Int j simul model 23 (2024) 3, 543-554
Original scientific paper

# OPTIMIZATION STRATEGIES AND SIMULATION OF INTEGRATED MANAGEMENT IN SUPPLY CHAINS

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**Abstract**

With global economic integration and rapid IT advancements, enterprises face complex market environments and intense competition. Efficient management and coordination of supply chains and manufacturing are critical. This study explores optimization strategies for integrated supply chain and manufacturing management using system dynamics. Initially, it investigates the contractual collaboration model based on system dynamics, analysing dynamic behaviours and optimization strategies. Subsequently, a system dynamics simulation model of the integrated system is constructed. Simulation analysis reveals the interactive relationships and dynamic patterns within the system. While many studies focus on static analysis, they often overlook dynamic changes and complex interactions. This study enriches the theoretical framework and provides solutions for enhancing management efficiency and competitiveness in a volatile market.

(Received in May 2024, accepted in July 2024. This paper was with the authors 3 weeks for 2 revisions.)

**Key Words:** Supply Chain Management, Manufacturing, Integrated Management, System Dynamics, Contractual Collaboration Model, Simulation Model

## 1. INTRODUCTION

Under the backdrop of global economic integration and the rapid advancement of IT, enterprises are confronted with an increasingly complex market environment and severe competitive pressures [1-3]. The management efficiency and collaborative capability of supply chains and manufacturing processes, as core components of business operations, are directly linked to the market response speed and competitive advantage of enterprises [4, 5]. With market demands becoming more diverse and dynamic, traditional management models of supply chains and manufacturing are no longer sufficient to meet the needs of modern enterprises, necessitating a scientific and effective method to optimize the integrated management of supply chains and manufacturing [6, 7].

The exploration of optimization strategies for the integrated management of supply chains and manufacturing holds significant theoretical and practical implications. By constructing simulation models based on system dynamics, a comprehensive analysis of the dynamic relationships among various elements within supply chains and manufacturing processes can be conducted, revealing the complex interaction mechanisms within the system [8]. This not only facilitates the comprehensive control of enterprises over supply chains and manufacturing processes but also aids in the formulation of scientifically sound management decisions [9, 10]. Furthermore, the optimization of contract collaboration models in supply chains and manufacturing can further enhance the collaborative efficiency between internal departments and external partners, achieving effective allocation and utilization of resources [11-14].

Many studies on supply chain management and manufacturing optimization primarily focus on static analysis, often overlooking the dynamic and complex interactions within systems [15-17]. Most methodologies fail to adequately consider the interdependencies and interactions among subsystems within integrated management, resulting in suboptimal optimization strategies in practice. Consequently, there is an urgent need for a method capable of

https://doi.org/10.2507/IJSIMM23-3-CO15

dynamically simulating and analysing the complexities of integrated supply chain and manufacturing management to overcome these limitations.

This study examines the optimization strategies of integrated supply chain and manufacturing management using system dynamics. It comprises two main parts: firstly, exploring contract collaboration models in supply chains and manufacturing, analysing the dynamic behaviours and optimization strategies of various models. Secondly, a system dynamics simulation model was constructed, revealing the interactions and dynamic changes within these systems. The findings provide theoretical insights and practical guidance for strengthening management strategies, thereby enhancing efficiency and competitiveness in dynamic market environments. This research contributes to the theoretical framework and offers scientific solutions to complex supply chain and management challenges.

## 2. CONTRACTUAL COLLABORATION MODEL IN SUPPLY CHAINS AND MANUFACTURING BASED ON SYSTEM DYNAMICS

Based on system dynamics in supply chains and manufacturing, this study investigates the contractual collaboration model by focusing on three types of contracts, i.e., wholesale price contracts, revenue-sharing contracts, and quantity flexibility contracts. These contracts significantly enhance the coordination and overall performance of supply chains. As fundamental tools in supply chain management, wholesale price contracts allocate benefits among various nodes in the supply chain through appropriately set wholesale prices, which reduces information asymmetry and conflicts of interest, fostering cooperation and coordination between upstream and downstream members of the supply chain. Revenue-sharing contracts, by reasonably distributing profits among supply chain members, effectively motivate stakeholders to enhance the overall efficacy of the supply chain, fostering a win-win or multi-win scenario that boosts the overall competitiveness of the supply chain. Quantity flexibility contracts primarily address the uncertainties of market demand by allowing adjustments within a certain range of order quantities, enhancing the flexibility and response speed of the supply chain, and reducing risks and losses due to demand fluctuations. By employing system dynamics, the impacts of these three types of contracts on the supply chain and manufacturing system can be dynamically simulated and analysed under various scenarios, revealing their inherent mechanisms and interaction patterns, thereby providing a theoretical foundation and data support for enterprises to formulate scientific and rational management decisions.

### 2.1 Wholesale price contract model

In the wholesale price contract model, supply chain enterprises are required to determine the wholesale quantity based on market demand and wholesale prices, while manufacturing enterprises organize production according to this quantity. The responsibility for managing inventory products falls on supply chain enterprises. Therefore, in this contract model, the profits of the manufacturing enterprises are relatively certain, primarily dependent on the wholesale quantity, with the supply chain enterprises bearing the full market risk. Research on the wholesale price contract model using system dynamics allows for the understanding and prediction of behaviours and interactions among different segments of the supply chain through dynamic simulation. The system dynamics model captures the dynamic changes of various factors such as market demand fluctuations, adjustments in wholesale prices, production planning, and inventory management, thereby providing data support and a decision-making basis for supply chain management. By simulating different market scenarios and wholesale pricing strategies, the impact of these strategies on the overall performance of the supply chain can be assessed, and an optimal wholesale pricing policy that balances the interests of all parties can be found.

It is assumed that the production cost of the manufacturing enterprises is represented by $z$, the agreed wholesale price between the manufacturing enterprises and the supply chain enterprises by $q$, the actual market demand by $F(w)$, the purchase quantity by $W$, and the selling price by $O$. With $\Pi_e(w, q)$ being a strictly concave function, when adopting the wholesale price contract, there is a unique optimal solution for the wholesale quantity ($w$) for the supply chain enterprises, which must satisfy the following conditions:

$$\begin{aligned}\frac{\partial\Pi_e(q,w)}{\partial q} &= (o+z_t+z_i-n)T'(w_e^*)-(q+z_r-n) \\ &= (o+z_t+z_i-n)\bar{\Theta}(q_r^*)-(q+z_r-n)=0\end{aligned} \tag{1}$$

$$w_e^* = \Theta^{-1}\left(\frac{o+z_i-q}{o+z_t+z_i-n}\right) \tag{2}$$

The core of the above-mentioned contract model is that supply chain enterprises determine wholesale quantities based on market demand and wholesale prices, while manufacturing enterprises organize production accordingly. However, with the expected sales volume, denoted as $T(w)$, being a monotonically decreasing function, theoretical coordination of the entire supply chain requires that $w*_e = w*$ and $q = z$, meaning the wholesale price equals the production cost. Under such conditions, manufacturing enterprises would not profit, clearly contradicting practical operations. Consequently, the simplistic wholesale price model struggles to achieve supply chain coordination, leading to a "double marginal benefit" issue where both manufacturing and supply chain enterprises prioritize their profits over the overall benefit of the supply chain, ultimately causing coordination failure.

The system dynamics model provides a detailed description and analysis of the dynamic interactions and feedback mechanisms among various segments of the supply chain. Within the wholesale price contract model, factors such as market demand fluctuations, adjustments in wholesale prices, production planning, and inventory management can be dynamically simulated using system dynamics, thus assessing the impact of different strategies on the overall performance of the supply chain. Using this approach, key factors causing "double marginal benefits" in wholesale price contracts can be identified, and solutions can be explored. In the system dynamics simulation, strategies such as revenue sharing mechanisms, buy-back contracts, and quantity discounts can be introduced to mitigate conflicts of interest among supply chain parties, thereby enhancing the overall coordination and efficacy of the supply chain.

## 2.2 Revenue-sharing contract model

The core idea of the revenue-sharing contract model is to achieve collaborative cooperation and overall optimization among all parties in the supply chain through adjusting the profit distribution mechanism. According to this model, manufacturing enterprises wholesale products to supply chain enterprises at a lower price, sometimes even below manufacturing costs, while supply chain enterprises share a portion of the sales revenue with the manufacturers. The proportion coefficient of revenue allocated to supply chain enterprises is denoted by $\theta$, thus the proportion coefficient for manufacturing enterprises is $1–\theta$. In practice, this contract model has achieved significant results in industries such as digital video disc (DVD) rentals. Through this revenue-sharing mechanism, supply chain enterprises can bear lower upfront procurement costs, thereby reducing sales pressure and risk. Manufacturing enterprises compensate for the initial wholesale price reduction and gain profits through shared sales revenue. This win-win model enhances the overall performance and coordination of the supply chain. The profit of supply chain enterprises can be calculated using the following equations:

$$\begin{aligned}\Pi_e &= \theta\left[oT(w)+nU(w)\right]-qw-z_rU(w)-z_iM(w)\\ &=\left[\theta(o-n)+z_r+z_i\right]T(w)-\left[q+z_r-\theta n\right]w-z_i\omega\end{aligned} \tag{3}$$

$$w_e^* = \Theta^{-1}\left(\frac{\theta o+z_i-q}{\theta(o-n)+z_r+z_i}\right) \tag{4}$$

Let $w^*_e = w^*$, which yields the following equation:

$$q=\theta z+(1-\theta)z_i-\frac{(1-\theta)(z_r+z_i)(o+z_i-z)}{o+z_r+z_i-n} \tag{5}$$

Upon incorporating it into Eq. (3), the following equation can be derived:

$$\Pi_e=\frac{\theta(o-n)+z_r+z_i}{o+z_r+z_i-n}\Pi_s-\frac{(1-\theta)(o-n)}{o+z_r+z_i-n}z_i\omega \tag{6}$$

Consequently, the profit for manufacturing enterprises is expressed as follows:

$$\Pi_t=\Pi_s-\Pi_e=\frac{(1-\theta)(o-n)}{o+z_r+z_i-n}\Pi_s+\frac{(1-\theta)(o-n)}{o+z_r+z_i-n}z_i\omega \tag{7}$$

Let $\eta = (1-\theta)(o-n)/o+z_r+z_i-n$, then $\Pi_t = \eta\,\Pi_s + \eta\, z_i\,\omega$, where clearly $0 < \eta < 1$. Through system dynamics simulation, a detailed analysis can be conducted on the impact of different revenue-sharing proportions on the overall benefit of the supply chain. The applicability and effectiveness of revenue-sharing contracts under varying market scenarios and demand fluctuations can be assessed. The primary objective of this study is to find the optimal revenue sharing proportion through dynamic simulation and optimization, achieving a balance of interests between the supply chain and manufacturing enterprises, thereby enhancing the overall synergy and competitive strength of the supply chain.

### 2.3 Quantity flexibility contract model

The core idea of the quantity flexibility contract model is to adjust the order quantities flexibly, enabling all parties in the supply chain to better respond to market demand fluctuations, and to optimize production and inventory management. According to this model, supply chain enterprises forecast the market demand as $w$ before the sales season and commit to a minimum purchase quantity of $(1-\alpha)w$, where $0 \le \alpha \le 1$. Manufacturing enterprises then organize production based on this forecast, setting the production quantity at $w_t = (1+\beta)w$, where $\beta \ge 0$. This contract model allows supply chain enterprises considerable flexibility during demand fluctuations, thereby reducing inventory risks and capital occupation. Manufacturing enterprises, by obtaining stable market demand forecast data, can better plan production and respond promptly to market changes. The overall efficiency and response speed of the supply chain are enhanced through this approach. The equations for calculating the expected purchasing and selling quantities of supply chain enterprises are as follows:

$$V(w,\beta,\alpha)=\int_0^{w(1-\alpha)} w(1-\alpha)\theta(a)fa+\int_{w(1-\alpha)}^{w(1+\beta)} a\theta(a)fa+\int_{w(1+\beta)}^{\infty} w(1+\beta)\theta(a)fa \tag{8}$$

$$T\left[w(1+\beta)\right]=\int_0^{w(1+\beta)}\bar{\Theta}(a)\,fa \tag{9}$$

$$T\left[w(1-\alpha)\right]=\int_0^{w(1-\alpha)}\bar{\Theta}(a)\,fa \tag{10}$$

If it is further assumed that the expected inventory and shortage quantities for supply chain enterprises are represented by $U\,[w\,(1-\alpha)]$ and $L\,[q\,(1+\alpha)]$, respectively, then the following equation can be obtained:

$$\Pi_e = oT\left[w(1+\beta)\right] + nU\left[w(1-\alpha)\right] - z_r M\left[w(1+\beta)\right] - qV\left(w,\beta,\alpha\right) \tag{11}$$

Let $\partial \Pi_e / \partial w = 0$, which yields the following equation:

$$(1+\beta)(o-q+z_i)\bar{\Theta}\left[(1+\beta)w^*\right] - (1-\alpha)(q-n+z_r)\bar{\Theta}\left[(1+\alpha)w^*\right] = 0 \tag{12}$$

Let $\varepsilon = 1+\beta/1-\alpha$, and according to $w^*_t = (1+\beta)\,w^*$, the following equation can be obtained:

$$\Theta\left({}^{w_t}\!\!\diagup_{\varepsilon}\right) = \varepsilon\left[{}^{(o-q+z_i)}\!\!\diagup_{(q-n+z_r)}\right]\left[1-\Theta\left(w_t^*\right)\right] \tag{13}$$

Let $w^*_t = w^*$, then the following equation can be deduced:

$$q = n - z_r + \frac{z-n+z_r}{\frac{1}{\varepsilon}\Theta\left[\frac{1}{\varepsilon}\Theta^{-1}\left(\frac{o+z_i-z}{o+z_r+z_i-n}\right)\right] + \frac{z-n+z_r}{o+z_r+z_i-n}} \tag{14}$$

The quantity flexibility contract achieves coordination between the supply chain and manufacturing enterprises by adjusting the contract parameters, i.e., the production increment coefficient $\beta$, the minimum committed purchase amount coefficient $\alpha$, and the wholesale price $q$. When considering the elasticity ($\varepsilon$) of the quantity flexibility contract, two extreme scenarios can be analysed: under the conditions of $\varepsilon = \infty$, $\beta = \infty$, and $\alpha = 1$, supply chain enterprises can completely avoid stock-out losses but are unable to generate any profit; whereas under the conditions of $\varepsilon = 1$, $\beta = 0$, and $\alpha = 0$, supply chain enterprises bear all market risks and capture all profits, effectively transforming the quantity flexibility contract into a wholesale price contract. Although these extreme scenarios are theoretically possible, they are impractical in real operations. Therefore, $\varepsilon$ must be set between these extreme scenarios, with the parameter adjustment of the quantity flexibility contract to achieve supply chain coordination and optimization.

In system dynamics simulations, supply chain enterprises can adjust expected purchasing and selling quantities based on market demand scenarios and contract parameters. The purchasing quantity is determined by $1-\alpha w$, and the selling quantity varies with actual market demand and production plans. These simulations help identify optimal parameter settings to enhance supply chain coordination and adaptability to market fluctuations.

## 3. SYSTEM DYNAMICS SIMULATION FOR INTEGRATED SUPPLY CHAIN AND MANUFACTURING MANAGEMENT

Fig. 1 presents a three-dimensional model for the complex system of integrated supply chains and manufacturing management. To further develop a system dynamics simulation model for this complex system, it is essential first to clarify the key variables and their interrelationships proposed in the previous section on the contractual collaboration model in supply chains and manufacturing. Based on system dynamics theory, the system comprises various types of variables and constants:

**Stock variables:** Quantities accumulated within the system, including inventory levels, work-in-process, and supplier inventories.

**Flow rate variables:** Determine the rate of change in stock variables, such as production rates, supply rates, and demand rates.

**Auxiliary variables:** Help explain changes in flow rates, including market demand and production capacity.

**Constants:** Fixed parameters in the system, like production cycle time and transportation time.

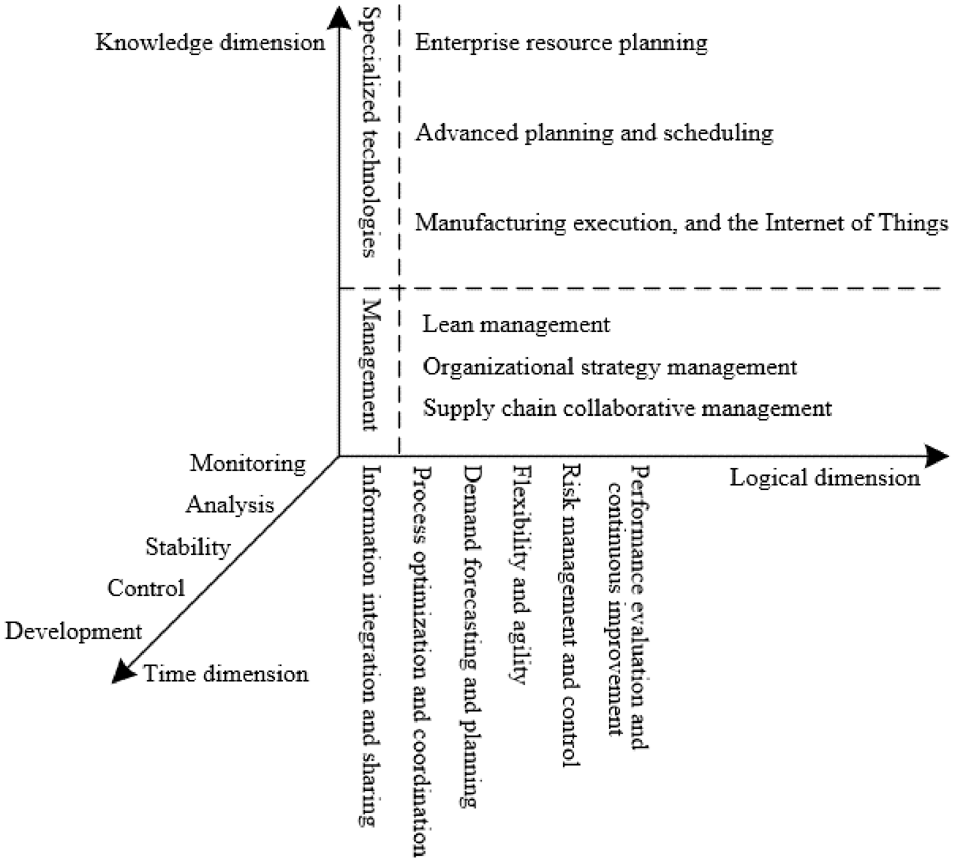


Figure 1: 3D model of integrated supply chain and manufacturing management system.

In Vensim, a causal loop diagram of the system was initially drawn to display the relationships among variables, including: a) an increase in demand raises the production rate, which further impacts inventory levels; b) high inventory levels may reduce the demand rate for new orders, forming a negative feedback loop; and c) supplier inventory affects the supply rate, which in turn impacts the levels of work-in-process. Based on the causal loop diagram, these relationships are translated into system dynamics flow diagrams. In Vensim, stock and flow rate variables are connected with arrows. These flow diagram components are linked by arrows and relational symbols, forming a comprehensive, visualized system dynamics model that displays the complex dynamic interactions within the system. Through these flow diagrams, the behaviour of the system under various conditions can be simulated and analysed to identify potential bottlenecks and optimization opportunities, thus providing a scientific basis and decision support for integrated management of supply chains and manufacturing.

To deeply understand the dynamic behaviours of the system, feedback structures within the system need to be identified and analysed. In the supply chain and manufacturing system, common feedback loops include negative and positive feedback loops. Specifically, when inventory levels are high, production rates may decrease, and demand rates may increase, thereby reducing inventory levels. This scenario is characterized by a negative feedback loop mechanism, which helps maintain system stability. Furthermore, an increase in market demand might prompt increases in production and supply rates, thereby further meeting market demand and increasing sales. This scenario is characterized by a positive feedback loop mechanism.

When inventory levels are too low, the system may respond by increasing production rates to replenish inventories, thus forming a negative feedback loop to stabilize inventory levels. Additionally, the sufficiency of supplier inventories can significantly impact supply rates, subsequently affecting production rates and inventory levels and forming complex feedback loops.

Finally, by setting simulation parameters such as the simulation time range and time step, the simulation model can be run, and dynamic change curves for various variables can be obtained. Analysing these curves helps identify behavioural patterns in the system. Based on the simulation results, system parameters can be adjusted and optimized to enhance the overall efficiency and response speed of the system.

The complex system of integrated supply chains and manufacturing management is broken down into multiple subsystems, each with specific variables that influence overall dynamic behaviour. Here's a concise overview of each subsystem: a) Supplier subsystem, which manages the supply and procurement of raw materials, focusing on variables like supplier inventory levels, supply rates, delivery times, and procurement costs. Optimizing these can ensure a reliable raw material supply and effective inventory control. b) Manufacturing subsystem, which oversees product production, with key variables such as work-in-progress, production rates, capacity, and equipment utilization. Adjusting production schedules and capacities enhances efficiency and reduces resource waste. c) Inventory management subsystem, which manages inventories of raw materials, work-in-progress, and finished goods. Optimization of inventory levels, inbound and outbound rates, and turnover can reduce costs and meet market demands efficiently. d) Logistics and distribution subsystem, which handles product transportation and distribution, focusing on in-transit inventory, distribution rates, transportation time, and capacity. Optimizing these variables improves logistics efficiency and reduces costs. e) Market demand subsystem, which deals with forecasting and managing market demand, with variables including customer orders, demand rates, and customer satisfaction. Effective forecasting and responsiveness enhance customer satisfaction and sales achievements. f) Information and technology support subsystem, which manages information flow and technology within the system, with variables such as data update rates, system response times, and IT support costs. Enhancing information management and technology support boosts system responsiveness and reliability. g) Financial and cost management subsystem, which focuses on cost control and financial management, analysing variables like working capital, cash flows, cost structures, and profitability to maximize cost efficiency and profits.

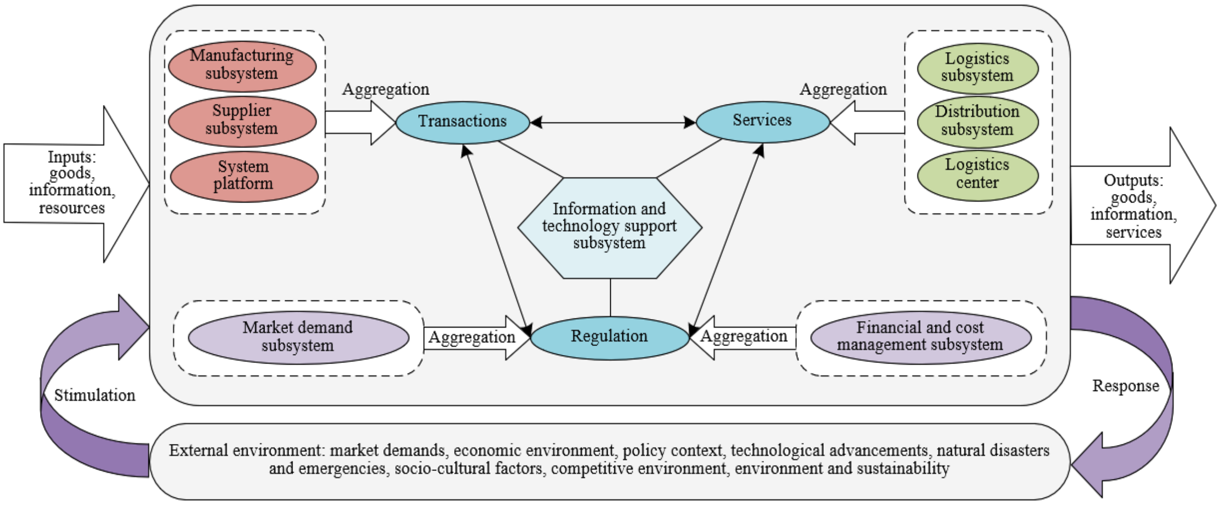


Figure 2: Operational structure of the complex system of integrated supply chains and manufacturing management.

Fig. 2 displays the operational structure diagram of the complex system of integrated supply chains and manufacturing management. By dynamically simulating and analysing these subsystems and their variables, enterprises can better understand and address the complexities and uncertainties in supply chains and manufacturing processes.

## 4. EXPERIMENTAL RESULTS AND ANALYSIS

Table I shows that the wholesale price contract model generally outperforms the traditional model in terms of sales volume and revenue growth rates. Initially, in the first period, the traditional model has a sales volume growth rate of 0.221, slightly higher than the simulated 0.21 of the wholesale model. However, the wholesale model's revenue growth rate starts higher at 0.34, compared to 0.3 in the traditional model. As the periods progress, the advantages of the wholesale model become more evident. From the second period, the wholesale model consistently achieves higher sales volume growth rates; by the fourth period, it records 0.28 versus the traditional 0.22. The revenue growth rate difference is more significant; in the fifth period, the wholesale model reaches 0.5, substantially higher than the traditional 0.34. By the eleventh period, while the traditional model's sales rate dips to 0.008, the wholesale model sustains a high rate of 0.31 and an impressive revenue growth rate of 0.72, greatly exceeding the traditional 0.21.

Table I: Comparison of traditional and wholesale price contract models.

| Period | Sales volume growth rate (traditional model) | Sales volume growth rate (simulated value) | Revenue growth rate (traditional model) | Revenue growth rate (simulated value) |
|---|---|---|---|---|
| 1 | 0.221 | 0.21 | 0.3 | 0.34 |
| 2 | 0.256 | 0.26 | 0.28 | 0.37 |
| 3 | 0.223 | 0.25 | 0.289 | 0.42 |
| 4 | 0.22 | 0.28 | 0.3 | 0.44 |
| 5 | 0.13 | 0.27 | 0.34 | 0.5 |
| 6 | 0.19 | 0.29 | 0.32 | 0.54 |
| 7 | 0.15 | 0.3 | 0.31 | 0.57 |
| 8 | 0.1 | 0.31 | 0.32 | 0.61 |
| 9 | 0.04 | 0.32 | 0.33 | 0.64 |
| 10 | 0.01 | 0.31 | 0.3 | 0.7 |
| 11 | 0.008 | 0.31 | 0.21 | 0.72 |

Data from Fig. 3 shows that under the wholesale price contract model, both the number of supply chain enterprises and wholesale prices consistently increase over time.

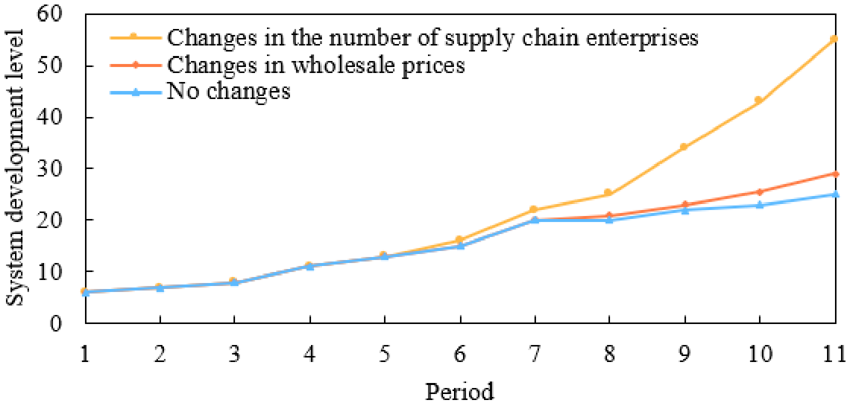


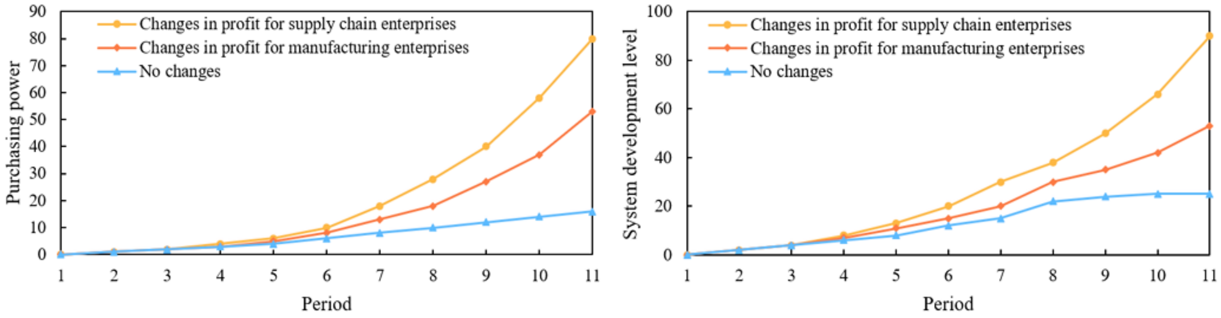
Figure 3: Trend in system development level under the wholesale price contract model.

The number of enterprises grows from 6 in the first period to 55 by the eleventh period, while wholesale prices rise from 6 units to 29 units in the same timeframe. Despite a temporary stabilization in prices during the eighth period, prices resume their upward trend and eventually surpass those in the unchanged scenario by the eleventh period. This trend indicates that the wholesale price contract model significantly drives the expansion of supply chains and elevates price levels, reflecting increased market demand and enhanced supply chain value. Notably, the rapid growth in the number of enterprises from the seventh to the eleventh period highlights a vibrant market and the capability of the supply chain system to expand effectively.

Table II: Comparative simulation values for the revenue-sharing contract model.

| Increment in sales volume | 0 | 10 | 20 | 30 | 40 |
|---|---|---|---|---|---|
| Increment in profit for supply chain enterprises | 0.105 | 0.082 | 0.081 | 0.073 | 0.072 |
| Increment in profit for manufacturing enterprises | 0.158 | 0.132 | 0.179 | 0.156 | 0.165 |

The data presented in Table II reveals different trends in profit increments for supply chain enterprises and manufacturing enterprises under varying increments of sales volume. As the increment in sales volume increases from 0 to 40, the profit increment for supply chain enterprises gradually decreases from 0.105 to 0.072, exhibiting a decreasing trend. Specifically, the profit increment for supply chain enterprises is 0.082 at a revenue increment of 10, 0.081 at 20, 0.073 at 30, and finally decreases to 0.072 at 40. In contrast, the profit increments for manufacturing enterprises display some volatility but overall also show a downward trend. At an increment in sales volume of 0, the profit increment for manufacturing enterprises is 0.158. As the increment in sales volume increases, the profit increment is 0.132 at 10, 0.179 at 20, 0.156 at 30, and 0.165 at 40. Despite some fluctuations, the overall trend indicates a decrease in profit increments amidst the fluctuations.



a) b)

Figure 4: Trends in purchasing power and system development with revenue-sharing model.

Fig. 4 a shows that under the revenue-sharing contract model, profits for both supply chain and manufacturing enterprises increase markedly over time. Specifically, profits for supply chain enterprises escalate from zero to 58 by the tenth period, and for manufacturing enterprises from zero to 37 in the same timeframe. In contrast, in an unchanged scenario, both types of enterprises see a more modest profit growth to 14 by the tenth period. Fig. 4 b illustrates that under the revenue-sharing model, profits for supply chain enterprises rise from zero to 90 by the eleventh period, while manufacturing enterprises see an increase from zero to 53. Under the unchanged scenario, both reach a profit of only 25 by the eleventh period. Overall, the revenue-sharing contract model significantly boosts profit growth compared to the unchanged scenario, with supply chain enterprises particularly benefiting from a rapid profit increase from the sixth period onward. In terms of development level, this model also substantially enhances profit growth for both enterprise types.

Table III: Comparative simulation values for the quantity flexibility contract model.

| Information flow and technical support level | 0 | 0.2 | 0.4 | 0.6 | 0.8 |
|---|---|---|---|---|---|
| Increment in expected purchase quantity | 0.1 | 0.12 | 0.14 | 0.19 | 0.05 |
| Increment in expected sales quantity | 0.11 | 0.22 | 0.24 | 0.26 | 0.3 |

According to the data in Table III, under the quantity flexibility contract model, both the expected purchase quantity and expected sales quantity show increments as the level of information flow and technical support increases. Specifically, when the level of information flow and technical support is at 0, the increment in expected purchase quantity is 0.1 and the increment in expected sales quantity is 0.11. As the level of information flow and technical support increases to 0.2, the increment in expected purchase quantity rises to 0.12, and the increment in expected sales quantity increases to 0.22. Further increases in the level of information flow and technical support to 0.4 and 0.6 result in increments in expected purchase quantity of 0.14 and 0.19, respectively, and increments in expected sales quantity of 0.24 and 0.26, respectively. However, when the level of information flow and technical support reaches 0.8, the increment in expected purchase quantity decreases to 0.05, while the increment in expected sales quantity continues to increase to 0.3.

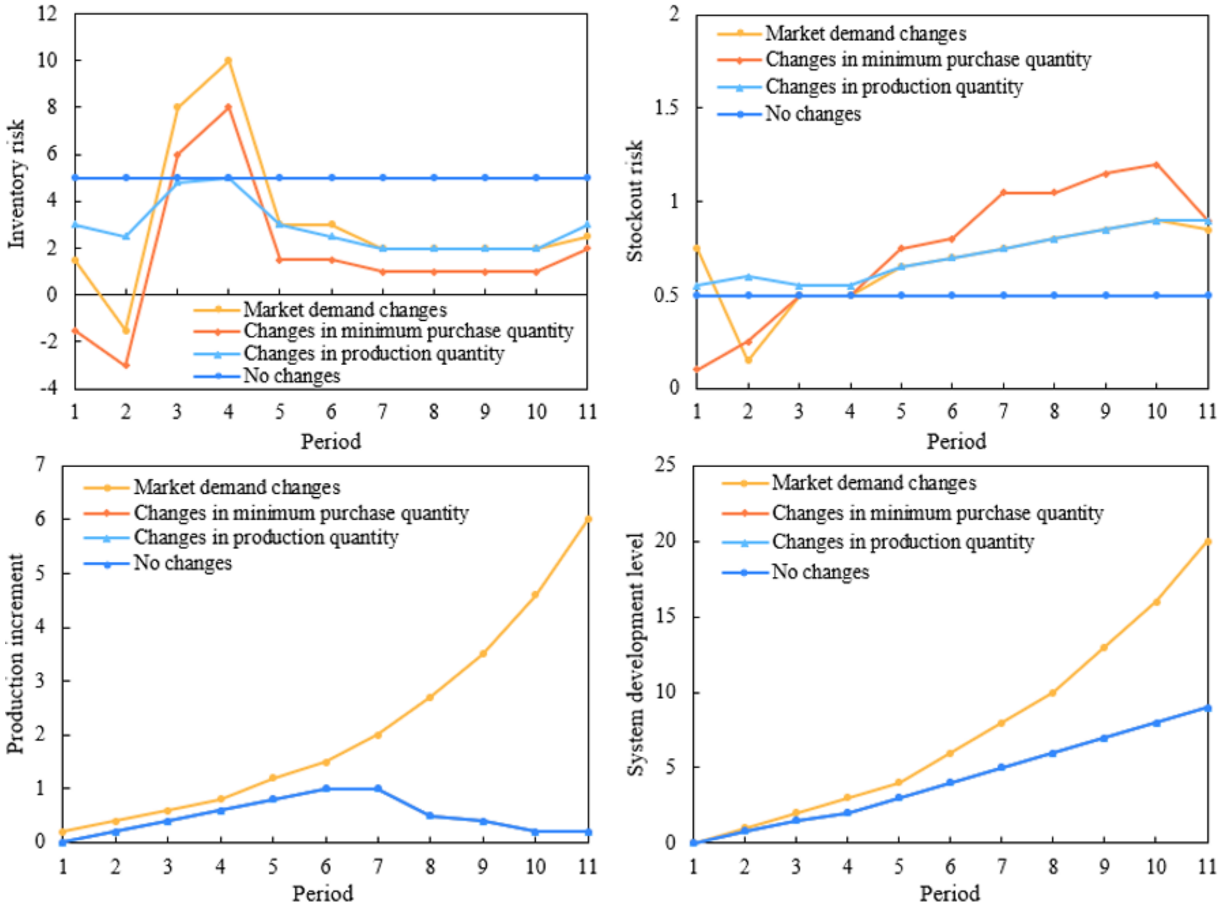


Figure 5: Trends in inventory risk, stockout risk, production increment, and development level under the quantity flexibility contract model.

Fig. 5 shows varied trends in inventory risk, stockout risk, production increment, and development level under the quantity flexibility contract model. Inventory risk spikes in periods 3 and 4 to levels of 8 and 10, influenced by market demand and minimum purchase requirements. Meanwhile, production quantity gradually increases from 3 to 5 before stabilizing.

Under unchanged conditions, inventory risk stays constant and stockout risk remains at 0.5, despite gradual increases in market demand (0.75 to 0.85), minimum purchase (0.1 to 1.2), and production changes (0.55 to 0.9). From periods 1 to 11, the production increment steadily climbs from 0.2 to 6, with the lowest procurement and peak production reaching 1.5, then decreasing back to 0.2; a similar peak at 1 is observed in the unchanged scenario. By the 11th period, the level of development has significantly risen from 0 to 20, with both the lowest procurement and production quantities increasing to 9, matching the growth observed under static conditions.

The analysis indicates that over time, the quantity flexibility contract model differentially impacts inventory risk, stockout risk, production increment, and development level. Initially, inventory risks increased due to substantial demand fluctuations and minimum procurement requirements but stabilized as production adjustments were gradually implemented, highlighting the importance of flexible production in the early stages of the supply chain. Due to the continuous increase in demand and procurement, stockout risks also rose, and the production growth did not entirely offset this increase, suggesting the need for better demand forecasting and production planning. Under this model, driven by changes in market demand, both production and development levels exhibited significant growth, indicating that both production capacity and demand were effectively enhanced. However, careful production management is required in later stages to prevent overproduction and resource waste.

## 5. CONCLUSION

This study explores optimization strategies for integrated supply chains and manufacturing management using system dynamics, revealing key insights across three contractual collaboration models: wholesale price, revenue-sharing, and quantity flexibility. The analysis shows that while the wholesale price model ensures stable system development, it lacks flexibility and may result in uneven benefit distribution. The revenue-sharing model promotes collaborative cooperation, improving system efficiency and equitable benefit sharing. The quantity flexibility model effectively manages demand fluctuations, minimizes inventory and stockout risks, and maintains a balance between production increments and development levels. Simulation results illustrate significant interactions and dynamic changes within the system under each model, allowing enterprises to predict performance and devise more effective strategies. Experimental results indicate that the revenue-sharing model significantly enhances purchasing power and system development, whereas the quantity flexibility model reduces risks and maintains production balance.

However, the study's limitations include the system dynamics model's reliance on specific assumptions that may not capture real-world complexities, and the simulation results are constrained by model parameter settings. Future research could improve the model's accuracy and applicability by incorporating real data and advanced algorithms, extending the scope to various industries, and exploring real-time data and dynamic optimization techniques for better supply chain and manufacturing management.

## ACKNOWLEDGEMENTS

This paper was supported by Project of Social Science Foundation of Jiangsu Province (Grant No.: 23GLD002); Talent Development Special Project of Jiangsu Social Science Application Research Excellence Project (Grant No.: 22SRC-12 and 22SRB-05); Education Science Planning Project of Jiangsu Province (Grant No.: C/2023/01/126); Chuzhou University Scientific Research Start-up Fund Project (Grant No.: 2023qd62).

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