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## Scenario Modeling in Demand-Constrained Supply Chains: A Forecast to Delivery View

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### Abstract

Demand-limited supply chains are continually challenged by the issues of globalizing production, stock, and delivery to satisfy the needs of customers that are dynamic and, in most cases, unpredictable. Scenario modeling is an analytical study technique that introduces a considered approach to the prediction of perturbations, optimum resource utilization, and the introduction of adaptive decision-making across the forecast-to-delivery spectrum. A recently performed survey provides an analysis of modern methods and the use of scenario modeling in the context of a demand-limited environment, with references to different industries, i.e., automotive manufacturing, healthcare, energy systems, and satellite communications. It explains the idea of supply chain responsiveness and resilience being enhanced with the assistance of systems thinking, simulation, additive manufacturing, edge computing, digital twins, and mixed-integer linear programming.

Another aspect that the paper demonstrates regarding supply chain design and performance is the impact of telecommunications infrastructure, policy intervention, climate needs, and macroeconomic forces. Using a multidisciplinary methodological approach to the solution, it can be indicated that the emergence of a situational framework—supported by the introduction of technologies and policy-oriented strategies—is one of the appropriate choices, offering a general response to an integrated and beneficial approach to supply chain management under circumstances of demand variability.

**Keywords:** Scenario Modeling; Demand-Constrained Supply Chains; Forecasting; Delivery Systems

### 1. Introduction

Global trade is increasingly becoming intricate and volatile, and because of this, supply chains are more than ever before anxious about the resiliency and agility of the chain. Supply chains have a list of fluid constraints that they must deal with, which not only alter the availability of goods but also affect the coordination between demand forecasts and the actual delivery of goods. Scenario modeling has therefore been adopted as a significant aspect of demand-based supply chain management, helping businesses to react, simulate, and predict changes in consumer demands, production bottlenecks, and logistics disruptions. According to supply chain perceptions regarding forecast-to-delivery, the emergent strategies and strategic implications of demand-constrained supply chains will be discussed in the paper.

The process of implementing scenario modeling is transforming the supply chain strategies used in organizations and supply chain planning. Very delicate demand-bound supply chains must be highly efficient in the accuracy of forecasts, inventory, capacity utilization, technological intervention, and global communication. The paper also sheds light on current trends in the sphere of systems thinking, digital twins, additive manufacturing, and algorithm-based solutions,

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drawing from experience in an infinite number of fields, including manufacturing, healthcare, energy, and space communications.

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## 2. Methodology

The conception of the fact that demand-constrained supply chains are embedded in scenario models makes the literature review integrative and systematic. It is assumed that the selected literature holds holistic significance for the application of diverse modeling techniques and technological advances in industries where demand factors are unstable and unpredictable.

### 2.1. Search Strategy

The list of potential sources for the systematic literature search was expanded to include peer-reviewed journal articles, conference proceedings, white papers, and research reports to support decisions regarding thematic academic publications. There was also interest in combinations such as scenario modeling, demand-constrained supply chains, forecast-to-delivery, systems thinking, digital twins, additive manufacturing, MILP, and edge computing. Boolean operators (AND/OR) were employed to narrow the search results to articles of utmost relevance to the thematic focus of the current paper.

### 2.2. Inclusion Criteria

To ensure that the sources were recent and of high quality, the following inclusion criteria were applied:

- The study must focus on modeling techniques applicable in unstable or demand-limited supply chain conditions.
- Articles must focus on at least one portion of the forecast-to-delivery process (i.e., forecasting, production, delivery, or inventory).
- Publications from 2020 onwards were preferred to ensure inclusion of the most recent advancements, especially in computerized and computational technology.
- Studies based on empirical analysis, simulation, or modeling frameworks were preferred.
- Studies could be from any industry (e.g., healthcare, automotive, energy, aerospace, etc.) to promote inter-industry learning.

### 2.3. Exclusion Criteria

The following articles were excluded from the review:

- Articles that considered surplus or unrestricted demand environments in supply chains.
- Articles lacking clarity in their approach or theoretical foundations.
- Non-text publications and non-English publications.

### 2.4. Selection Process

The initial search resulted in the identification of over 100 articles. Title and abstract screening led to the shortlisting of articles for full-text inspection based on the inclusion/exclusion criteria mentioned above. Among these, 12 were chosen and further evaluated, as they were found to be topically aligned with the objectives of the current study. The selection was performed cyclically and based on the thematic relevance of each article and the core pillars of scenario modeling, which include systems thinking, simulation, edge computing, optimization, and policy integration.

The final set of articles constitutes a heterogeneous collection and provides a justifiable platform for a general perspective on scenario modeling in demand-constrained supply chains.

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## 3. Systems Thinking and Structural Modeling

The significance of scenario modeling in supply chains lies in the fact that a supply chain is never a linear flow of events but a complex and dynamic system. The modeling medium provided by systems thinking has allowed people to model the interdependencies and feedback mechanisms, which are impossible to capture in traditional linear models. Systems thinking enables an understanding of the reciprocating influence of individual decisions within the supply chain, which is generally presented with the help of causal loop diagrams and stock-and-flow representations.

Examples of the application of systems thinking have also been found in the Indian building industry through the implementation of energy transition modeling, which demonstrated that the tool has been successfully applied to the complex infrastructural systems of modeling. Supply chains share the same methodologies, in which interdependencies in energy consumption, material utilization, and regulatory pressures exist. Structural modeling, which can be enabled by systems thinking, allows for a closer examination of the ripple effects of changes in demand on procurement and production schedules, as well as delivery timelines [1].

Systems thinking has become an inevitable part of modeling long-run situations in the environment of aligning supply chains with the requirements of national policy, energy efficiency, and sustainability. The models developed within this framework can employ an untold number of inputs, such as demand growth, constraints in material resources, and policy interventions, to provide predictions of potential phenomena. It proves useful in the construction of robust structures that are capable of managing demand peaks that have never been experienced or supplementing services in the supply chain where demand is extremely high.

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#### **4. Simulation and Additive Manufacturing in Forecast Scenarios**

The notion of additive manufacturing, or 3D printing, has in many ways reshaped strategic thinking in production and inventory control within the supply chain. It offers shorter lead times and greater ease in prototyping, which is particularly beneficial in situations of low demand. Agile supply chains that apply additive manufacturing have also been identified as complementary to agile supply chains through scenario modeling based on simulation.

The impact of the adoption of additive manufacturing technologies on the supply chain is approximated with the assistance of simulation models and helps to minimize congestion or respond to abrupt consumer demand. The automotive industry is one example where virtual twins can be managed and executed to simulate scenarios involving multiple disruptions in the supply chain, such as supplier delays, workforce shortages, or changes in customer preferences. The effects of these problems can be modeled operationally, and quantitative information on how to mitigate them is provided—such as by increasing inventory turnover, reducing carbon emissions, and minimizing lead times [2].

Additionally, additive manufacturing is considered a cleaner method of production, not only because of reduced material usage but also because it promotes local production. This is especially useful in areas where the logistics infrastructure is weak or where carbon regulations are strict. Simulation tools allow for the estimation of potential benefits across different demand profiles, providing a more specific picture of the supply chain's feasibility. The insights leave a lasting impression on decision-makers, encouraging them to consider cost, speed, and sustainability in demand-limited settings.

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#### **5. Edge Computing and Resource Optimization**

This has been achieved through the innovative technology of edge computing, which enhances data processing for supply chain strategy, enabling real-time and low-latency decision-making. In one instance, when demand is low and a decision must be made—such as where to store inventory or which path to take for delivery—being able to act within a few seconds may result in colossal gains or losses. Edge computing can be employed to model the situation in real time.

Another aspect of ensuring that supply chain models are scalable and responsive involves the provisioning of resources through edge computing. Algorithmic edge environment architectures have the ability to dynamically schedule computing resources for high-impact simulations—for example, spikes in demand due to the sudden failure of a single supplier. The models are used to provide demand forecasting and determine inventory quantities based on the real-time movement of IoT devices, ERP systems, and logistic networks [3].

In addition, edge computing minimizes bandwidth usage and time delays in the central processor, which means that supply chains are able to make decisions at the point of action as much as possible. As an example to demonstrate this point, predictive analytics based on edge computing can be applied to the perishable goods market to reroute deliveries—specifying when goods will spoil and when they should be redirected. The scenario modeling offered in this case provides stakeholders with a graphical illustration of how the variability of delivery time, cost implications, and changes in inventory under different circumstances of demand uncertainty can be visualized.

## 6. Digital Twins in Healthcare and Beyond

The digital twins application is based on digital scenario modeling, which develops virtual representations of real systems in real time. Healthcare has adopted the use of digital twins to simulate the flow of patients, equipment, and personnel in various cases of demand. This is also applicable in the supply chain for such technologies, where errors in forecasting can result in the ineffective use of resources—or even the complete inability to leverage them.

The invariable supervision and responsive design of demand-driven supply chain systems are key findings of scenario modeling in the case of digital twins. Real-time data (such as supply chain disruptions) and historical data are useful in predicting system behavior under hypothetical conditions, such as changes in demand or delays in logistics. For example, the direct impacts on delivery, financial performance, and order records can be simulated through a digital twin model in the case of a manufacturing freeze by one of the main suppliers [4].

In addition, digital twins may be used to test the design of the supply chain in extreme, though plausible, scenarios. Such stress tests can be conducted to identify weak points within logistics systems, supplier dependencies, and warehouse capacities. This is particularly necessary in high-risk industries such as pharmaceuticals or aerospace, where scenario modeling is not theoretical but a practical implementation requirement in high-stakes situations.

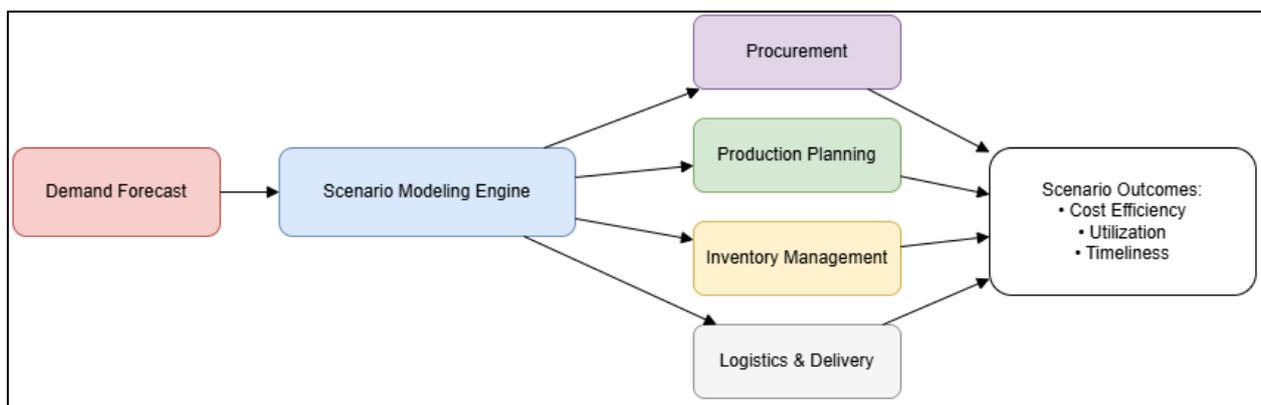
## 7. Mixed Integer Linear Programming and Scenario Optimization

The complexities of supply chains have gained importance with the introduction of MILP optimization models that solve problems and simulate various scenarios. MILP methods have the capability to establish the limits of production capacity, transportation, and inventory, and can optimize objectives such as cost, time, or even the level of service.

MILP is applied to various functional demands of ground infrastructure and inter-satellite connections in space communication networks. These applications resemble supply chains, where branches, distribution centers, and supply lines must be streamlined in response to changes in demand. Planners can use MILP scenario modeling to develop various delivery schedules and to balance the cost and reliability of the service [5].

The suggested modeling approach may be extremely relevant to the issue of the demand-limited supply chain, as it can be applied to find the most efficient solutions for asset allocation under each demand scenario. The ability to perform a wide variety of forecasts allows firms to model optimal responsiveness, such as the selection of suppliers, transportation paths, and deployment of human resources. The simulations are implemented to minimize the chances of inefficient resource utilization, even if this involves reducing resources to maintain the flexibility to scale up operations in the event of demand recovery.

Figure 1 illustrates the flow of scenario modeling within a demand-constrained supply chain, linking forecasting to core operational modules and outcome evaluation.



**Figure 1** Diagram of Scenario Modeling in a Demand-Constrained Supply Chain (Forecast to Delivery Perspective)

Source: Compiled based on reviewed literature

**Table 1** Comparison of Modeling Techniques Across Industries

Modeling Technique	Sector Applied	Key Benefits	Source
Systems Thinking	Energy & Infrastructure	Holistic view, policy integration	[1]
Simulation & Additive Mfg.	Automotive	Decentralized production, resilience	[2]
Edge Computing	IT & Logistics	Real-time data, localized decisions	[3]
Digital Twins	Healthcare	Real-time updates, stress testing	[4]
MILP Optimization	Space Communications	Optimal configuration under constraints	[5]

## 8. Integration with Next-Generation Telecommunications

The telecommunications infrastructure of the future is transforming supply chains—for example, through the use of 5G and Non-Terrestrial Networks (NTNs), which provide high-speed and low-latency communication in a distributed network. These functions are essential within the framework of real-time scenarios, where demand constraints or changes in delivery plans and supply require the integration of real-time response systems.

RAN architecture is currently helping supply chains build their own designed and adaptable network systems, which support communication between manufacturing plants, warehouses, and logistic hubs. This results in improved forecasting model accuracy and increased speed in the flow of information across the supply chain. It is also ensured that data-driven scenario modeling is not restricted to urbanized or developed areas only, as the prospect of NTNs providing access to remote or underserved areas also exists [6].

5G NTNs also reduce latency and delays associated with data transmission among nodes, making them an ideal fit for scenario modeling. It is the optimal connectivity and functionality of 5G NTNs that enable scenario models to be more accurate and responsive. One example would be sensor values from factory locations used in real-time within primary simulation models to incorporate adaptive adjustments in procurement policies or inventory placement. This network is particularly crucial in the global supply chain, where the concerned parties may differ significantly in terms of technological capabilities.

## 9. Policy, Regulation, and Governmental Influence

Parameters that specify the operational capacity of supply–demand-constrained scenario modeling include policy environments. These can impose restraints or create conditional opportunities through government laws related to trade, labor, and the use of technology. The cost-efficiency of different supply chain structures is also affected by macroeconomic factors such as tariffs or subsidies.

Governmental intervention has become an increasing concern among some nations due to its potential to limit operational flexibility and, in some cases, stifle innovation. These environments require that both inhibiting and facilitating policies be considered in scenario models. For instance, when supply chains become over-bureaucratized or lose control, a lack of quick responsiveness can occur, and real-time scenario modeling is needed to predict regulatory choke points and devise contingency plans [7].

Factors that scenario modeling would need to take into consideration in this case include taxation, compliance costs, or political unrest—particularly in cross-border supply chains. In this way, companies will be able to simulate the effects of policy decisions prior to their implementation and adjust their operations accordingly. The policy-sensitive model has also been greatly applied in businesses operating across various jurisdictions with differing rules and regulatory frameworks.

## 10. Climate Imperatives and Sustainable Supply Chain Transitions

The global shift toward net-zero carbon has transformed environmental pressure into a sense of urgency to make supply chains sustainable, and this is already reflected in scenario modeling. One of the most visible spheres of interest is the steel industry, where the traditionally technology-oriented, high-carbon-footprint production processes are now being

replaced with cleaner technologies. Such developments represent both a challenge and an opportunity for supply chains to integrate environmental considerations into their prediction and provisioning models.

Supply chains that are demand-related are especially affected by the switching costs and risks associated with adopting low-emission technologies. The green production transition process can be facilitated by scenario analysis, as it assists companies in determining whether the transition is viable without compromising cost and reliability. Case analysis has revealed that, in the steel production scenario, the transformation to new technology can result in the preservation of jobs in addition to achieving emission reduction goals. The insights from these lessons can be applied to any industry, supporting evidence-based practices and the redesign of operations [8].

This has been brought to the fore, especially in the contemporary regulatory environment, where emissions reporting, energy consumption measures, and policy incentives are increasingly becoming part of regulatory scenario models. It also means that supply chain designs are not only economically efficient but also aligned with climate commitments, making the entire forecast-to-delivery process reliant on sustainability.

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## 11. Geopolitical Fragmentation and Global Supply Network Complexity

The bilateral nature of supply chain relationships is gaining momentum due to protectionist policies and the heightened globalization of trade. These factors must be modeled under conditions involving trade barriers, sanctions, and geopolitical shocks. Fragmentation may include abrupt limitations on sourcing within operations, supplier instability, and disruptions to transportation systems that are otherwise most efficient in meeting demand.

Supply chains should be prepared to adapt to alternative forms in the event of likely geopolitical occurrences, including border closures, diplomatic retaliation, or war situations. The impact of such contingencies on delivery times, cost, and customer service levels can be assessed through simulation using scenario modeling. Companies that fail to incorporate such dimensions of risk into their predictive frameworks are often casualties of operational blindness, which may lead to colossal outages or customer complaints [9].

The increasing phenomenon of globalization is also giving rise to the localization of supply chains and dual sourcing. When applied appropriately, these strategies can make supply chains more resilient to unforeseen geopolitical disruptions. With the availability of a scenario model, trade restrictions can be assessed to determine differences in lead times and cost between local and foreign suppliers.

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## 12. Algorithmic Precision in Scenario Forecasting

The constraint of supply chains on demand is a requirement that necessitates and expects low-bias forecasting and statistical accuracy in scenario modeling. The results of new experimental designs, such as double diagonal estimators, have improved the accuracy of estimating treatment effects in simulations. This leads to better predictions of the impact of certain manipulations in input variables on supply chain performance indicators—e.g., fill rate, speed, and total landed cost of delivery.

The recent advancements in algorithms are especially useful during A/B testing of supply chain changes. Scenario modeling is an improved decision-making tool because it does not suffer from bias in estimates. It can be applied to determine the effectiveness of a new procurement strategy, warehouse design, or delivery system before undertaking comprehensive investment in such new approaches [10].

In addition, more accurate algorithms reduce forecast errors in identifying the most sensitive elements of the supply chain. For example, when customer demand is highly dynamic, it can be modeled using such tools to capture the variability of buffer stocks or the flexibility of dynamic pricing plans. The result is a viable and intelligent supply chain that learns and adapts based on empirical knowledge.

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## 13. Productivity and Capacity Underutilization

Among the issues that are significant in limited-demand supply chains is the wastage of firm capacity. Non-utilized production lines eventually lead to inefficiencies and increased unit production costs, as well as inaccuracies in demand forecasts; the distortion of supply and production processes cannot be resolved in a timely manner. This underuse not only suppresses productivity but also disrupts decision-making.

The tendencies of such underutilization can be identified with the assistance of scenario modeling, which also provides opportunities to optimize capacity usage. To illustrate this, if a manufacturing plant operates at 60 percent of total production under pessimistic demand assumptions, scenario analysis can simulate alternative procurement or marketing strategies to maximize throughput. Such models are capable of maximizing resource utilization and allocating fixed expenses to more profitable production [11].

Besides this, poor use of capacity affects capital investment decisions. Once it is realized that even the pessimistic scenario does not permit a reduction in persistent overcapacity, it becomes necessary to reduce capacity or redistribute resources. On the other hand, simulations may reveal situations where overcapacity can be easily absorbed. In both instances, companies are making more strategic decisions.

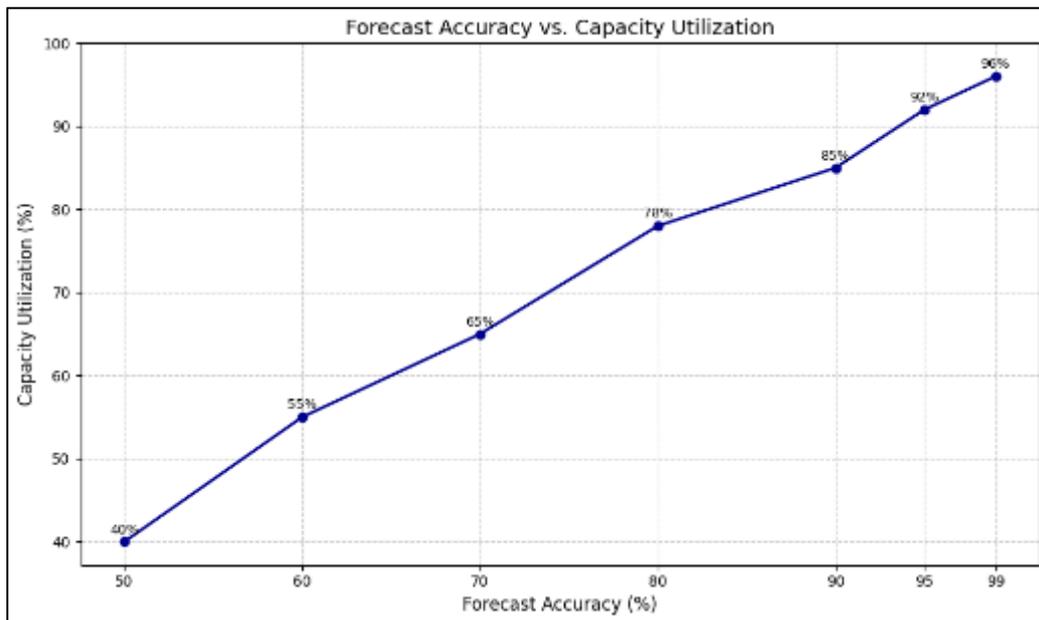
#### 14. Macroeconomic Linkages and Distributional Impacts

Supply chain scenario modeling should reasonably be suited to the dynamism of macroeconomies, especially in economies with high disparity or regional development tendencies. Consumer demand, production incentives, and supply chain formations may be downstream effects of income redistribution and fiscal policies aimed at human development in such cases.

Human development and growth models, together with supply chain models, provide a more comprehensive explanation of the impact of economic policy on supply chain behavior. Taking the example of a policy aimed at raising rural income, demand patterns for various products may shift, and scenario models would be required to simulate new inventory or delivery patterns. These relationships are authoritative in defining the locus of supply chain strategies relative to broader developmental intentions [12].

With these macroeconomic factors, scenario modeling ensures that supply chains are not operating in a vacuum but are cognizant of society at large. This responsiveness increases resilience, optimizes performance, and supports viable growth necessary to meet the demands of limiting environments.

Figure 2 shows a positive correlation between forecast accuracy and capacity utilization, highlighting the impact of accurate demand predictions on operational efficiency.



**Figure 2** Graph Showing Forecast Accuracy vs. Capacity Utilization in a Demand-Constrained Supply Chain

Source: Synthesized from reviewed literature

## **15. Future Directions**

The situation of demand-constrained supply chain scenario modeling remains a research question, although it presents a wide range of drawbacks and limitations. This is why process improvement and further research can be undertaken in the future.

### **15.1. Limited Integration of Policy and Modeling**

Although the effects of macroeconomic and regulatory environments on supply chains may be significant, most models continue to treat them as constant. To use the paper written by Hager and Huber (2025) as an example, excessive government control is said to decrease system dynamism, but in practice, this is not demonstrated in interactively simulated cases. More detailed structures are required to incorporate policy volatility and regulatory changes directly into scenario engines, enabling supply chains to be designed to accommodate policy constraints.

### **15.2. Underutilization of Advanced Experimental Estimators**

A/B testing and scenario simulation are more precise when the estimator is low-bias, such as the double diagonal estimator (Chawla and Syrgkanis, 2025). Nonetheless, existing supply chain models have largely relied on outdated forecasts and Monte Carlo simulations, which may produce biased outcomes in cases of complex demand dynamics. Future research will require the use of such advanced estimators to enhance the accuracy of demand-response models and predictions.

### **15.3. Sustainability Metrics Still Marginal**

Environmental metrics are also construed as secondary, despite sustainability being a dominant trend in scenario modeling. One example of a scenario designed to achieve emission-reduction goals while remaining economically feasible is the steel industry scenario proposed by Bataille et al. (2025). Nevertheless, these practices are not always implemented across industries. Research on carbon emissions, energy efficiency, and lifecycle sustainability should become core model outcomes rather than mere model additions.

### **15.4. Overemphasis on Technological Tools, Underdeveloped Human-Centric Models**

Supply chains are developing at an extremely high rate due to technologies such as edge computing and digital twins, as seen in the case of Sasitharasarma et al. (2025). However, scenario models often do not consider human behavior and labor relations, which are crucial in sectors like healthcare and manufacturing. Incorporating behavioral models, workforce decision heuristics, and labor market dynamics would help make scenario outcomes more realistic and feasible.

### **15.5. Sectoral Bias and Lack of Generalizability**

The selection of most studies is usually case-based and applies mainly to certain industries (e.g., automotive, aerospace) that possess infrastructure and digital maturity. It is not thoroughly researched whether these models are applicable in low-resource settings. Although the comment on geopolitical fragmentation (Sinclair, 2025) is present, scenario modeling in low- and middle-income countries (LMICs) is largely absent. Research should be expanded to test frameworks in weak, undeveloped, or politically unstable environments.

### **15.6. Forecast-Driven Capacity Planning Remains Reactive**

Due to poor demand forecasting and the inability of models to capture dynamic variation, firms often fail to exploit capacity, as McMillan and Kebede (2025) suggest. More attention should be given to dynamic capacity planning that matches forecast error margins with capital allocation and production flexibility. This will require models capable of responding to capacity conditions not only in relation to demand but also in relation to trends in forecasting accuracy over time.

### **15.7. Distributional Effects and Developmental Linkages**

Bose and Banerjee (2025) assert that consumption patterns and supply chain outcomes are influenced by macroeconomic policy, growth, and human development. Scenario models rarely take into account their wider distributional implications. Further research is required to replicate the effects of fiscal policies or developmental initiatives (e.g., income redistribution, rural electrification) on demand patterns in emerging markets.

## 16. Conclusion

One of the most useful approaches in handling the complexity of demand is constrained supply chain modeling grounded in demand. Integrating forecasting, production, inventory, and delivery models has been well outlined in scenario modeling, as global supply chains struggle with new volatility, limited capacity, and emerging regulatory checks and balances. As demonstrated in this review, there is a vast array of modeling techniques—including systems thinking, additive manufacturing, digital twins, edge computing, and mixed-integer linear programming—that can be applied to simulate and test processes under different constraints and uncertainties.

The automotive, healthcare, energy, and satellite communications sectors offer the possibility to be more flexible, responsive, and resilient. The added application of next-generation telecommunications, 5G, and non-terrestrial networks has simplified the implementation of real-time scenario models that support decentralized and time-constrained decisions. In addition, the climatic imperative and sustainability requirements are shifting scenario modeling from a functionalist orientation to a socio-environmental one.

It is also an indication of how much importance is attached to aligning scenario modeling with macroeconomic forces, policy interventions, and trends in geopolitics. In an ever-changing world where the regulatory environment becomes unpredictable or capacities are located in the wrong place, the strategic management of the supply chain relies on scenario-based decision-making.

The sustainability requirements and policy-sensitive simulation models, combined with sophisticated experimental estimators, will demonstrate the future usefulness of scenario modeling in the demand-restricted supply chain. The modeling frontier will extend to multidimensional data, real-time feedback, and cross-sectoral knowledge to ensure that it not only makes supply chains effective but also resilient.

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