Scalable Computing: Practice and Experience, ISSN 1895-1767, http://www.scpe.org
© 2024 SCPE. Volume 25, Issues 6, pp. 5365–5371, DOI 10.12694/scpe.v25i6.3380

DECISION-MAKING OPTIMIZATION OF CROSS-BORDER E-COMMERCE SUPPLY CHAIN BASED ON GENETIC SIMULATED ANNEALING ALGORITHM

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Abstract. This paper mainly studies the collaborative operation of a cross-border e-commerce supply chain composed of manufacturers, e-commerce platforms and foreign warehouses. Firstly, the decision models of transnational e-commerce enterprises based on decentralized, centralized, and hybrid modes are established. The sensitivity of the contract and each determining variable is analyzed using the simulation method. Through the joint contract of "revenue sharing + volume discount," the production efficiency of the enterprise and the logistics service of the international warehouse can be improved. The genetic algorithm combined with simulated annealing was adopted. Finally, a concrete example is given to verify the feasibility of the proposed method. The results show that the member departments can work together better under centralized decision-making compared to the decentralized management mode. Manufacturers to increase production capacity and improve the level of logistics services in overseas warehouses will help improve the profitability of cross-border e-commerce.

Key words: Transnational e-commerce; Cooperation contract; Benefit sharing + quantity discount; Genetic algorithm; Simulated annealing algorithm

AMS subject classifications.

1. Introduction. Driven by the "Belt and Road" Initiative, China's cross-border e-commerce has been developing rapidly, but its position in the international market still needs further improvement. From supply to consumption, it includes many complex and scattered subjects. In addition, customers have increasingly high expectations for goods and logistics, making it difficult for a single enterprise to achieve a complete transnational trade. Businesses are looking for new ways to grow. It is necessary to establish a multinational e-commerce supply chain with cross-industry, cross-region, cross-border information collaboration, benefit sharing and efficient collaboration based on core enterprises and multi-subject participation.

What customers value most is the guarantee of authenticity. Favorable price, rich product variety, distribution speed, product quality, price, distribution speed, product quality, price and distribution speed are all critical factors affecting customer satisfaction. Literature [1] has conducted in-depth research on the synergy mechanism of the supply chain. The researchers studied low-carbon supply chains' price and emission reduction decisions based on customers' sales channel preferences. The company provides a cost-sharing contract for the return of profits to customers and the reduction of emissions. Literature [2] intends to study the two-level supply chain collaboration model composed of manufacturers and retailers from product quality, price, distribution time, etc. The author constructs a revenue-sharing mechanism to achieve Pareto optimization. Literature [3] studies the secondary supply chain collaboration of a single supplier and a double retailer. It reveals that the supply chain based on behavioral considerations cannot cooperate with the bulk discount contract and introduces it into the fixed cost contract.

This paper uses the contract model combining revenue sharing and volume discount to study the cooperative operation of a transnational e-commerce supply chain. Different from the existing studies: First, the collaborative operation problem of "producer-B2C cross-border e-commerce platform - overseas warehouse", which is more in line with the operation practice of cross-border e-commerce enterprises, is studied. The second is to incorporate endogenous factors, such as production capacity and logistics services, into the demand analysis of transnational goods [4]. Third, different from the conventional revenue-sharing contract, the introduction of a remuneration factor. Then, reward the supply chain members based on the increase of market sales brought

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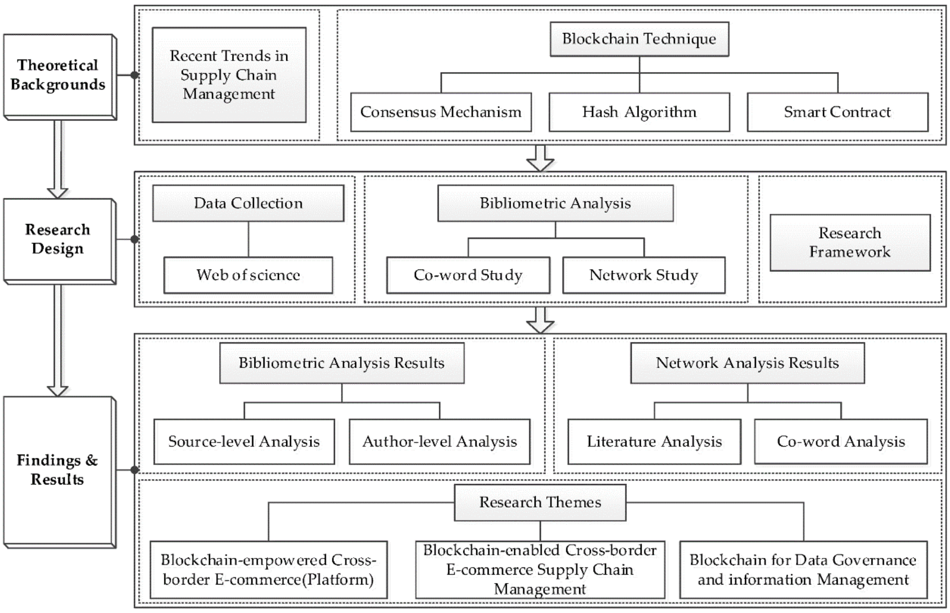

Fig. 2.1: *Concept diagram of cross-border e-commerce supply chain coordination operation.*

by the improvement of business level, further strengthening the effect of the incentive [5]. Then, this paper establishes the mathematical expression of the cooperative relationship and the optimal decision method. An example verifies the correctness of the method.

2. Research on collaborative decision-making mechanism of supply chain under a transnational e-commerce environment. With the vigorous development of international trade, this logistics method of foreign warehouses also comes into being. Cross-border e-commerce platforms store goods in a third-party warehouse and then sort, package and distribute them according to the order's requirements. Because it is a foreign warehouse, it often keeps its logistics service level at a medium or low level to reduce logistics costs [6]. At the same time, the low level of logistics service will also have a particular impact on customers' shopping feelings. In the same case, to maximize their profits, manufacturers will maintain a specific capacity for product quality without affecting the expansion of enterprises [7]. Its conceptual pattern is shown in Figure 2.1.

The cross-border e-commerce platform, the manufacturer and the overseas warehouse should form a long-term and stable partnership, and the three are committed to maximizing the overall profit of the cross-border e-commerce supply chain, sharing revenue and taking risks [8]. The company selects the best capacity level based on the order information [9]. It determines the best retail price for goods based on the volume of orders and encourages producers to increase production capacity by sharing profits with companies. The warehouse was responsible for storage and management. Once the customer places an order in the location of a foreign warehouse, the warehouse will deliver the goods to the customer in a timely, accurate and intact manner following the requirements of the order [10]. Discount them according to the quantity of logistics services to ensure maximum profit. They make reasonable profit distribution by cooperating with overseas warehouses. Third, the optimal product price is formulated according to the principle of maximizing the profit of the supply chain based on ensuring the manufacturer's best production capacity and the overseas warehouse's optimization.

3. Determination of partnership and multi-criteria modeling. Assume that the virtual enterprise consists of n various partners. The first candidate partner, $H = \{h_i \mid i \in [1, n]\}$, represents all n working sets of the virtual enterprise. $S_i = \{s_{ij} \mid j \in [1, m_i]\}$ $(i = 1, 2, \ldots, n)$ represents a group of candidates that can meet the requirements of project $h_i.m_i$ is the number of candidate companies that can meet the requirements of the project h_i. The performance indicators required by enterprise s_{ij} to achieve operation h_i mainly include t_{ij} (time), g_{ij} (quality), E_{ij} (inherent cost), c_{ij} (reliability) and $\varepsilon_{ijj'j'}$ (connection cost). Where T, G, E, C, P stands for total time, quality, inherent costs, reliability and connection costs. The optimal problem of this problem is the selection of enterprise $Y = \{y_1, y_2, \ldots, y_n\}$. The following purposes can now be achieved: $\min T; \max G; \min E, \max C; \min P$. This paper builds the following model based on these multi-objective optimization problems:

$$\min U = \lambda_1 \sum_{i=1}^{n}\sum_{j=1}^{m_i} \frac{t_{ij}}{t_{\max}}\chi_{ij} + \lambda_2 \sum_{i=1}^{n}\sum_{j=1}^{m_i}\left(1-\frac{g_{ij}}{g_{\max}}\right)\chi_{ij} + \lambda_3 \sum_{i=1}^{n}\sum_{j=1}^{m_i}\frac{e_{ij}}{e_{\max}}\Bigg)\chi_{ij}+$$

$$\lambda_4 \sum_{i=1}^{n}\sum_{j=1}^{m_i}\left(1-\frac{c_{ij}}{c_{\max}}\right)\chi_{ij} + \frac{1}{2}\lambda_5 \sum_{i\neq i'}\sum_{j\neq j'}\frac{\varepsilon_{iji'j'}}{\varepsilon_{\max}}\chi_{ij}\chi_{i'j'}$$

$$st \sum_{k=1}^{5}\lambda_k = 1, g_{\max} = \max_{i\in[1,n]} g_i, e_{\max} = \max_{i\in[1,n]} e_i,$$

$$c_{\max} = \max_{i\in[1,n]} c_i, t_{\max} = \max_{i\in[1,n]}, \varepsilon_{\max} = \max_{i\in[1,n]} \varepsilon_i$$

$$\chi_{ij} = \begin{cases} 1, & s_{ij} \text{ in} \\ 0, & \text{otherwise} \end{cases}$$

λ_k focus on enterprise composition, using the expert scoring method, analytic hierarchy process, and entropy method to determine the weight.

3.1. Genetic algorithm and simulated annealing algorithm. Genetic algorithm (GA) simulates the mechanism of natural selection and gene evolution in nature. The method has global adaptability and randomness [11]. A series of gene manipulations such as selection, hybridization and variation are carried out on the existing population to form a new population generation Using the population search method. Step by step, the population evolves to a stage that contains or approximates the optimal solution [12]. This paper presents a multi-objective optimization method based on a genetic algorithm. Implicit parallel and global search are the two most prominent features. This method provides a general framework for solving optimal problems. The type of question is very robust.

The simulated annealing (SA) algorithm is a new stochastic optimization method developed based on Monte Carlo iteration. The starting point of this study is from two aspects. That is the similarities between the physical annealing and composite processes. A probabilistic jump feature based on Metropolis sampling is used to search a high-temperature point randomly. Sampling is repeated at continuously reduced temperatures until the overall optimization result is obtained.

3.2. Combination of genetic algorithm and simulated annealing algorithm. Genetic and simulated annealing algorithms are optimized based on random distribution mechanisms. The difference is that it gives a mutation that changes over time and eventually tends to 0. Therefore, the algorithm can effectively prevent the occurrence of local minima and make the algorithm tend to global optimization [13]. The idea of "survival of the fittest" is used to carry out genetic calculations on the population to achieve the optimal solution. The combination of these two methods can make the optimization work more fulfilling. The optimization effect of the algorithm in the overall and partial importance is improved. The steps of combining genetic algorithm and simulated annealing algorithm are:

1. The initial temperature of the simulation t_0 is given, and $k = 1$.
2. Binary coding expresses each gene as shown in Figure 3.1. The coding length is $D = \sum_{i=1}^{n} m_i$, and each χ_{ij} in the code string is the identity of the candidate partner. $\chi_{ij} = 0$ means no choice [14]. Assume that the population number is W, and W binary coding sequences $\sum_{j=1}^{m_i}\chi_{ij} = a_i (i = 1, 2, \ldots, n)$ are randomly generated in the population to satisfy the original population. Here a_i represents the number of firms that can choose between different firms, $a_i \in (1, 2, \ldots, m_i)$.

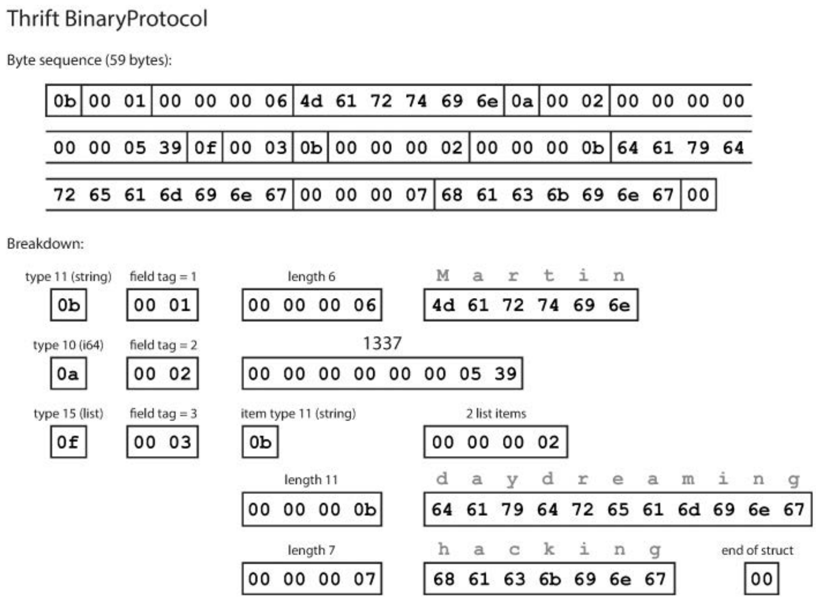

Fig. 3.1: *Binary encoding.*

3. Individual assessment within the population: Ranking from highest to lowest according to the degree of fitness of W individuals in the same generation population. With $i(i = 1, 2, \ldots, W)$ as the number, the adaptation value of i is:

$$y_i = \frac{2i}{W(1+W)}$$

4. Genetic calculations on individuals in populations:
   (a) Selective operation. The ratio selection operator is introduced. When the population size is W, individual X_i with y_i adaptability is likely to choose to be the offspring.

   $$\Gamma_i = y_i / \sum_{i=1}^{W} y_i$$

   (b) Interactive operation. Individual X_1 and X_2 in the paternal line cross with a probability of Γ_e to produce the next generation by crossing two parents.
   (c) Variable operation. Each site of individual X_i changes with mutation probability Γ_m, that is, an arbitrary site in Γ_m changes the original value. In this operation to determine whether $\sum_{j=1}^{m_i} \chi_{ij} = a_i (i = 1, 2, \ldots, n)$ is true, if not, restart the encoding string. The selection, crossover, or mutation steps are repeated until the resulting individual meets a specific limit.
5. Put forward the optimal reservation scheme.
6. Introduce simulated annealing operations to each individual in the group:
   (a) A new factor $w'(k), w'(k) = w(k) + \delta$ is generated by the state-generating function of SA, where $\delta \in (-1, 1)$ is a random disturbance.
   (b) The difference ΔE between the value of the index function calculated by $w'(k)$ and the value calculated by $w(k)$ is obtained.
   (c) Calculate the receiving possibility $\Gamma_c = \min\left[1, \exp\left(-\Delta E / t_k\right)\right]$.
   (d) If it is $\Gamma_c > \text{random}[0, 1)$, then choose $w(k) = w'(k)$. And the same is true for $w(k)$.
   (e) Propose the optimal reservation scheme.

Table 4.1: Comparison of optimal results.

Argument	p_k	ω_z	ω_l	Q_2	π_k	π_z	π_l	π
Decentralized decision making	94.58	8.44	1.95	341.81	11211.45	6017.63	4758.05	21987.13
Centralized decision	79.76	15.22	6.75	527.08			25261.84	

(f) Perform annealing using the annealing function $t_{k+1} = at_k$, where $a \in (0, 1]$ is the annealing rate.

7. Determine whether the end condition of the genetic algorithm operation is confirmed. If it is not valid, the process goes to the 3). Otherwise, it goes to the 8).
8. The best individual obtained by the genetic performance is decoded to obtain the final best optimization effect.

4. Collaborative decision-making mechanism of supply chain in transnational e-commerce. According to the field investigation and expert

$$p_z = 30, p_l = 20,$$

advice, the relevant parameter is set as $C_z = 6, C_k = 8,$. The research has analyzed

$$\beta = 1200, n = 4.5,$$
$$\gamma_z = 20, \gamma_l = 15$$

the sensitivity of commodity price, quality and logistics service and found that customers attach the most importance to product quality, followed by price, and then logistics service, so $b_1 = 10, b_2 = 4, b = 2$ is set.

The above parameters are brought into the distributed and centralized optimization decision-making mode in the first step, and the optimization effect is obtained (Table 4.1). Distributors' pricing will increase, and manufacturers' production capacity will decrease, leading to the decline of foreign warehouses' logistics service level and product sales decline [15]. In addition, the total revenue of transnational e-commerce enterprises in the distributed decision-making mode is 3274.72 lower than that in the centralized mode, indicating that enterprises can better collaborate in the centralized mode.

Under the second combination contract, it can be seen from Figures 4.1, 4.2 and 4.3 that the subsidies of transnational e-commerce platforms to manufacturers will be higher, while the subsidies of manufacturers to cross-border e-commerce will also be higher, but the range shall not be greater than 0.0165 . Otherwise, the synergies of the contract will be lost [16]. If a lower incentive is provided to the overseas warehouse, the preferential margin of the number of logistics services obtained from the overseas warehouse will be less than 0 . Its amplitude must not be greater than 0.010o. Otherwise, this July will not be accepted. $\theta_z, \delta_z, \theta_l$ and δ_l are set to (o.7, 0.0125, 0.9, 0.0076) respectively in Figure 4.3. The sensitivity of ω_z and ω_l was analyzed [17]. The results show that manufacturers reward their sales growth under the contract model according to the capacity increase. It can reduce enterprises' incomes due to capacity improvement [18]. The composite contract proposed in this project can balance the interests of transnational e-commerce and foreign warehouses, and the contract optimization effect will be more significant when the ω_l value is more prominent.

5. Conclusions and Suggestions.

1. Unlike decentralized decision-making, various enterprise departments can collaborate more efficiently.
2. Manufacturers improve production capacity, and overseas warehouses improve their logistics service level, which helps to improve the profits of transnational e-commerce.
3. Through the joint contract of "revenue sharing + volume discount," the production capacity of the enterprise and the logistics service quality of the enterprise's overseas warehouse can be significantly improved, thus reducing the double marginal effect of the enterprise.

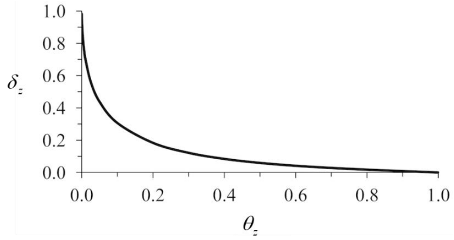

Fig. 4.1: Relationship between θ_z and δ_z.

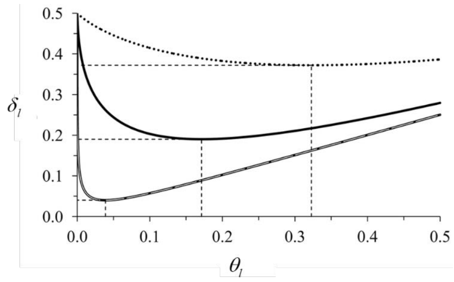

Fig. 4.2: The relationship between θ_l and δ_l.

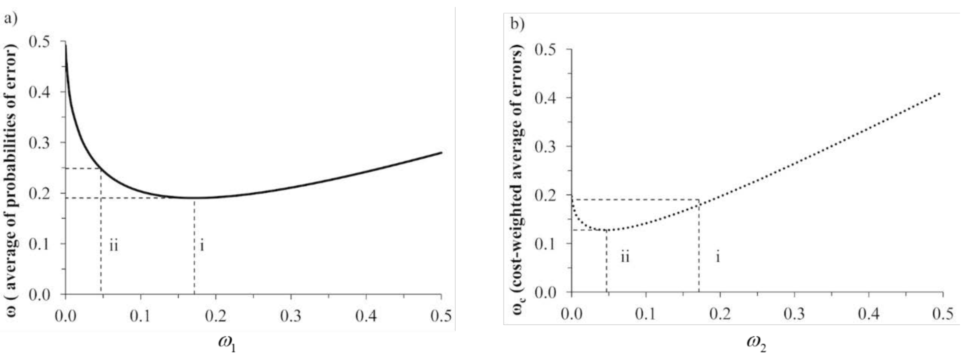

Fig. 4.3: Comparison of the impact of coordination ω_z and ω_l decentralization on cross-border ecommerce supply chain.

In this article, there are the following proposals.

Cross-border e-commerce platforms must make full use of their advantages. The remote cross-border e-commerce platform should fully mobilize the production capacity of enterprises, encourage enterprises to improve their capabilities, and encourage them to improve the quality of their logistics services in the international market. This brings high-quality products and high-quality logistics services to foreign customers. Revenue-sharing mechanisms, technical support, and other means ensure that the rights and interests of all participants are fully protected to maintain the long-term and smooth operation of the cross-border e-commerce supply chain.

The transformation from traditional foreign warehouse enterprises to modern logistics enterprises must be completed quickly. Ocean warehouses should introduce intelligent and automated logistics technology. On the one hand, strengthen the warehouse management and realize the timely sharing of the warehouse information. This prevents the loss of the goods in storage. At the same time, it can also improve the classification and transportation time of goods, ensuring the real-time update and traceability of logistics information. In this way, we have become a modern logistics service company that can provide professionalism, flexibility and efficiency.

Manufacturers should continue to improve their level of intelligent production. Manufacturers should be committed to intelligent transformation, introducing intelligent robots, and increasing industrial automation to ensure the best production process and zero-defect production. Integrate its resources and integrate more innovative elements into its products to meet the individual needs of foreign customers.

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Edited by: Hailong Li
Special issue on: Deep Learning in Healthcare
Received: Feb 18, 2024
Accepted: Apr 7, 2024