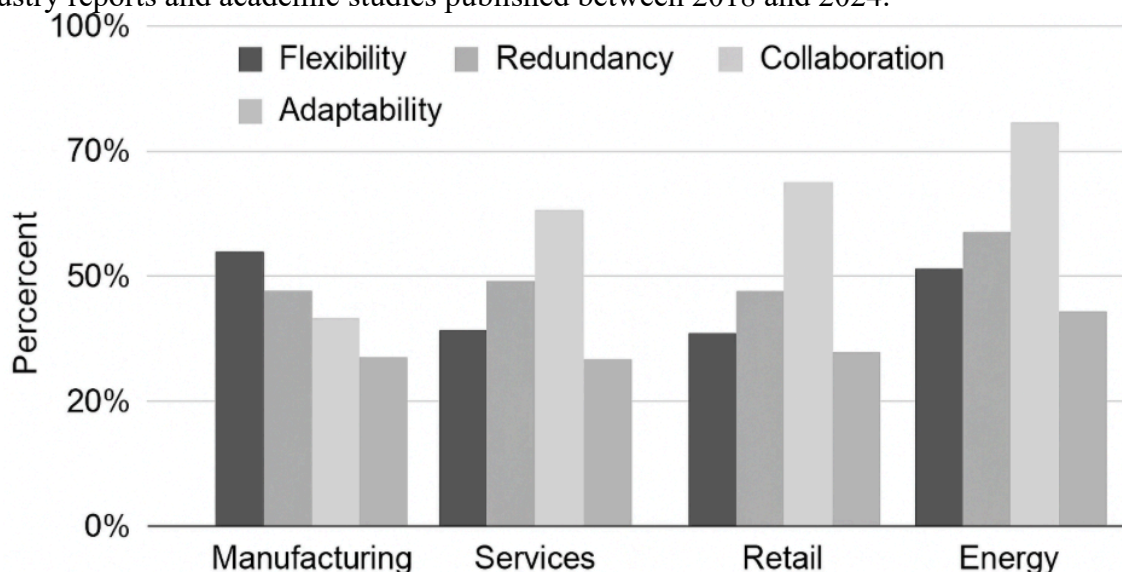


Figure 1. Distribution of resilience strategy types across sectors

As shown, structural redundancy remains the most frequently deployed approach in manufacturing and logistics, reflecting the need for operational continuity under material disruptions. Conversely, procedural agility and learning loops dominate in healthcare settings, where human-centric responsiveness and error recovery are paramount [11]. ICT environments demonstrate a strong bias toward real-time monitoring and autonomous decision systems, indicative of their digital infrastructure and cyber-threat exposure.

This typological mapping reinforces the argument that resilience engineering must be context-sensitive [12, 13]. Rather than applying a uniform blueprint, strategic operations management should align resilience mechanisms with sectoral risk architectures and performance expectations. Moreover, mixed-strategy approaches—those combining technical redundancy with organizational learning—offer the most promising paths to sustainable operational resilience in an increasingly uncertain global environment.

Conclusion

Resilience engineering has emerged as a foundational pillar for strategic operations management in the face of escalating complexity, uncertainty, and disruption. Unlike conventional risk mitigation frameworks, which focus primarily on avoidance and correction, resilience-oriented approaches emphasize systems that can adapt dynamically, recover efficiently, and learn continuously. This paradigm shift demands the integration of modular infrastructure, data-driven forecasting, decentralized decision-making, and organizational learning into core operational strategies.

The analysis presented in this article highlights the multidimensional nature of resilience engineering, demonstrating its applicability across manufacturing, logistics, healthcare, and ICT sectors. Through comparative tables, performance benchmarks, and typological mapping, the study shows that operational resilience must be sector-specific, strategically aligned, and metrics-driven. As global volatility intensifies, embedding resilience engineering into organizational DNA will be crucial for sustaining performance, safeguarding competitiveness, and enabling long-term value creation in strategic operations.

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