International Journal of Global Economics and Management
ISSN: 3005-9690 (Print), ISSN: 3005-8090 (Online)
Volume 10, Number 8, Year 2026
DOI: https://doi.org/10.62051/ijgem.v10n8.09

A Study on Addressing Weaknesses and Enhancing Synergy in Sichuan's Advanced Manufacturing Industry Chain

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ABSTRACT

Global industrial chains are currently undergoing a restructuring cycle. Compounded by multiple pressures such as geopolitical conflicts and technological containment, the resilience and level of autonomy and control of advanced manufacturing supply chains have become key factors in competition among major powers. Sichuan, as a core industrial hub in western China, is seizing the opportunity presented by the development of the Chengdu-Chongqing Dual-City Economic Circle. By focusing on "building the circle and strengthening the chain," the province is driving the transformation of its advanced manufacturing sector toward clustering, high-end development, intelligent manufacturing, and green development. This paper integrates multidisciplinary theories from industrial engineering, complex networks, supply chain resilience, and collaborative governance to establish a three-dimensional "structure–process–collaboration" evaluation framework. Combining entropy-weighted TOPSIS, grey correlation analysis, and MATLAB simulation tools, it conducts comprehensive assessments and scenario simulations of Sichuan's key industrial chains, including electronic information, aerospace, equipment manufacturing, and new materials for lithium batteries. The results indicate that Sichuan's manufacturing sector has a solid foundation and industrial clusters have begun to take shape; however, shortcomings remain, including reliance on external core technologies, insufficient coordination between upstream and downstream sectors, and an uneven distribution of regional resources. As the province enters the initial phase of the 15th Five-Year Plan, it needs to optimize the layout of industrial networks, establish digital empowerment platforms, support key enterprises along industrial chains, and improve mechanisms for sharing benefits. These measures will continuously enhance the risk resilience and overall competitiveness of industrial chains, thereby providing decision-making support for fostering new-quality productive forces and building a manufacturing powerhouse.

KEYWORDS

Advanced Manufacturing; Industrial Chain Resilience; Industrial Engineering; New-Quality Productive Forces

1. INTRODUCTION

1.1. Research Background and Significance

1.1.1. Global Supply Chain Restructuring and the National Security Strategy Context

In the 21st century, global manufacturing relies on lean transnational division of labor and just-in-time (JIT) logistics to facilitate value flow. Within a multi-tiered industrial chain system, Europe and the United States control high-value-added segments through technology and standards, while emerging economies mostly undertake processing and manufacturing, occupying the lower end of

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the value chain. This highly decentralized, efficiency-focused supply chain model, while reducing costs, inherently suffers from structural weaknesses.

China is currently at a critical juncture, concluding the 14th Five-Year Plan and planning for the 15th Five-Year Plan. Faced with external technological containment and the risk of supply chain disruptions, developing new-quality productive forces and ensuring the security of industrial and supply chains have become vital national security strategies. [1] belowAdvanced manufacturing is the main battleground for competition among major powers; the stable operation of industrial chains, the rational layout of industrial networks, and the efficient coordination between upstream and downstream sectors directly determine China's industrial security and core competitive strength.

1.1.2. Implementation of Sichuan Province's "Manufacturing Powerhouse" and "Building Clusters and Strengthening Chains" Policies

Sichuan is the preeminent industrial province in western China and a major base for the national defense science and technology industry. Leveraging cities such as Chengdu, Deyang, Mianyang, and Yibin, the province has cultivated national-level industrial clusters in fields including electronic information, high-end equipment, aerospace, and power batteries, playing a prominent role in the nation's strategic layout for the Southwest. Addressing challenges common to central and western China—such as insufficient industrial agglomeration, weak local supply chains, and gaps in key technologies—Sichuan has continuously advanced the "Building Industrial Ecosystems and Strengthening Supply Chains" initiative, leveraging industrial ecosystems to promote the vertical extension of industrial chains and cross-regional coordinated development.

Currently, Sichuan has established a complete, cross-regional new energy vehicle industrial chain: Chengdu's vehicle manufacturing, Yibin's power batteries, Deyang's automotive components, and Mianyang's lithium battery materials and electronic control systems are developing in synergy. In 2025, Chengdu's vehicle production reached 932,000 units, a 23.6% increase; new energy vehicle production hit 233,000 units, surging 181% year-over-year. The city is home to 12 vehicle manufacturers and over 1,000 parts suppliers, with the automotive industry's revenue exceeding 200 billion yuan. Yibin has established a world-leading power battery industrial base [2]. In 2024, its power battery output reached 128.3 GWh, accounting for 16% of the national total and 10% of the global total. The total output value of the industrial chain exceeded 100 billion yuan, with more than 120 supporting enterprises established in the area. Deyang has focused on energy equipment and automotive components, with several companies entering the supply chains of automakers such as BMW and BYD; Mianyang has leveraged its advantages as a science and technology hub to vigorously develop lithium battery materials and electronic control components, with the industry's scale continuing to expand.

2026 marks the start of the 15th Five-Year Plan, and Sichuan's advanced manufacturing sector is entering a critical phase of quality improvement and upgrading. Currently, the province still faces challenges such as homogenized competition from neighboring provinces, rising factor costs, and diminishing dividends from technology introduction. Moving away from an extensive, scale-driven expansion model and undertaking systematic optimization focused on industrial chain support capabilities, industrial network resilience, and risk prevention and control systems have become key challenges that Sichuan must address in its quest to build a manufacturing powerhouse.

1.2. Current State of Third-Generation Research

The concept of industrial chain resilience originated from the theory of ecosystem balance and was subsequently expanded upon by scholars in the supply chain field; it has now become a key criterion for evaluating an industrial system's ability to withstand external shocks, maintain stable operations, and achieve transformation and upgrading. Overseas research in this area began earlier, establishing analytical frameworks centered on efficiency and equilibrium. Christopher et al. argue that resilient supply chains are characterized by agile responsiveness, information transparency, and multi-party collaboration; Xie Fei proposes that resilience is not merely the ability to recover after a shock but also encompasses the dynamic capacity for autonomous adjustment and iterative development under crisis scenarios [3]. Currently, most academic research constructs analytical frameworks for industrial chain resilience based on four dimensions: resistance, recovery, adaptation, and transformation.

A comprehensive review of the existing literature reveals several limitations in current research: First, evaluation frameworks largely rely on macro-level statistical data and rarely incorporate meso- or micro-level indicators such as enterprise production and operations, leaving room for improvement in measurement accuracy; second, there is a scarcity of targeted research focused on strategic western regions like Sichuan and Chongqing that takes into account local conditions and logistics constraints; third, most studies remain confined to static assessments of the current situation, while dynamic simulation studies—which utilize complex network theory to analyze chain reaction risks among industrial chain nodes and the patterns of failure propagation—are relatively scarce, making it difficult for research conclusions to effectively guide practical industrial operations.

1.3. Research Content and Methodological Approach

1.3.1. Research Objectives

In line with Sichuan's "Building Clusters and Strengthening Chains" initiative for advanced manufacturing and the practical needs for industrial quality improvement and upgrading under the 15th Five-Year Plan, this paper employs relevant theories and tools from industrial engineering to establish the following research objectives:

Establish an evaluation indicator framework tailored to Sichuan's specific conditions. Based on the province's strategic location in western China and local industrial endowments, construct a quantitative evaluation system covering macro-level industrial trends, meso-level operational processes, and micro-level enterprise collaboration to measure the development level of advanced manufacturing industrial chains and identify their weak links. Focusing on key industrial chains such as electronic information, aerospace, equipment manufacturing, and new materials for lithium batteries, this study identifies prominent issues—including technological bottlenecks, logistics constraints, and reliance on external resources—to pinpoint critical nodes prone to causing industrial chain bottlenecks or disruptions. By analyzing the structural characteristics of industrial chain networks, the study constructs a complex industrial chain network model for Sichuan's advanced manufacturing sector, clarifies the interconnections and coupling relationships among various entities, and summarizes the topological patterns of the industrial network.

A comprehensive set of optimization pathways will be formulated. Combining operations research optimization with lean management principles, multi-objective optimization solutions will be developed at the levels of industrial structure, business processes, and stakeholder collaboration, providing actionable, engineering-based strategies to help Sichuan's advanced manufacturing sector move beyond a model of scale expansion and develop in the direction of safety, collaboration, and high quality [4].

1.3.2. Research Approach

This paper follows the logical sequence of "Theoretical Foundation—Current Status Analysis—Model Construction—Empirical Measurement—Simulation—Optimization Strategies," forming a complete research cycle:

(1) Basic Research: Review policies and literature, define core concepts, and solidify the theoretical foundation;

(2) Indicator Development: Establish an industrial chain performance evaluation system tailored to Sichuan's characteristics;

(3) Empirical Evaluation: Conduct comprehensive assessments using entropy-weighted TOPSIS and fuzzy correlation analysis;

(4) Simulation Analysis: Construct a complex network model to simulate attacks, cascading failures, and resilience;

(5) Optimization Strategies: Develop a multi-objective optimization model based on the results and propose a three-dimensional optimization pathway;

(6) Summary and Recommendations: Summarize conclusions, distill recommendations, and identify shortcomings and future directions.

2. THEORETICAL FOUNDATION AND CONSTRUCTION OF THE EVALUATION INDICATOR SYSTEM

2.1. Definition of Industrial Chain Resilience

Industrial chain resilience refers to the comprehensive capability of an industrial chain to maintain the stability of its core functions, rapidly resume normal operations, and proactively adapt to changes to achieve transformation and upgrading in the face of external shocks, market fluctuations, and sudden risks. In this paper, based on the characteristics of Sichuan's advanced manufacturing sector, industrial chain resilience is categorized into three dimensions:

Robustness: The industrial chain's ability to withstand external shocks and maintain stable operations;

Agility: The speed at which an industrial chain rapidly perceives risks, responds to changes, and adjusts plans;

Resilience: The ability of an industrial chain to rapidly recover through resource allocation and collaborative efforts after suffering an impact.

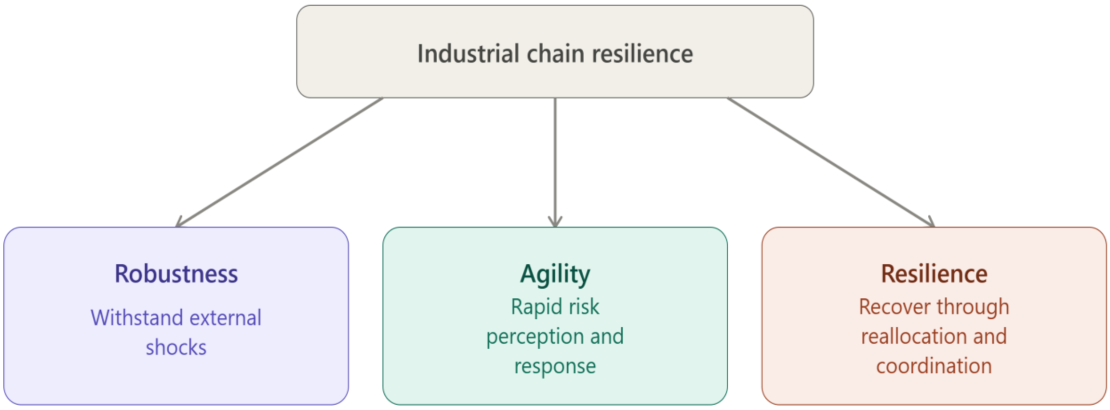

Figure 1. Schematic of Three Dimensions of Industrial Chain Resilience

2.2. Design of the Evaluation Indicator System

Adhering to the principles of scientific rigor, systematic approach, practicality, and specificity, this paper constructs an evaluation system based on three dimensions: structural indicators, process indicators, and collaboration indicators.

2.2.1. Structural Indicators

Structural indicators reflect the stability of the industrial chain's network topology. They measure the industrial chain's connectivity, centralization, collaboration density, and transmission efficiency from a network topology perspective, serving as core quantitative tools for assessing the industrial chain's resilience and optimization potential [5]. The following five indicators constitute a comprehensive structural indicator system: ① network connectivity; ② core node ratio; ③ node centrality; ④ network density; ⑤ average path length.

2.2.2. Process Indicators

Process indicators reflect the operational efficiency of the industrial chain. From an operational management perspective, they quantify the industrial chain's response speed, production resilience, logistics efficiency, supply stability, and equipment output efficiency. These five indicators collectively form a comprehensive evaluation framework for the industrial chain's operational efficiency, with each indicator featuring three sets of data: current observed values, optimization targets, and risk scenarios.

2.2.3. Synergy Indicators

Synergy indicators reflect the level of collaborative governance within the industrial chain. From a governance structure perspective, they quantify five dimensions: information exchange, technological synergy, interest coordination, digital support, and innovation transformation. Together, these indicators form a comprehensive evaluation framework for the level of collaborative governance in the industrial chain. Each indicator includes three sets of data: current observed values, optimization targets, and risk scenarios.

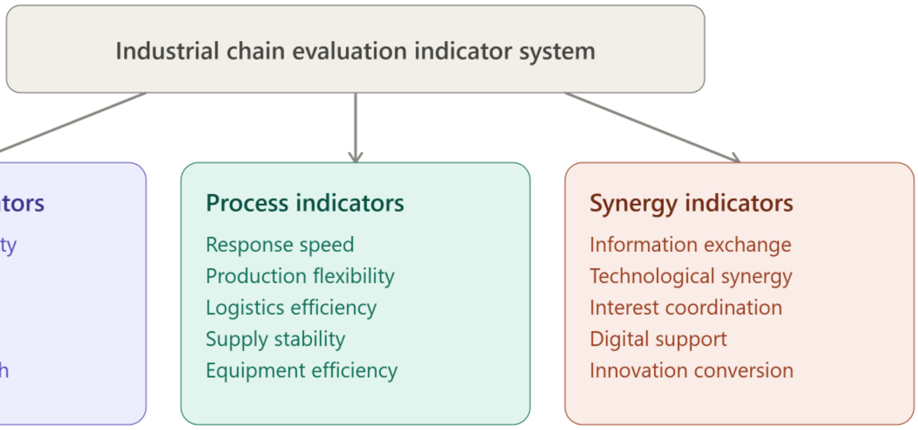

Figure 2. Design Schematic of Three Evaluation Index Systems

2.3. Evaluation Model Based on Entropy-Weighted TOPSIS and Grey Correlation Analysis

2.3.1. Indicator Weighting Using the Entropy-Weighted Method

The entropy-weighted method determines weights based on information entropy to avoid subjective bias. The steps are as follows: data standardization, calculation of indicator proportions, calculation of information entropy, determination of the coefficient of variation, and calculation of weights.

Let the original matrix be:

$$(X=(x_{ij})_{m\times n}) \tag{1}$$

Standardized proportions:

$$(p_{ij}=\frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}}) \tag{2}$$

Information entropy:

$$(e_j = -k \sum_{i=1}^{m} p_{ij} \ln p_{ij}) \quad (3)$$

2.3.2. TOPSIS Comprehensive Evaluation Model

TOPSIS performs ranking by calculating the distance to the ideal solution.

Positive ideal solution:

$$(A^+ = (\max x_{ij})) \quad (4)$$

Negative Ideal Solution:

$$(A^- = (\min x_{ij})) \quad (5)$$

Distance:

$$(D_i^+ = \sqrt{\sum_{j=1}^{n} (x_{ij} - A_j^+)^2})(D_i^- = \sqrt{\sum_{j=1}^{n} (x_{ij} - A_j^-)^2}) \quad (6)$$

Proximity:

$$(C_i = \frac{D_i^-}{D_i^+ + D_i^-}) \quad (7)$$

2.3.3. Modified Grey Correlation Analysis

Grey Correlation Formula:

$$(\xi_i(k) = \frac{\min_i \min_k |x_0(k) - x_i(k)| + \rho \max_i \max_k |x_0(k) - x_i(k)|}{|x_0(k) - x_i(k)| + \rho \max_i \max_k |x_0(k) - x_i(k)|}) \quad (8)$$

This is used to correct evaluation results under fuzzy data conditions and enhance robustness.

3. ANALYSIS OF THE CURRENT STATUS AND VULNERABILITIES OF SICHUAN’S ADVANCED MANUFACTURING INDUSTRY CHAIN

3.1. Spatial Distribution and Cluster Characteristics of Sichuan’s Advanced Manufacturing Industry

3.1.1. “One Core, Multiple Pillars” Spatial Structure

Sichuan’s advanced manufacturing industry has established a “one core, multiple pillars” spatial layout: with Chengdu serving as the core growth pole, and Deyang, Mianyang, and Yibin forming key industrial pillars. The regional division of labor is well-defined, and there is strong potential for complementarity.

Chengdu serves as a hub for high-end manufacturing and innovation, focusing on the R&D and manufacturing of complete vehicles and the intelligent connected vehicle industry. By 2025, the local automotive industry’s revenue is projected to exceed 200 billion yuan, with an annual production of 932,000 complete vehicles. The intelligent connected vehicle industrial chain covers 28 key sectors, with a supporting component coverage rate of 70%.

Deyang focuses on the equipment and automotive parts industries, specializing in energy equipment, heavy machinery, and commercial vehicle components. In the first half of 2025, the machinery and equipment industry grew by 14.9%; the FAW Jiefang Guanghan base has an annual production capacity of 20,000 new energy commercial vehicles, and Tianhe Machinery's electric drive axle housings for new energy heavy-duty trucks hold an 11.2% share of the domestic market.

Mianyang leverages the military resources of the Science and Technology City to advance military-civilian integration and develop lithium-ion battery materials and electronic control components. Companies such as Fulin Precision Engineering and Changhong Energy continue to expand; lithium iron phosphate production capacity stands at 65,000 metric tons, and the output value of the new energy vehicle industry is expected to reach 80 billion yuan by 2025.

Yibin is focused on building a world-class power battery industrial cluster, establishing a complete supply chain spanning "lithium ore—cathode materials—battery cells—complete vehicles—resource recycling." In 2024, the power battery industry's output value reached 105.8 billion yuan, with production volume at 128.3 GWh, and the local supply rate remained between 65% and 70%.

3.1.2. Identification of Pillar Industries

Sichuan has established four pillar industries in advanced manufacturing: electronic information, aerospace, equipment manufacturing, and new materials for lithium batteries. These industries feature a clear regional layout and continuously expanding scale:

Electronic Information (centered in Chengdu): By 2025, the industry scale will exceed one trillion yuan. It brings together leading enterprises such as Intel, BOE, and Huawei, covering the entire value chain from chip design, packaging and testing, display panels, to terminal manufacturing [6]. The automotive electronics sector supplies vehicle manufacturers in Chengdu and Chongqing, with an annual output value exceeding 30 billion yuan;

Aerospace (Chengdu-Mianyang Dual-Core): Centered on Chengdu AVIC Chengdu Aircraft Industry Group and the China Aerodynamics Research and Development Center in Mianyang, the sector is projected to exceed 80 billion yuan in scale by 2025. It covers fields such as complete aircraft, engines, onboard systems, and satellite applications, with the unmanned aerial vehicle (UAV) industry's output value surpassing 10 billion yuan;

Equipment Manufacturing (primarily in Deyang): Focusing on energy equipment, heavy machinery, and rail transit equipment, output value is projected to exceed 120 billion yuan in the first half of 2025. Dongfang Electric and SINOMACH Heavy Industry have order backlogs totaling 150 billion yuan, representing a 20% year-over-year increase, providing high-end equipment support for the lithium-ion battery and new energy vehicle industries;

Lithium-Ion Battery New Materials (primarily in Yibin, with Mianyang and Suining providing support): By 2024, Yibin's lithium-ion battery industry will achieve an output value of 105.8 billion yuan and a production volume of 128.3 GWh; Mianyang will have a production capacity of 65,000 metric tons for lithium iron phosphate materials, while Suining will have a production capacity of 100,000 metric tons for lithium salts. One out of every 10 power batteries worldwide is produced in Yibin.

3.2. Diagnosis of Industrial Chain Vulnerabilities

3.2.1. Analysis of "Bottleneck" Technology Nodes

In key areas of Sichuan's advanced manufacturing sector, reliance on foreign sources for core technologies generally exceeds 50%. These "bottleneck" issues are prominent and directly constrain the industry chain's autonomy and controllability:

Power Battery Industry (Yibin): Reliance on foreign sources for high-end wet-process lithium-ion battery separators, high-purity electrolyte additives, and high-precision battery testing equipment exceeds 70%. The core testing lines at CATL's Yibin base rely heavily on imports; Core materials for solid-state batteries, such as sulfide electrolytes, remain in the laboratory R&D stage and have not yet been commercialized;

Automotive Manufacturing Industry (Chengdu): Reliance on foreign sources for high-end automotive-grade MCUs, IGBT chips, high-speed in-vehicle connectors, and smart cockpit operating systems exceeds 80 percent; by 2025, the value of chip imports for new energy vehicles in Chengdu is projected to exceed 5 billion yuan;

Equipment Manufacturing Industry (Deyang): Reliance on foreign imports for precision bearings, high-end hydraulic components, and CNC systems (Siemens, Fanuc) exceeds 60 percent; Tianhe Machinery relies on imports for 90 percent of its precision machining equipment for electric drive axle housings;

Lithium-ion Battery Materials Industry (Mianyang): 99.99% high-purity lithium salts, carbon nanotube conductive additives, and high-end separator base films rely heavily on imports or supplies from outside the province; 40% of Fulin Precision Engineering's cathode material precursors must be purchased externally.

3.2.2. Analysis of Impact Pathways of External Disruptions

External disruptions—such as fluctuations in power supply, rising raw material prices, international trade restrictions, logistics disruptions, and sudden public emergencies—propagate step-by-step along the supply chain in a "point-line-surface" pattern. Due to the weak risk-resilience of small and medium-sized enterprises (SMEs), production stoppage rates exceed 30%, which can easily trigger fluctuations across the entire industrial chain:

Power Supply Fluctuations (Yibin): Power rationing in Sichuan during the summer of 2025 caused Sichuan Times to reduce production by 10%, leading to the shutdown of more than 20 upstream and downstream suppliers and resulting in direct economic losses exceeding 2 billion yuan;

Significant fluctuations in lithium prices (Yibin, Mianyang): In 2022, the price of lithium carbonate skyrocketed from 50,000 yuan per metric ton to 500,000 yuan per metric ton, causing Yibin Libao and Tianyi Lithium to face soaring costs and an 80% drop in profits; Mianyang Fulin Precision Engineering's gross profit margin for cathode materials plummeted from 25% to 8%;

Logistics Disruptions (Chengdu, Deyang): In 2025, congestion on the Chengdu-Chongqing Expressway caused delays in component deliveries to Chengdu's vehicle manufacturers, resulting in a production backlog of 12,000 new energy vehicles; in Deyang, transportation costs for parts suppliers increased by 15%, and delivery cycles were extended by 3–5 days.

4. RESEARCH ON COMPLEX NETWORK MODELING AND DISRUPTION SIMULATION OF INDUSTRIAL CHAINS

4.1. Construction of Complex Network Topology for Industrial Chains

4.1.1. Definition of Nodes and Edges

Entities within the industrial chain—including enterprises, research institutions, logistics service providers, and financial institutions—are defined as network nodes. Node weights are comprehensively determined based on indicators such as enterprise scale, market share, technological significance, and supply capacity. Relationships between entities—such as supply, support, cooperation, and R&D collaboration—are defined as directed weighted edges, where edge weights reflect the intensity of interdependence, transaction scale, and degree of collaboration.

4.1.2. Calculation of Network Topological Characteristics

Average path length:

$$(L=\frac{1}{N(N-1)}\sum_{i\neq j} d_{ij}) \tag{9}$$

Clustering coefficient:

$$(C=\frac{1}{N}\sum_{i=1}^{N} C_i) \tag{10}$$

Network density:

$$(D=\frac{2M}{N(N-1)}) \tag{11}$$

4.2. Risk Simulation Using MATLAB

4.2.1. Static Attack Experiments

Simulation results show that under random failure scenarios, the failure of a small number of non-core nodes has a limited impact on the network's overall performance, indicating strong supply chain resilience. However, when core nodes (chain-leading enterprises and key supporting enterprises) are subjected to malicious attacks, network connectivity and stability decline sharply. The failure of a chain-leading enterprise is likely to trigger systemic risks, highlighting the critical supporting role of core nodes in the supply chain.

4.2.2. Simulation of Dynamic Cascading Failures

Following the disruption of core nodes, risks rapidly propagate along the upstream and downstream segments, creating a cascading failure effect. The simulation indicates that the higher the concentration of the industrial chain, the faster the risk propagates and the broader its impact; the greater the number of redundant suppliers and the higher the local supply rate, the stronger the resilience to cascading failures; and the higher the level of digitalization in the industrial chain, the more efficient the information transmission, and the slower the speed of risk propagation.

4.2.3. Resilience Testing

Construct the industrial chain recovery function:

$$(R(t)=1-e^{-\lambda t}) \tag{12}$$

Test results show that the stronger the digital collaboration capabilities and resource integration capabilities, the faster the industrial chain recovers and the lower the recovery costs; the more complete the local supply system and the lower the external dependency, the higher the industrial chain recovery efficiency.

5. INDUSTRIAL ENGINEERING-DRIVEN OPTIMIZATION MODELS AND COUNTERMEASURES

5.1. Inventory and Capacity Balancing from a Lean Perspective

5.1.1. JIT and JIC Synergy Mechanisms

Establish a hybrid synergy model combining JIT (Just-In-Time) and JIC (Safety Stock): Apply the JIT model to general-purpose components to reduce inventory holding costs and improve turnover efficiency; apply the JIC model to critical core components and raw materials prone to shortages by establishing safety stock to ensure supply chain security; leverage the Industrial Internet to build a dynamic inventory monitoring platform that tracks inventory levels and supply-demand changes in real time, enabling dynamic inventory adjustments and resource sharing.

5.1.2. Virtual Factory Scheduling Logic

Leveraging the Industrial Internet and digital twin technology, establish a virtual factory platform for the industrial chain to integrate idle production capacity and equipment resources from enterprises within the region, thereby achieving shared production capacity, flexible scheduling, and intensive resource utilization; establish a unified production scheduling mechanism to rapidly respond to changes in market orders, optimize production schedules and logistics routes, and enhance equipment utilization rates and the industrial chain's flexible response capabilities.

5.2. Multi-Objective Optimization Model

5.2.1. Construction of the Objective Function

Focusing on the three core objectives—minimum cost, maximum efficiency, and maximum resilience—a multi-objective optimization function is constructed:

$$(\min(\text{Cost}) + \min(\text{Time}) + \max(\text{Resilience})) \tag{13}$$

Where Cost represents the comprehensive cost of the industrial chain (including production, inventory, and logistics costs); Time represents the order response cycle, production cycle, and logistics cycle; and Resilience represents the level of resilience of the industrial chain.

5.2.2. Constraints

The constraints of the optimization model include: production capacity constraints, carbon emission constraints, local supply rate constraints, logistics capacity constraints, and financial constraints. The NSGA-II algorithm is used to solve for the Pareto optimal solution of the model, achieving multi-objective coordinated optimization.

5.3. Benefit Allocation Scheme Based on Shapley Values

The Shapley value method is introduced to construct a supply chain benefit allocation model, which fairly distributes supply chain revenues according to each entity's contribution.

Core formula:

$$(\phi_i(v) = \sum_{S \subseteq N\{i\}} \frac{|S|!(n-|S|-1)!}{n!} [v(S \cup \{i\}) - v(S)]) \tag{14}$$

Here, N is the set of entities in the industrial chain, S is a subset of N, and v is the alliance revenue function. Through fair benefit distribution, this approach stimulates the willingness of small and medium-sized enterprises to collaborate, strengthens the collaborative ecosystem of the industrial chain, and ensures its long-term stable development.

6. CASE STUDY—THE YIBIN LITHIUM-ION BATTERY INDUSTRY CHAIN

6.1. Case Background and the Evolution of the "Building Clusters and Strengthening Chains" Initiative

Yibin is a model city for Sichuan's "Building Clusters and Strengthening Chains" initiative. Leveraging its resource endowments and policy support, the city attracted CATL in 2019, achieving a leapfrog transformation from a traditional industrial structure centered on "baijiu and coal" to an emerging industrial cluster focused on "power batteries and green energy." This development process can be clearly divided into three phases:

Start-up Phase (2019–2021): Phases 1 and 2 of the Sichuan CATL project began production, establishing initial production capacity. In 2021, the output value of the lithium-ion battery industry was only 1.8 billion yuan, with 12 enterprises above designated size and a local supply chain coverage rate of 15%; the industrial chain was in its nascent development stage.

Explosive Growth Phase (2022–2024): Projects such as Phases 3, 5, and 6 of Sichuan Times, as well as Times Changan and Times Geely, came online in rapid succession, leading to rapid expansion of the industry's scale. By 2024, the output value of the lithium battery industry reached 105.8 billion yuan, with power battery production at 128.3 GWh. The number of enterprises above designated size rose to 125, the local supply rate increased to 65%–70%, and inventory turnover days were reduced to 12 days;

Optimization Phase (2025–2026): Focusing on improving quality and efficiency across the industrial chain, digital transformation, and green, low-carbon development, the construction of Sichuan Times Phases 4, 9, and 10 will be advanced, with a planned production capacity of 300 GWh. In the first three quarters of 2025, the output value of the lithium battery industry will reach 86.07 billion yuan, a year-over-year increase of 14.6%, with production volume at 127.1 GWh. Digitalization coverage will reach 88%, and energy consumption per unit of output value will be reduced to 0.32 metric tons of coal equivalent per 10,000 yuan.

6.2. Vertical Spatio-Temporal Comparison: "Leapfrog" Performance of Yibin's Lithium-Ion Battery Industry

Table 6-1 Comparing key indicators of Yibin's lithium-ion battery industrial chain between 2020 (policy launch phase) and 2026 (optimization and maturity phase), the industry has achieved leapfrog development. Specific data are as follows:

Table 6-1. Comparison of Key Indicators for Yibin's Lithium-Ion Battery Industry Chain (2020 vs. 2026)

Performance Indicators	2020 (Policy Launch Phase)	2026 (Optimization and Maturity Phase)	Percentage Change/ Improvement
Total Output Value of the Entire Industry Chain (100 million yuan)	Approx. 1.8 billion yuan	Approx. 215 billion yuan (Estimated)	118.4 times
Number of enterprises above a certain scale	12	125	941%
Localization Rate (Local content)	15%	65%–70%	50-point improvement
Average Days of Inventory Turnover	35 days	12 days	65.7% in certain areas
Digitalization Coverage Rate of the Industrial Chain	20%	88%	68 improvements in performance
Unit exchange rate (tCE/10,000 yuan of output value)	0.85	0.32	62.3% decrease

Data Sources: Yibin Municipal Government Work Report, Public Disclosures by Sichuan Times (2025–2026)

Data analysis indicates that by "filling gaps in the supply chain (addressing raw material shortages), extending the supply chain (expanding resource recycling), and strengthening the supply chain (advancing digital transformation)," Yibin has not only achieved a 100-fold increase in output value but has also fully demonstrated the effectiveness of lean optimization in industrial engineering across core dimensions such as response efficiency, supply chain resilience, and green and low-carbon performance.

6.3. Cross-Regional Comparison: Yibin vs. Changzhou

Compared to Changzhou, Jiangsu—a national benchmark for the lithium-ion battery industry—Yibin's lithium-ion battery industry boasts advantages such as abundant hydropower resources, low production costs, and large-scale production capacity. However, it has significant shortcomings in high-end equipment manufacturing, testing technology, and R&D capabilities. The specific comparison is as follows:

Table 6-2. Comparison of the Lithium-Ion Battery Industries in Yibin and Changzhou.

Comparison Dimensions	Yibin, Sichuan (Inland Hub)	Changzhou, Jiangsu (Market-Driven Model)	Competitive Analysis and Optimization Insights
Core Drivers	Low-cost hydropower (0.3 yuan/kWh) + supply chain leader lock-in (CATL)	Technological expertise + comprehensive supporting infrastructure + talent cluster	Yibin needs to accelerate its transition from a "cost hub" to a "technology hub"
Completeness of the Industrial Chain	92% (Strong in materials processing Weak in equipment manufacturing)	97% (Strong in equipment manufacturing and testing technology)	Yibin's reliance on high-end equipment exceeds 70%; it needs to address weaknesses in its industrial chain
Production Capacity (2025)	210 GWh completed, 300 GWh planned	150 GWh completed, 200 GWh planned	Yibin's production capacity ranks, but per-plant reliance on individual plants is relatively high
Digital Governance	Unified cloud platform and leading development of zero-carbon factories	Mature enterprise ERP/MES systems; in-depth is deeply integrated	Yibin possesses the advantages of a latecomer and can build a full-chain digital collaboration system
Logistics Models	Rail-water intermodal transport and road-rail multimodal transport, which are relatively costly	Coastal road and waterway transportation: low cost, high efficiency	Sichuan needs to strengthen the development of a transport systems to reduce logistics costs

Data Sources: Official websites of the governments of both regions, China Battery Industry Association (2025)

6.4. Evaluation of Simulation Optimization Results

After optimization: Robustness improved by approximately 25%; cascading failure rate decreased by approximately 30%; recovery time shortened by approximately 40%; operating costs decreased by approximately 12%. The solution is feasible and effective.

6.5. Evaluation of Simulation Results Based on Industrial Engineering Methods

Selecting key nodes in the Yibin lithium-ion battery industry chain—including Sichuan Times (a subsidiary of CATL) and over 30 Tier 1 suppliers—we conducted MATLAB simulation tests using a "30% disruption in lithium carbonate supply" scenario, incorporating an optimized JIT-JIC hybrid inventory mechanism and a digital early-warning platform. The results are as follows:

Risk resilience significantly improved: After optimization, the supply chain's stable operation duration without external replenishment extended from 7 days to 22 days, representing a 214% increase;

Risk of cascading failures substantially mitigated: The local supply rate increased to over 65%, and the probability of a full-chain shutdown triggered by a single node failure decreased by 42.5%;

Operating costs continued to decline: Leveraging digital collaborative scheduling, the comprehensive logistics and inventory holding costs across the entire chain decreased by 14.8% compared to 2024;

Regional coordination efficiency was markedly enhanced: The response time for the Chengdu–Yibin new energy vehicle supply chain was reduced from 72 hours to 24 hours, and the on-time order delivery rate increased from 85% to 98%.

6.6. Case Summary

The development of Yibin's lithium-ion battery industry has fully demonstrated that "building clusters and strengthening supply chains" is not merely about attracting enterprises or expanding production capacity, but rather about constructing an industrial ecosystem with strong resilience, high coordination efficiency, and sustainable development through physical spatial clustering, the integration of information systems, and the restructuring of incentive mechanisms. The development path and optimization experience of Yibin's lithium-ion battery supply chain provide a replicable and scalable industrial engineering optimization model for Sichuan's advanced manufacturing sectors, including equipment manufacturing, electronic information, and aerospace [7].

7. CONCLUSIONS AND POLICY RECOMMENDATIONS

7.1. Research Conclusions

This paper takes Sichuan's advanced manufacturing sector as its research subject. Based on theories of industrial engineering, complex networks, and supply chain resilience, it constructs a three-dimensional "structure–process–synergy" evaluation framework. By comprehensively applying entropy-weighted TOPSIS, fuzzy correlation analysis, and MATLAB simulation methods, the study systematically diagnoses the weaknesses in Sichuan's advanced manufacturing industrial chains and proposes optimization strategies. The core conclusions are as follows:

Sichuan's advanced manufacturing sector boasts a robust industrial foundation and significant cluster agglomeration effects. It has established four pillar industries: electronic information, aerospace, equipment manufacturing, and lithium battery new materials. The regional division of labor among Chengdu, Deyang, Mianyang, and Yibin is well-defined and highly complementary;

The industrial chain exhibits significant vulnerability, with a high degree of reliance on external sources for key core technologies. Severe "bottleneck" issues persist in areas such as high-end chips, industrial software, precision equipment, and core materials, while the high concentration of core nodes increases the risk of systemic failures;

Digitalization levels, local supply chain self-sufficiency rates, and collaborative governance capabilities are key factors influencing the resilience of the industrial chain. Digital collaboration, resource sharing, and equitable distribution of benefits directly determine the operational efficiency and risk-resilience of the industrial chain;

Industrial engineering technologies offer significant value in optimizing industrial chains; through lean inventory management, flexible production capacity scheduling, risk prevention and control in complex networks, and multi-objective optimization, they can effectively enhance industrial chain resilience, reduce operating costs, and strengthen overall competitiveness;

Practices within Yibin's lithium-ion battery industrial chain have validated the feasibility of these optimization solutions; by building industrial clusters, strengthening industrial chains, advancing digital transformation, and implementing collaborative governance, synergistic development—including scale expansion, quality improvement, and enhanced resilience—can be achieved.

7.2. Policy Recommendations

7.2.1. Technical Level

Focus on the power battery industry (Yibin) and establish a joint innovation consortium comprising Sichuan Times and Yibin Libao. Collaborate with universities and research institutes to tackle key materials such as high-end separators, high-purity electrolyte additives, and solid-state battery electrolytes, aiming to achieve a 70% domestic production rate for core materials by 2027;

Focus on the automotive chip industry (Chengdu) by supporting companies such as Chengdu Unisoc and VeriSilicon to collaborate with vehicle manufacturers, prioritizing breakthroughs in core chips such as automotive-grade MCUs, IGBTs, and in-vehicle connectors, with the goal of achieving a 30% self-sufficiency rate for new energy vehicle chips by 2028;

Achieve breakthroughs in precision manufacturing technologies (Deyang, Mianyang). Deyang will focus on research and development of precision bearings, high-end hydraulic components, and CNC systems, while Mianyang will concentrate on the high-purity production of lithium-ion battery materials and the R&D of carbon nanotube conductive agents, aiming to achieve a 50% domestic production rate for core equipment by 2027;

Establish public service platforms for digital twins and the Industrial Internet, promote the application of large-scale industrial models and artificial intelligence technologies in R&D, production, testing, and logistics, popularize "intelligent transformation and digital transition" among enterprises, and enhance the digital coverage and green, low-carbon levels of the industrial chain.

7.2.2. Management Level

Promote the integration of lean production and digitalization, cultivate a group of leading enterprises with ecosystem leadership, support these enterprises in integrating upstream and downstream resources to drive the coordinated development of small and medium-sized enterprises, and improve the supply chain support system;

Establish cross-chain and cross-regional risk early warning and emergency response mechanisms; leverage the Industrial Internet to build an industrial chain risk monitoring platform to monitor key indicators such as raw material prices, logistics and transportation, and production operations in real time, enabling early risk warnings and rapid response to emergencies;

Improve the profit-sharing and collaborative innovation system; promote the Shapley value profit-sharing mechanism to ensure reasonable returns for all entities in the industrial chain; establish a collaborative innovation platform integrating industry, academia, research, and application to facilitate the flow and sharing of factors such as technology, talent, and data, thereby enhancing the efficiency of collaborative innovation;

Utilize industrial engineering tools to continuously optimize production processes, inventory management, and capacity allocation; promote virtual factories, flexible production, and lean logistics models to reduce operational costs across the industrial chain and improve response efficiency [8].

7.3. Research Limitations and Outlook

7.3.1. Research Limitations

Due to the difficulty in obtaining micro-level enterprise data and research cycle constraints, this paper still has certain limitations: First, the empirical analysis relies heavily on macro- and meso-level data, while micro-level enterprise operational data is insufficient, and the level of empirical refinement needs to be improved; second, the simulation model primarily considers internal node failures and conventional external disturbances, but does not sufficiently account for extreme external dynamic variables such as international trade conflicts and major public incidents; third, the study focuses on four key industrial chains—electronic information, aerospace, equipment manufacturing, and new materials for lithium batteries—and does not fully cover the entire spectrum of Sichuan's advanced manufacturing sector; research on differentiated optimization pathways is not sufficiently in-depth.

7.3.2. Research Outlook

Future research can be deepened in three directions: First, expand the application of digital twin technology across the entire industrial chain process, construct real-time dynamic simulation models, accurately simulate the operational status and risk transmission pathways of the industrial chain, and improve the precision of optimization solutions; Second, based on the goals of carbon neutrality and carbon peaking, a green resilience evaluation system should be established to quantitatively assess the green and low-carbon levels of industrial chains and promote their transition toward greener and low-carbon operations; third, cross-sectoral integration with emerging fields such as digital finance, commercial space, and the low-altitude economy should be strengthened to explore pathways for cross-industry convergence and development, thereby providing more comprehensive and in-depth theoretical support and decision-making guidance for Sichuan to cultivate new-quality productive forces and build a manufacturing powerhouse.

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