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# Analysis of the Causes of Pharmaceutical Supply Chain Vulnerability and Response Strategies under the Centralised Purchasing Model

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## ABSTRACT

With the deepening implementation of the centralized drug procurement policy in China, procurement efficiency has significantly improved, and the economic burden of medication on the public has been alleviated. Meanwhile, the structure and operational environment of the pharmaceutical supply chain have undergone notable changes. This study analyzes the emerging pharmaceutical supply chain structures under the centralized procurement model, summarizes the causes of pharmaceutical supply chain vulnerability based on previous research, and employs a system dynamics causal model to examine the causal relationships and influence pathways among these factors. The study identifies the vulnerability drivers at key nodes, including active pharmaceutical ingredient (API) suppliers, pharmaceutical manufacturers, public healthcare institutions, and retail pharmacies. Finally, it proposes reasonable strategies for enterprises to address pharmaceutical supply chain vulnerability from both preventive and mitigating perspectives.

## KEYWORDS

Pharmaceutical supply chain; Supply chain vulnerability; Centralized procurement of drugs; System dynamics

## 1. INTRODUCTION

Against the backdrop of deepening global economic integration, the complexity of supply chains has significantly increased. In recent years, frequent occurrences of uncertainties such as natural disasters and geopolitical conflicts have severely disrupted global supply chains, leading to production halts, supply shortages, and a cascade of adverse effects that impact societal operations. As a result, there is growing attention to supply chain vulnerability. Initially, supply chain vulnerability was defined as a form of "random disturbance" by Svensson [1], emphasizing the sensitivity and resilience of supply chain systems to both external and internal risks. Subsequent research has further developed this concept, highlighting diverse dimensions that span from identifying risk sources [2] to analyzing systemic consequences [3-5].With the acceleration of globalization, supply chain vulnerability has become a critical issue in supply chain management. Identifying the causes of supply chain vulnerability, analyzing its mechanisms, and formulating effective countermeasures are essential for ensuring the stable operation of supply chains.

The pharmaceutical supply chain (PSC) plays a vital role in safeguarding public health but remains highly susceptible to external disruptions. This vulnerability stems from its inherent characteristics, including a vast range of products, rigorous quality standards, and unpredictable demand exacerbated by forecasting difficulties [4]. Such disruptions frequently lead to drug shortages and price inflation, posing risks to public health and potentially inciting social unrest—consequences that can significantly undermine the stability of healthcare systems. The persistent occurrence of public health

emergencies and natural disasters has further exposed weaknesses in the PSC, drawing increasing attention from both researchers and policymakers.

To reduce the cost of pharmaceuticals and medical consumables, healthcare institutions in the United States were encouraged to adopt more efficient procurement methods, leading to the development of group purchasing organizations (GPOs) in 1980s [6]. China has been implementing a nationwide pilot program for centralized drug procurement since 2018. Group Purchasing Organizations (GPOs), which originated in the United States in the 1980s, aggregate downstream procurement demands to leverage economies of scale and negotiate discounts with suppliers, thereby lowering procurement costs. In China, the centralized procurement model is primarily government-led, significantly improving procurement efficiency in public hospitals and alleviating the financial burden of medication for the public. However, it has also introduced new challenges. As the centralized procurement policy advances, pharmaceutical companies face further profit margin compression, while the government imposes strict regulatory oversight on the supply capabilities of winning bidders. Additionally, discrepancies in drug quality and difficulties in demand forecasting may result in suboptimal procurement catalogs, posing new vulnerability factors. Therefore, analyzing the new pharmaceutical supply chain structure under the centralized procurement model, identifying vulnerability drivers, examining how these factors impact PSC operations, and proposing mitigation strategies are crucial for enhancing the supply chain management capabilities of participating enterprises.

## 2. LITERATURE REVIEW

### 2.1. Identification of Pharmaceutical Supply Chain Vulnerability Drivers

There is limited research on identifying the causes of PSC vulnerability. Existing studies primarily summarize PSC risk factors from different perspectives, such as identifying risks based on various stages of the PSC process [7], analyzing risks from the perspective of PSC nodes [8], or classifying factors into internal and external dimensions [9]. Xu identified risks within the pharmaceutical supply chain from the perspective of internal control management in public hospitals [10]. Similarly, Gupta and Kayande summarized pharmaceutical supply chain risk factors with a focus on enhancing supply chain resilience [11]. However, existing studies have rarely considered the new impacts introduced by the centralized procurement model on the pharmaceutical supply chain. To ensure a more comprehensive identification of PSC vulnerability factors and provide practical recommendations for pharmaceutical companies' supply chain management, this study adopts a literature analysis approach to identify vulnerability factors across different PSC system nodes.

### 2.2. Analysis of Pharmaceutical Supply Chain Vulnerability Drivers

Due to the complexity of the pharmaceutical supply chain, the relationships among various vulnerability factors are often highly interdependent, with inherent causal linkages. Therefore, to ensure that the indicator system remains both comprehensive and concise, it is necessary to screen and analyze the identified vulnerability drivers. This process provides a rational foundation for constructing a PSC vulnerability assessment framework. In the field of screening and structuring hierarchical relationships among supply chain vulnerability drivers, various methodologies have been employed to identify key risk factors affecting supply chain vulnerability. These include survey-based hypothesis testing, principal component analysis [9], bayesian network models [12], and causal analysis using fishbone diagrams [13]. However, these methods have limitations in fully capturing the causal relationships among influencing factors. While fishbone diagrams can illustrate basic causal linkages, they fail to depict interactions among factors at the same hierarchical level and cannot provide a more precise definition of inter-factor influences. System dynamics (SD) has emerged as a powerful simulation and analytical tool, particularly effective in exploring the internal dynamics and

long-term behavioral changes within complex systems. Consequently, System dynamics has been widely applied in the supply chain field [14-16].

Therefore, this paper combines the characteristics of PSC, based on the system dynamics causal model, analyses the causal relationship and role path of the vulnerability factors of the pharmaceutical supply chain, derives the main vulnerability factors of each node system of PSC, and ultimately proposes vulnerability coping strategies for each node.

## 3. ANALYSIS OF THE STRUCTURE AND CAUSES OF VULNERABILITY OF THE PHARMACEUTICAL SUPPLY CHAIN UNDER THE CENTRALISED PURCHASING MODEL

### 3.1. Establishment of Pharmaceutical Supply Chain Structure

The implementation of centralized drug procurement policies has effectively diminished the core role of traditional pharmaceutical distributors within the supply chain. Specifically, public healthcare systems, including hospitals and clinics, have redirected the majority of their drug procurement needs to GPO platforms for centralized purchasing. As a result, pharmaceutical companies must participate in government-led centralized procurement to secure orders from public healthcare systems. Meanwhile, members such as retail pharmacy chains have gained greater autonomy, allowing them to choose to procure drugs directly from pharmaceutical companies. Fig. 1 illustrates the structure of the PSC under the GPO model. This model has resulted in the emergence of two primary types of PSCs: "Active Pharmaceutical Ingredient (API) Suppliers–Pharmaceutical Company–Public Healthcare Institutions" (referred to as A-B-C) and "API Suppliers–Pharmaceutical Company–Retail Pharmacies" (referred to as A-B-D). This structure intensifies market competition among pharmaceutical companies. As a result, certain PSC segments may experience financial constraints and insufficient production capacity. Additionally, the strict oversight imposed by GPO necessitates continuous improvements in supply chain reliability.

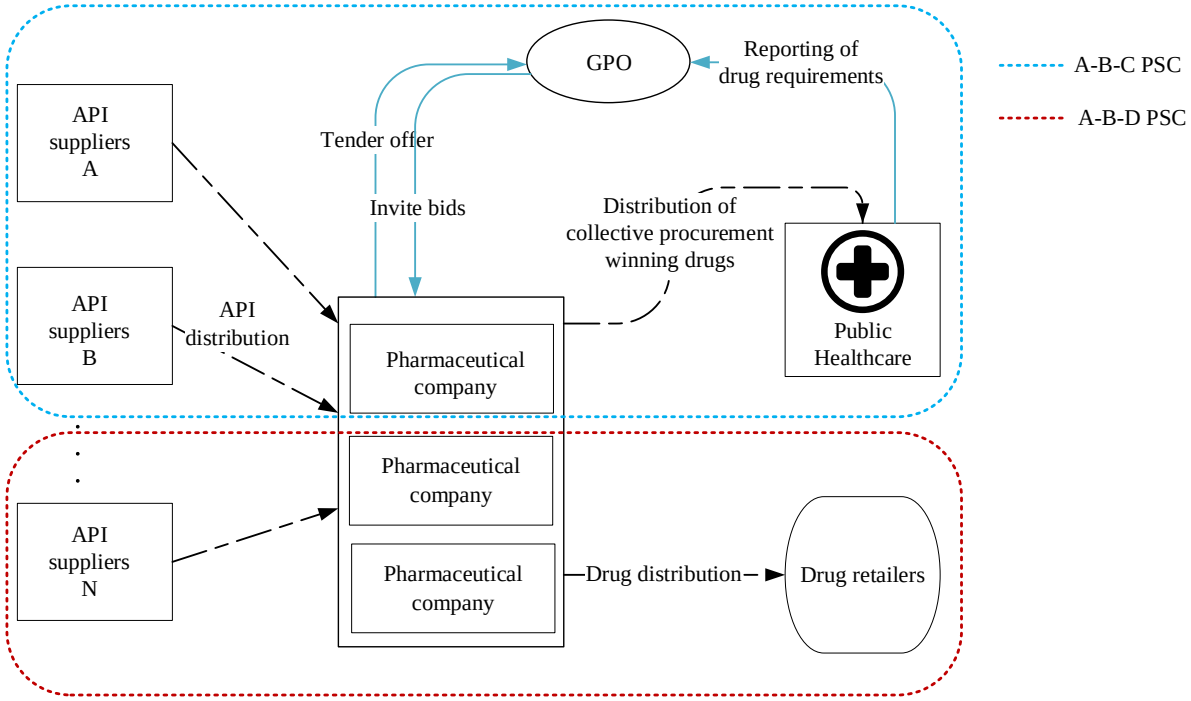


**Figure 1.** PSC Structure under centralized procurement mode

### 3.2. Mechanistic Analysis of Vulnerability in the Pharmaceutical Supply Chain Based on System Dynamics

The driving factors contributing to PSC vulnerability were identified through a literature review. The author systematically collected past research and utilized keywords such as "pharmaceutical supply chain risks," "pharmaceutical supply chain vulnerabilities," and "centralized procurement" to search for relevant studies, thereby compiling and summarizing the main driving factors of PSC vulnerability [17-26]. These factors were then input into VensimPLE software, and Fig. 2- Fig. 5 illustrate the positive and negative feedback relationships between vulnerability factors of each node based on the system dynamics causal model, as well as how these factors affect the vulnerability of various PSC nodes. Fig. 2- Fig. 5, positive relationships are typically represented by arrows with a "+" symbol. For example, in the pharmaceutical supply chain, enhanced stability in API delivery may lead to increased production capacity for pharmaceutical companies, thereby improving their credibility—this forms a positive relationship. Negative relationships are typically represented by arrows with a "-" symbol. For instance, an increase in drug prices may reduce consumer demand, thereby affecting the stability of the pharmaceutical supply chain, which demonstrates a negative relationship.

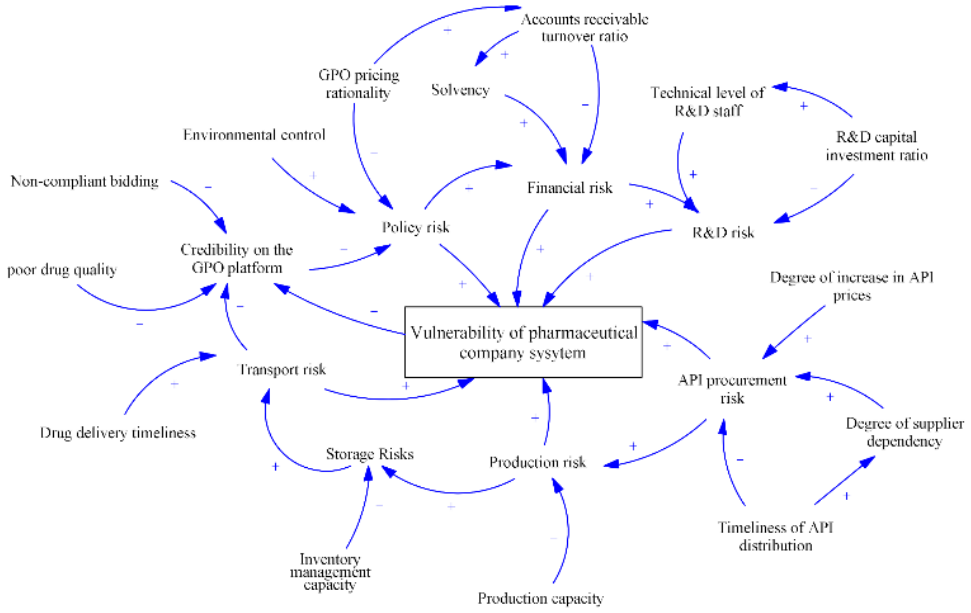


**Figure 2.** Causal diagram of node vulnerability factors for pharmaceutical companies

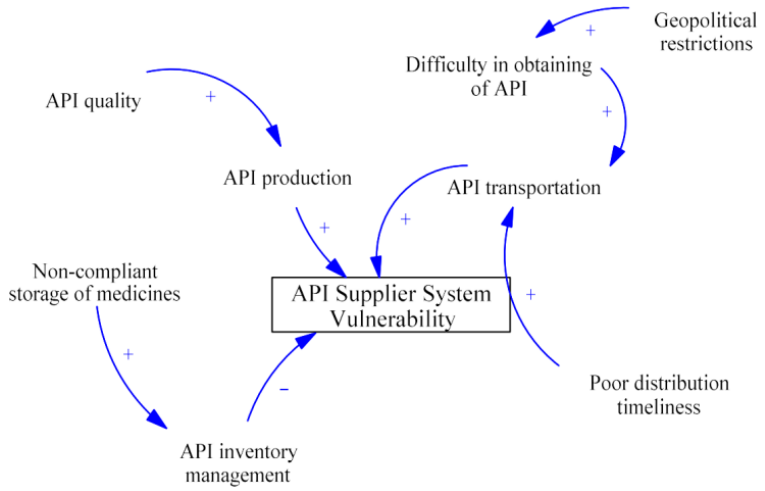


**Figure 3.** Causal diagram of node vulnerability factors for API supplier

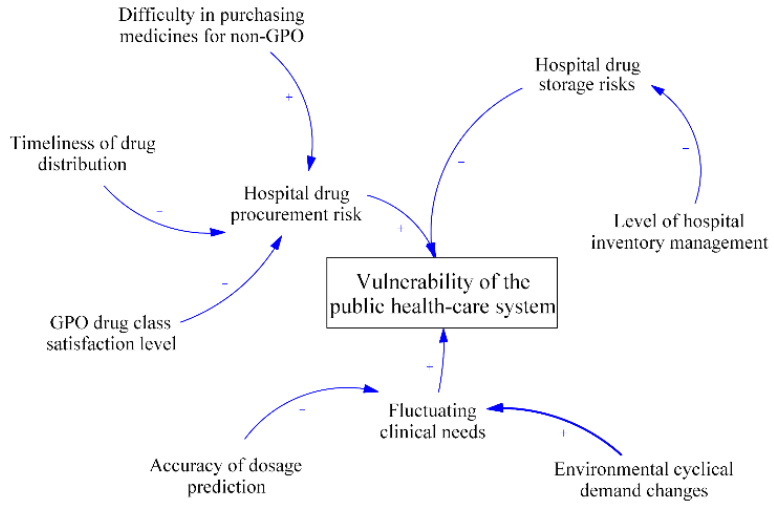


**Figure 4.** Causal diagram of node vulnerability factors for public health-care

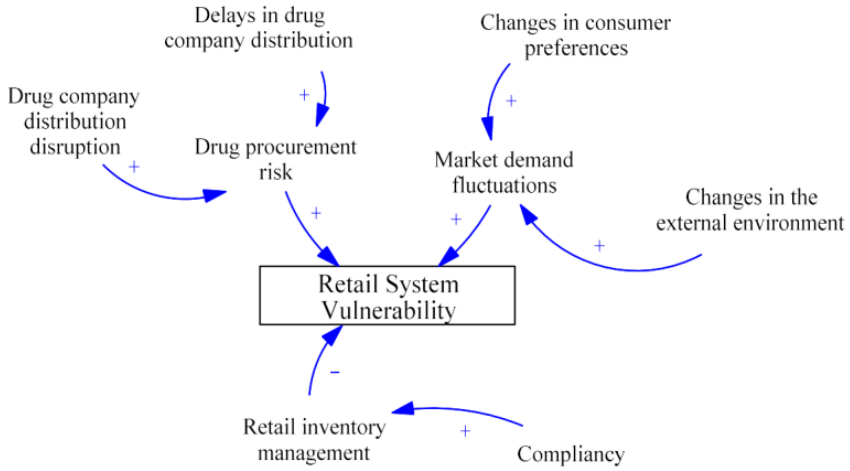


**Figure 5.** Causal diagram of node vulnerability factors for retail

Based on the aforementioned model, the vulnerability factors influencing the various node systems are as follows:

(1) API supplier system vulnerability: This is primarily driven by risks related to API production, transportation, and storage. API production risks include issues such as production quality, difficulty in obtaining apis, over-reliance on a single supplier, and geopolitical restrictions, all of which directly impact the stability of raw material supply. Transportation and storage risks, such as low delivery timeliness and insufficient inventory management capabilities, further exacerbate the vulnerability of the API supplier system.

(2) Pharmaceutical company system vulnerability: Vulnerabilities in pharmaceutical companies are evident across several areas, including finance, research and development (R&D), procurement, production, storage, transportation, and policy. Financial risks: Weak debt repayment capabilities and low accounts receivable turnover can lead to cash flow disruptions, hindering raw material procurement and production investments. R&D Risks: A low proportion of investment in R&D and insufficient personnel undermine the company's ability to adapt to market demand changes and technological upgrades. Policy risks: These include environmental protection regulations, the reasonableness of GPO platform pricing, and the credibility of GPO platforms.

When a company's production capacity is insufficient, storage risks increase, leading to poor drug delivery timeliness, which directly affects the company's ability to fulfill contracts and, consequently, reduces its credibility on the GPO platform. Additionally, poor drug quality and non-compliant

bidding can lower the company's credibility and the reasonableness of GPO platform pricing. The inherent vulnerability of the pharmaceutical company system also leads to decreased trust in the company by the GPO platform.

(3) Public healthcare system vulnerability: This is primarily influenced by procurement risks, clinical demand fluctuations, and drug storage issues. Procurement risks: These include the low satisfaction of GPO drug categories and difficulties in procuring non-GPO drugs, both of which can result in shortages of clinical drugs. Clinical demand fluctuations: These are mainly influenced by environmental cyclical changes and the accuracy of drug demand forecasting. Storage risks: Public healthcare system storage risks are primarily related to poor compliance with clinical drug storage standards, which can lead to drug deterioration and expiration.

(4) Retail system vulnerability: This is mainly driven by market demand fluctuations, retailer procurement, policy issues, and storage concerns. Market Demand Fluctuations: These include changes in consumer preferences and environmental cyclical changes, increasing the uncertainty of demand. Retailer Procurement: This is largely influenced by the delivery timeliness of pharmaceutical companies. Policy and Regulatory Risks: Stricter government regulations on operational quality increase the compliance costs and operational pressures on retailers. Storage Risks: Retailers' inventory management capabilities are primarily influenced by the compliance of drug storage standards.

# 4. STRATEGIES FOR COPING WITH THE VULNERABILITY OF THE PHARMACEUTICAL SUPPLY CHAIN UNDER THE CENTRALISED PROCUREMENT MODEL

In the centralized procurement model, the operational modes of the API suppliers, pharmaceutical companies, public healthcare systems, and pharmaceutical retail systems have undergone significant changes. These changes have, to some extent, exacerbated the vulnerability of the supply chain. Based on the summary and analysis of the main vulnerability drivers for each node system in the PSC outlined earlier, this study proposes corresponding strategies for addressing vulnerability in the four node systems, focusing on both the prevention and mitigation of PSC vulnerabilities.

## 4.1. Strategies for Addressing API Supplier Vulnerability

(1) Prevention Measures: (a) Enhancing API Production Capacity: Encourage companies to increase investment in advanced production technologies to improve production efficiency and quality stability, thereby reducing the impact of unexpected events on the supply chain. (b) Optimizing Inventory Management: Suppliers should adopt intelligent inventory management systems to ensure stable supply even during demand fluctuations. (c) Improving Policy Adaptability: Suppliers should actively adapt to changes in the centralized procurement policies, adjusting production and supply strategies flexibly to ensure compliance and maintain market competitiveness.

(2) Mitigation Measures: (a) Optimizing Inventory Allocation: In cases of limited supply, prioritize shipments to key pharmaceutical companies, and use temporary inventory allocation mechanisms to reduce supply chain pressure. (b) Information Sharing and Collaboration: Maintain transparency with pharmaceutical companies, sharing raw material supply information in a timely manner so that they can adjust production plans in advance and reduce the risk of production disruptions. (c) Government and Industry Collaboration: In extreme cases, seek support from the government or industry cooperation, such as establishing strategic raw material reserves to address emergency supply shortages.

## 4.2. Strategies for Addressing Pharmaceutical Company Vulnerability

(1) Prevention measures: (a) optimizing production layout: pharmaceutical companies should adjust the layout of their production bases based on market demand and centralized procurement policies, avoiding overconcentration of the supply chain in a single region to enhance resilience to risks. (b) strengthening supply chain digital management: leverage big data and ai technologies to predict market demand, improve the transparency and responsiveness of the supply chain, and optimize production plans. (c) enhancing R&D and technical reserves: increase investment in research and development to improve production efficiency, and develop alternative production processes for raw materials to reduce dependence on specific suppliers. (d) improving quality control: ensure strict supervision of the production process to minimize product recalls or supply chain disruptions caused by quality issues.

(2) Mitigation measures: (a) quickly adjusting production strategies: in the event of supply chain disruptions, rationally adjust production plans, such as prioritizing the production of essential drugs while reducing production of non-critical drugs. (b) strengthening emergency procurement capabilities: establish a rapid response mechanism and collaborate with multiple raw material suppliers to quickly source and redistribute supplies during shortages. (c) implementing emergency inventory management: set up safety stock in key regions and use intelligent inventory management systems to dynamically adjust inventory levels, minimizing the impact of unforeseen events on the supply chain. (d) enhancing communication with government and procurement platforms: in the event of emergencies, actively coordinate with government agencies and GPO platforms to seek policy support.

## 4.3. Strategies for Addressing Public Healthcare System Vulnerability

(1) Prevention measures: (a) optimizing drug procurement strategies: public hospitals should establish flexible procurement mechanisms based on gpo centralized procurement, tailored to their specific needs, in order to avoid over-reliance on a single channel. (b) strengthening inventory management capabilities: implement intelligent inventory management systems to ensure adequate drug reserves and the ability to dynamically adjust based on changes in demand. (c) improving distribution efficiency: collaborate with logistics companies and pharmaceutical enterprises to optimize the distribution network, ensuring timely drug supply. (d) enhancing risk assessment and emergency planning: develop emergency plans for unexpected events, including alternative procurement solutions during supply shortages, to reduce the risk of drug shortages.

(2) Mitigation measures: (a) establishing temporary procurement mechanisms: in cases of drug shortages under gpo procurement, hospitals can quickly replenish stock through non-gpo channels or direct collaboration with pharmaceutical companies. (b) strengthening medical consortium cooperation**: in times of supply chain disruptions, public hospitals can share inventory with other healthcare institutions and coordinate cross-hospital supply to ensure drug availability. (c) optimizing patient medication management: during drug shortages, prioritize medications for critically ill patients and provide proper guidance on alternative drugs. (d) enhancing government coordination: in situations of tight drug supply, actively communicate with the government to report issues and secure policy support, as well as emergency drug allocations.

## 4.4. Strategies for Addressing Retail System Vulnerability

(1) Prevention measures: (a) implementing multi-channel procurement models: retail pharmacies should establish supply partnerships with multiple pharmaceutical companies to avoid stockouts due to disruptions in any single supply chain link. (b) enhancing market demand forecasting: utilize big data analytics to predict consumer demand accurately, enabling efficient inventory planning to mitigate the impact of seasonal and unexpected demand fluctuations. (c) optimizing warehousing and

logistics networks: adopt advanced warehouse management systems to increase inventory turnover and ensure a stable drug supply. (d) ensuring compliance and adapting to policies: strictly adhere to government regulatory systems, ensuring that procurement and operations comply with regulatory requirements, while avoiding stockpile or stockout issues caused by policy changes.

(2) Mitigation measures: (a) establishing emergency restocking mechanisms: in the event of supply shortages, retail pharmacies can quickly replenish inventory through regional transfers, collaboration with wholesalers, or emergency procurement. (b) strengthening communication with consumers: in cases of drug shortages, retail pharmacies should promptly provide consumers with alternative options and communicate through digital platforms to minimize customer attrition. (c) expanding online sales and distribution: utilize online pharmaceutical sales platforms to increase drug accessibility and reduce sales losses in physical stores due to supply issues. (d) introducing compensation and membership schemes: provide discounts, vouchers, or other compensatory measures to address the inconvenience caused by supply chain issues, maintaining customer loyalty and brand reputation.

## 5. CONCLUSION

China's centralized drug procurement model, a government-led procurement system, has played a significant role in optimizing the allocation of medical resources, reducing drug costs, and improving supply chain efficiency. This model has greatly standardized market competition and strengthened the supervision of the supply chains of the awarded drugs, improving the contract fulfillment capabilities of pharmaceutical companies and ensuring the stability and safety of drug supplies. Additionally, it has contributed positively to public health protection and optimized the distribution of medical resources. This paper primarily analyzes the new structure of the PSC under the centralized drug procurement model. It summarizes the core causes of PSC vulnerability from past literature and then constructs a system dynamics-based vulnerability causal model, revealing the interactions between different vulnerability factors. Based on this, the paper proposes vulnerability response strategies for four supply chain node systems, addressing both the prevention and mitigation of PSC vulnerability. These strategies aim to help the companies at each node in the supply chain better manage PSC vulnerabilities, ensuring the stable operation of the supply chain.

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