

Digital Planning Transformation: A Paradigm for Supply Chain Intelligence in U.S. Manufacturing

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ABSTRACT

This article examines the paradigm shift from traditional planning methodologies to digitally-enabled, intelligence-driven supply chain systems within U.S. manufacturing contexts. Digital planning transformation fundamentally alters how manufacturing enterprises conceptualize and execute planning decisions by integrating real-time data, advanced analytics, and intelligent automation across organizational boundaries. The article explores the theoretical foundations underpinning this transformation while analyzing the evolution from conventional Sales and Operations Planning to modern Integrated Business Planning frameworks. Technological enablers, including digital twins, artificial intelligence, cloud-based collaboration platforms, and automation systems, are evaluated for their role in creating synchronized planning ecosystems. The organizational dimensions examined include workforce transformation requirements, change management approaches, cross-functional competency development, and educational alignment initiatives essential for successful implementation. The implications for U.S. manufacturing competitiveness and resilience are assessed, with policy recommendations for accelerating adoption across diverse industrial contexts. The article identifies critical knowledge gaps requiring further scholarly attention and examines emerging frontiers in sustainability integration within next-generation planning models, providing a comprehensive framework for understanding both current implementations and future directions in digital planning transformation.

Keywords: Digital Planning Transformation, Integrated Business Planning, Supply Chain Intelligence, Manufacturing Competitiveness, Organizational Capability Development

Original Contributions of This Study

This article presents several original contributions to the emerging body of knowledge on digital planning transformation. First, it proposes an integrated planning transformation model that unifies technical enablers (digital twins, advanced analytics, cloud collaboration, and automation) with methodological frameworks (IBP maturity evolution, probabilistic scenario modeling, and resilience-driven planning cycles) and organizational capabilities (workforce literacy, cross-functional competency development, and change management). This tri-dimensional integration is not present in existing literature, which typically examines these areas separately.

Second, the study extends current digital planning discourse by linking planning architecture directly to national manufacturing competitiveness, demonstrating how predictive intelligence and cross-enterprise coordination contribute to U.S. strategic priorities such as supply chain resilience, nearshoring, and sustainability compliance. This explicit connection to industrial policy offers a unique strategic lens missing from traditional operations and supply chain research.

Third, the article identifies emerging capability gaps and outlines a forward-looking research agenda centered on resilience measurement, cross-enterprise governance models, and AI-driven decision ecosystems. These propositions advance theoretical understanding by positioning digital planning not merely as a technology initiative but as a structural shift in how modern manufacturing organizations sense, interpret, and respond to environmental complexity.

Collectively, these contributions establish a novel, holistic perspective on digital planning transformation that can guide future academic research, policy design, and industrial practice.

Introduction and Theoretical Framework

Manufacturing supply chain operations across the United States have reached an inflection point, transitioning from historically reactive models toward anticipatory frameworks built on predictive intelligence. Conventional planning methodologies built upon periodic forecasts, compartmentalized decision structures, and labor-intensive data harmonization falter increasingly when confronted with global supply volatilities and intricate network interdependencies. Built on periodic forecasts, segmented decision structures, and labor-intensive data harmonization, standard planning approaches fail more and more when faced with worldwide supply volatility and complex network dependencies. Contemporary production environments call for complex analytical systems able to combine large datasets, spot relevant trends, and provide actionable insights throughout challenging operational matrices. This transition toward digitally-enhanced planning transcends routine enhancement; it marks a fundamental reconceptualization of planning architecture within manufacturing enterprises operating across sophisticated value systems [1]. The implementation of advanced digital planning infrastructures yields measurable advantages in predictive precision, stock optimization, and continuity preservation when compared against legacy methodologies. This digital evolution empowers manufacturers to cultivate forward-looking operational capabilities that transform market unpredictability from operational liability into competitive advantage.

Planning intelligence's emergence marks a paradigmatic change in manufacturing settings, whereby computational analytics, synchronised data ecosystems, and cognitive algorithms allow businesses to forecast market dynamics rather than just adapt to them. This development replaces conventional planning constructs with adaptive, interconnected intelligence frameworks able to capture demand indicators, forecast potential disturbances, and create optimum responses with little human intervention. The incorporation of computational intelligence into planning protocols creates a hybrid decision environment where algorithmic processing amplifies human judgment while preserving experiential knowledge critical to contextualized decision-making [1]. Performance evaluations indicate superior outcomes through this collaborative approach compared to either purely automated systems or exclusively human-driven planning frameworks. Temporal aspects of operational planning undergo substantial reconfiguration within digital environments, transitioning from scheduled evaluation intervals toward perpetual calibration driven by real-time operational indicators and market signals.

The strategic importance of this transformation extends throughout individual enterprise performance metrics into broader industrial competitiveness considerations and national manufacturing resilience. Strategic manufacturing policies increasingly position digital capabilities as foundational elements for maintaining economic leadership and supply network security across critical industrial sectors. Digital planning transformation addresses essential manufacturing priorities, including comprehensive supply visibility, operational adaptability, and sustainable production methodologies. Correlational analyses examining relationships between planning sophistication and manufacturing performance demonstrate that organizations with mature digital planning architectures consistently establish performance advantages across multiple operational indicators [2]. This examination explores implementation variations, success determinants, and performance outcomes associated with digital planning transformation across diverse manufacturing contexts, with particular emphasis on contributions toward organizational and national resilience imperatives.

The conceptual foundations supporting digital planning transformation integrate perspectives from complexity theory, information systems, and organizational adaptation frameworks. Digital planning infrastructures exhibit characteristic patterns of complex adaptive systems, where distributed intelligence emerges through interconnected component interactions rather than centralized control mechanisms. Recent theoretical contributions have established classification systems for planning architectures based on adaptive characteristics, information processing capabilities, and decision autonomy parameters [2]. These perspectives align with dynamic capability frameworks emphasizing organizational capacity to integrate, develop, and reconfigure resources responding to environmental changes. Collectively, these theoretical constructs establish a foundation for understanding how digital planning enables manufacturing organizations to develop environmental sensing through advanced analytics, opportunity capture through scenario modeling, and structural adaptability through integrated execution systems. The integration of these perspectives creates a comprehensive framework for examining organizational development and deployment of digital planning capabilities responding to environmental complexity.

This examination enhances both theoretical understanding and practical application by establishing connections between conceptual frameworks and implementation approaches within digital planning transformation. It addresses significant knowledge gaps regarding manufacturing organizations' integration of advanced planning technologies within established operational frameworks while developing specialized capabilities required for effective utilization. Through analysis of theoretical principles manifested across diverse manufacturing implementations, the examination provides insights regarding both enabling factors and implementation barriers. These insights help organizations negotiate major changes in planning methods and capability development, as well as academic discussion about digital transformation processes [2]. This multifaceted approach questions the technologically focused stories dominant in current writing and provides a more all-encompassing implementation plan including technical, methodological, and organizational components.

Methodological Approaches to Integrated Business Planning

From traditional Sales and Operations Planning (S&OP) toward more complete Integrated Business Planning (IBP) frameworks, manufacturing planning processes have changed significantly. S&OP formerly focused on matching production capacity to market needs; today's IBP systems span both functional borders and temporal horizons to create whole planning environments. The essential structural distinction lies in IBP's expansive scope, which consolidates financial targets, strategic directives, and operational imperatives within a unified decision apparatus, facilitating perpetual

alignment throughout organizational hierarchies. Conventional S&OP operated through prescribed monthly evaluation cycles focused primarily on production scheduling and inventory management, while IBP establishes synchronized planning rhythms connecting long-range, mid-term, and immediate decisions through structured review mechanisms and formal governance systems. Where traditional approaches depended extensively on disconnected spreadsheet calculations and manual adjustments, modern IBP leverages sophisticated modeling techniques establishing continuous connections between strategic imperatives and shop-floor execution through interconnected planning hierarchies [3]. Analytical evaluation demonstrates that this methodological progression fundamentally transforms decision propagation throughout manufacturing organizations, substituting sequential functional calculations with integrated determinations that concurrently balance numerous competing priorities and limitations. This architectural innovation lets industrial companies keep strategic consistency while dynamically responding to operating needs and market changes.

The technical basis underlying modern IBP systems, advanced analytical capabilities enable cross-departmental decision clarity otherwise unattainable in traditional planning designs. The incorporation of predictive and prescriptive analytical engines transforms planning from deterministic calculations based on single-point projections toward probabilistic assessments explicitly accommodating uncertainty while building adaptive capacity through scenario development. Machine intelligence enables pattern identification across extensive information repositories, recognizing correlations between marketplace signals and demand behaviors undetectable through conventional statistical evaluations. These computational systems support early market change detection, supplier reliability assessment models anticipating potential disruptions, and inventory parameter engines that perpetually recalibrate based on evolving circumstances [3]. The analytical infrastructure within mature IBP environments supports coordinated intelligence generation where insights develop automatically, undergo validation against diverse information sources, and translate into harmonized actions across organizational domains. This capability fundamentally transforms organizational responses to complexity and uncertainty, replacing manual coordination efforts with algorithmic optimization, identifying balanced solutions across procurement, manufacturing, distribution, and financial imperatives simultaneously.

Implementation variations across manufacturing classifications demonstrate considerable differences in methodological sophistication and adoption strategies. Assessments spanning industrial contexts reveal distinct evolutionary patterns, typically advancing through recognizable maturity phases rather than revolutionary transformations. Initial implementation stages concentrate on process standardization, information consistency, and governance establishment before progressing toward sophisticated capabilities in predictive modeling and autonomous planning functions. Critical success determinants include executive endorsement, multi-departmental governance structures, value proposition clarity, and methodical capability development [4]. Common implementation obstacles encompass data reliability challenges, departmental resistance toward integrated methodologies, systems integration complexities, and difficulties measuring implementation advantages. Implementation effectiveness correlates strongly with organizational characteristics, including leadership commitment, change management proficiency, and investment in specialized planning competencies, bridging traditional departmental boundaries. These implementation observations suggest that successful IBP transformation represents organizational development rather than merely technological deployment, requiring systematic attention toward process redesign, capability enhancement, and cultural alignment. Industry-specific adaptation patterns emerge, with consumer-oriented sectors generally demonstrating advanced implementations compared with process manufacturing, while larger organizations typically exhibit greater methodological sophistication than smaller enterprises.

Performance assessment methodologies have progressed to reflect the multidimensional objectives characterizing integrated planning processes. Traditional measurements, narrowly focused on forecast precision and inventory efficiency, have expanded toward comprehensive evaluation frameworks assessing planning effectiveness across multiple dimensions. Contemporary assessment approaches incorporate balanced measurement systems evaluating forecasting performance, inventory optimization, customer service fulfillment, financial outcomes, and planning efficiency through interconnected metrics reflecting the integrated nature of planning decisions [4]. Advanced frameworks additionally evaluate planning resilience through stress-testing protocols, measuring responsiveness against simulated disruption scenarios. The development of measurement systems mirrors the methodological move from functional toward integrated planning; assessment frameworks now aim to assess coordination efficiency rather than departmental performance. Effective measurement systems combine confirmatory measures confirming past results with predictive indicators projecting future performance, therefore allowing companies to proactively spot areas for improvement. Typically, establishing hierarchical systems linking operational measurements with tactical indicators and strategic goals, these frameworks align assessment systems with corporate priorities. Essential enablers, comprehensive measurement systems provide planned feedback mechanisms, driving methodical perfection and capability development throughout planning ecosystems, therefore supporting constant improvement in planning efficiency.

Feature	Traditional S&OP	Integrated Business Planning
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Table 1: Comparative Analysis of Planning Frameworks. [3, 4]

Technological Enablers of Digital Planning

The technological foundation supporting digital planning transformation comprises interconnected systems collectively converting data into planning intelligence and execution directives. Digital twin technologies represent transformative capabilities, creating virtual models mirroring physical supply networks, enabling simulation, optimization, and risk evaluation within consequence-free environments. The architectural structure comprises multiple interconnected layers functioning cohesively to create dynamic virtual replicas mirroring physical supply chain ecosystems. The foundational component establishes comprehensive data integration synchronizing physical and virtual environments through distributed sensor networks and enterprise system connections, maintaining representation fidelity with actual operations. Above this foundation, sophisticated simulation capabilities employ multiple modeling techniques to predict system behaviors under various conditions, enabling scenario analysis across numerous planning dimensions. The analytical components utilize statistical methodologies and machine learning algorithms, identifying patterns, anomalies, and optimization opportunities within simulated environments. The interface layer translates complex system behaviors into intuitive visual representations, enabling planners to comprehend intricate relationships and formulate informed decisions [5]. This architectural framework supports applications spanning multiple planning horizons, from long-range network design decisions carrying multi-year implications through mid-term inventory positioning and immediate transportation optimization with direct operational impact. Offering previously unattainable thorough visibility and consequence evaluation tools, these technologies radically change planning efficiency by enabling companies to virtually assess situations before making physical environment alterations.

Recognizing patterns in large datasets and producing predictive insights that guide decision-making processes, artificial intelligence and machine learning abilities improve human planning ability. These technologies employ diverse algorithmic approaches customized for specific planning challenges throughout supply networks. Supervised learning applications, including regression models and neural networks, enable demand forecasting capabilities that substantially outperform traditional statistical methods, particularly for products exhibiting complex demand patterns influenced by multiple variables, including seasonality, promotional activities, and external factors. Classification and clustering algorithms support segmentation strategies, optimizing inventory positioning and service policies based on product characteristics and demand behaviors. Reinforcement learning methodologies enable parameter optimization through iterative improvement processes, continuously adapting planning variables, including safety stock levels and reorder points, responding to evolving conditions [5]. Natural language processing extracts relevant information from unstructured sources, including customer communications, social media, and industry publications, identifying early warning indicators potentially affecting demand patterns or supply availability. Computer vision applications within warehouse and transportation operations provide immediate feedback, improving planning accuracy by detecting execution variations as they occur. These diverse applications collectively transform planning from periodic, retrospective processes toward continuous, forward-looking systems anticipating changes and generating optimal responses before disruptions impact performance, fundamentally altering relationships between planning systems and operational environments.

Cloud-based collaboration platforms establish an integration infrastructure enabling seamless information exchange across organizational boundaries. These platforms implement sophisticated technical architectures specifically designed to enable multi-enterprise planning processes while addressing security, performance, and interoperability challenges inherent within cross-organizational collaboration. Foundational elements include standardized information models ensuring semantic consistency across diverse systems; adaptable integration frameworks enabling connection with heterogeneous enterprise applications; comprehensive security protocols providing detailed access controls while facilitating appropriate information sharing; and scalable infrastructure accommodating variations in transaction volumes and participant engagement [6]. Advanced platforms incorporate additional capabilities, including version control systems tracking, planning, iterations, and modifications; consensus-building mechanisms facilitating collaborative decision-making; exception management workflows orchestrating responses to disruptions; and performance visualization providing visibility into plan adherence across network partners. Cloud deployment models enable rapid implementation, simplified maintenance, and continuous feature enhancement without substantial internal technology resource requirements. These capabilities collectively enable transformation from organization-centric planning approaches toward network-optimized models where information flows seamlessly between trading partners, creating synchronization capabilities extending beyond organizational boundaries, encompassing entire supply ecosystems. This technological foundation supports collaborative processes, including joint demand planning, coordinated capacity management, and synchronized material planning, aligning activities across multiple enterprises toward common objectives.

Automation technologies transform planning from periodic, manual processes toward continuous, intelligence-driven activities by systematically reducing human intervention within routine planning tasks while enhancing decision quality through algorithmic optimization. The automation spectrum encompasses multiple sophistication levels collectively redefining planning process operation, and resource deployment. Fundamental process automation streamlines data collection, validation, and manipulation activities previously consuming substantial planner time, including forecast aggregation, inventory position calculation, and performance metric generation. Intelligent

automation builds upon this foundation by incorporating rules engines and machine learning capabilities, identifying exceptions requiring attention, suggesting potential responses based on historical patterns, and implementing standardized resolution approaches for common scenarios [6]. Advanced autonomous planning systems make and execute routine decisions independently, continuously monitoring conditions, detecting deviations from expected patterns, and implementing corrective actions without human intervention, while escalating only complex exceptions requiring judgment or cross-functional coordination. This automation continuum enables fundamental transformation in planning operations from labor-intensive, periodic reconciliation exercises toward intelligence-driven, continuous optimization systems operating with minimal human oversight for routine activities. These technologies redefine planner responsibilities from tactical data manipulation toward strategic exception management, scenario evaluation, and continuous process improvement, creating augmented intelligence environments where human capabilities are enhanced rather than replaced by technological solutions, resulting in planning systems combining algorithmic optimization with experiential knowledge.

Architectural Layer	Primary Function	Planning Application
Data Integration	Physical-digital synchronization	Real-time status monitoring and deviation detection
Simulation Engine	Multi-scenario modeling	Risk assessment and contingency planning
Analytics Layer	Pattern recognition and optimization	Opportunity identification and decision support

Table 2: Digital Twin Architecture for Supply Chain Planning. [5, 6]

Organizational and Human Capital Dimensions

Success in digital planning hinges on people, not just technology. Manufacturers often underestimate the human element when implementing advanced planning systems.

Workforce development requires attention to three key areas. First, planners need analytical skills to interpret data and statistics - a sharp departure from traditional experience-based planning. Second, they must develop systems thinking to understand how decisions ripple across interconnected functions. Third, [7] need technical fluency with planning systems and AI tools. Forward-thinking firms develop these skills via classroom instruction, practical projects, mentoring, and in-workflow guidance.

Change management cannot be limited only to technical execution. Cultural adaptation proves equally vital. Successful transformations start with a compelling story connecting planning technologies to both company goals and personal benefits. Leadership must visibly commit through resource allocation and consistent messaging. Phased rollouts work better than big-bang approaches, building capability while delivering early wins [7].

Digital planning blurs traditional functional boundaries. Rather than specialized demand planners, inventory managers, and production schedulers working separately, integrated planning requires cross-functional skills. Business translation abilities help connect analytics to operations. Team-based problem-solving combines several points of view to create improved solutions. Process design skills

help create workflows spanning traditional boundaries [8]. Professional bodies have revised credentials to reflect digital literacy. Universities provide specialized courses integrating domain expertise with technical skills. Advisory panels, joint initiatives, internships, and shared labs help to match educational outcomes with employment needs through industry-academic partnerships [8]. Although there has been progress, gaps still exist in building genuinely coordinated talent development systems.

Competency Domain	Key Capabilities	Development Approaches
Analytical Literacy	Statistical interpretation and data visualization	Formal training and applied analytics projects
Systems Thinking	Cross-functional dependencies and cause-and-effect modeling	Rotation programs and simulation exercises
Technology Fluency	Algorithm interpretation and digital tool proficiency	Hands-on system experience and guided application

Table 3: Critical Workforce Competencies for Digital Planning. [7, 8]

Research Implications and Future Directions

Digital planning fundamentally transforms manufacturing competitiveness beyond mere efficiency gains. Successful implementations integrate technology, methodology, and organizational elements - not just system upgrades.

The competitive impact manifests through several mechanisms. Operational excellence emerges through synchronized decisions across previously siloed functions. Market responsiveness improves through faster planning cycles and better demand sensing. Capital efficiency increases through precision inventory management. Innovation accelerates through streamlined planning processes. These capabilities prove especially valuable for American manufacturers facing structural cost disadvantages [9].

Beyond competitiveness, digital planning significantly enhances supply chain resilience. Addressing increasing worries about supply security in key industries, including semiconductors, medicines, and defense, advanced planning systems offer better disruption detection, scenario planning, coordinated response, and quick recovery capabilities.

Accelerating adoption calls for tackling impediments confronting resource-limited businesses. Policy frameworks should target workforce development through educational alignment and transitional programs. Rural connectivity, interoperability standards, and balanced cybersecurity are among the infrastructure priorities. Implementation support might include tax incentives, technical assistance, and shared demonstration environments [9].

Several knowledge gaps require further exploration. It lacks standardized approaches for measuring planning resilience. Governance structures for cross-enterprise planning remain underdeveloped. The long-term implications of AI-driven planning for organizational knowledge need examination - particularly how algorithmic decisions affect learning processes [10].

Sustainability integration represents an emerging frontier. Digital technologies enable unprecedented optimization across economic, environmental, and social dimensions. Advanced planning platforms

increasingly incorporate carbon tracking, circular economy principles, and social impact considerations - allowing manufacturers to operationalize sustainability commitments through everyday decisions rather than isolated initiatives [10].

Resilience Dimension	Capability Enhancement	Strategic Benefit
Disruption Sensing	Early warning systems and pattern detection	Proactive rather than reactive response
Scenario Preparedness	Simulation-based vulnerability assessment	Reduced disruption impact through readiness
Response Orchestration	Integrated decision frameworks	Coordinated actions across functional boundaries

Table 4: Digital Planning Contribution to Manufacturing Resilience. [9, 10]

Conclusion

Digital planning transformation represents a fundamental reimagining of how manufacturing organizations navigate complexity, uncertainty, and volatility in modern supply networks. By integrating advanced technologies, methodological innovations, and organizational capabilities, digital planning enables manufacturing enterprises to develop unprecedented levels of intelligence, agility, and resilience across their operations. The transition from reactive to predictive planning models fundamentally alters the relationship between planning systems and operational environments, enabling organizations to anticipate changes, evaluate alternatives, and implement optimal responses before disruptions impact performance. The article demonstrates that successful transformation depends on synchronized advancement across technological, methodological, and organizational dimensions rather than isolated technology deployment. For U.S. manufacturing sectors facing intense global competition, digital planning capabilities provide critical advantages through operational excellence, market responsiveness, capital efficiency, and innovation agility. The policy framework proposed addresses systemic barriers to transformation while leveraging existing institutional structures to accelerate adoption across manufacturing ecosystems. As digital planning continues to evolve, the integration of sustainability considerations represents a significant frontier, enabling organizations to operationalize environmental and social commitments through daily planning decisions alongside traditional economic objectives. The future of digital planning lies in increasingly intelligent, interconnected systems that continuously learn and adapt to changing conditions while balancing multiple performance dimensions across complex manufacturing networks.

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