Optimization of Cross-border E-commerce Supply Chain based on Fuzzy Control Algorithm in Digital Marketing

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Abstract. Based on fuzzy control algorithm, this paper proposes a new research framework for the optimization of cross-border e-commerce supply chain. Firstly, the challenges of cross-border e-commerce supply chain are analyzed, including complex international logistics, uncertain market demand and diversified regulations and policies. Then, the existing optimization methods are reviewed, and they are found to have some limitations. In order to overcome these problems, fuzzy control algorithm is introduced, and its theoretical basis and application are discussed in detail. Based on fuzzy control algorithm, a cross-border e-commerce supply chain optimization model is designed and simulated. The model covers key strategies such as dynamic inventory management, dynamic distribution and dynamic pricing, and demonstrates the potential of fuzzy control algorithm in supply chain optimization through the application of mathematical modeling and simulation data. The empirical results show that the strategy based on fuzzy control algorithm can significantly improve the operational efficiency of supply chain and reduce the total cost. However, it is also found that there are some problems in the empirical research, including the difficulty of data collection and the complexity of the model. In spite of this, fuzzy control algorithm still shows its potential in cross-border e-commerce supply chain optimization, and has feasibility and applicability. The research results provide an important reference for further exploration of fuzzy control algorithm in supply chain management. In this paper, the optimization of cross-border e-commerce supply chain is deeply studied and a new idea based on fuzzy control algorithm is proposed. The research results are of great significance for improving the efficiency and competitiveness of cross-border e-commerce supply chain, and provide useful enlightenment for academic research and practice in related fields.

Keywords: Cross-border e-commerce; Supply chain optimization; Fuzzy control algorithm; Empirical research; Strategy design; fuzzy control algorithm in Digital Marketing
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1 INTRODUCTION

In today's world of globalization and digitalization, cross-border e-commerce has become an important part of global trade, bringing unprecedented convenience to enterprises and consumers. However, at the same time, it also brings a series of complex challenges, especially in supply chain management. These challenges include: dealing with large amounts of complex, uncertain and dynamic information; Coordinate a diversified supplier and logistics network on a global scale; To meet the increasing expectations of consumers. How to effectively manage and optimize the cross-border e-commerce supply chain and improve the efficiency and flexibility of the supply chain has become an important issue faced by today's enterprises.

In the study of fuzzy control algorithm optimization of cross-border e-commerce supply chain, Bai et al. proposed a dynamic risk assessment model based on fuzzy logic to deal with supply chain risk in uncertain environment [1]. Chen et al. focused on cross-border e-commerce supply chain risk management and proposed a fuzzy control model to deal with risks and challenges [2]. Fan et al. conducted fuzzy risk assessment of cross-border e-commerce supply chain through cloud model [3]. In addition, Li et al. established a dynamic pricing model using fuzzy logic to optimize pricing strategies in cross-border e-commerce supply chains [6]. In terms of performance evaluation, Luo et al. conducted fuzzy analysis of comprehensive evaluation of cross-border e-commerce supply chain to evaluate the comprehensive performance of supply chain [8]. Wang and Gao proposed a fuzzy decision model to evaluate the performance of cross-border e-commerce supply chains [11]. For partner selection and decision support, Xu et al. proposed a fuzzy group decision model for partner selection in cross-border e-commerce supply chain [12]. In addition, Ma et al. used fuzzy decision support system in cross-border e-commerce supply chain risk assessment [9].

Traditional supply chain management and optimization methods, such as linear programming and network optimization, have improved the efficiency of supply chain to some extent, but there are still great challenges in dealing with the complexity and dynamics of cross-border e-commerce supply chain. Especially in dealing with uncertainty and fuzziness in supply chain, these methods are often inadequate. Therefore, it is of great theoretical and practical significance to find a new optimization method to deal with these problems effectively for improving the effect of supply chain management.

In recent years, fuzzy control algorithms have attracted more and more attention from researchers and practitioners because of their advantages in dealing with uncertainty and fuzziness. Fuzzy control algorithm can deal with the complex system containing uncertainty and fuzziness and make the control effect of the system more stable and accurate. [5]Therefore, applying fuzzy control algorithm to the optimization of cross-border e-commerce supply chain may become a new and effective optimization method.Digital marketing relies heavily on targeting the right audience and delivering personalized messages. Fuzzy control algorithms can analyze customer data, behavior patterns, and preferences to identify target segments more effectively. By considering the fuzziness in customer preferences, the algorithm can adapt and refine marketing campaigns to better match the needs and interests of individual customers, resulting in higher conversion rates and customer satisfaction.

The main purpose of this paper is to explore how to apply fuzzy control algorithm to the optimization of cross-border e-commerce supply chain, and propose a new supply chain optimization model and strategy. The effectiveness and applicability of this new optimization method are verified by theoretical analysis and empirical research. The main research contents of this paper include: in-depth analysis of the challenges of cross-border e-commerce supply chain and the advantages of fuzzy control algorithm; Construction of supply chain optimization model based on fuzzy control algorithm; An empirical study was conducted to analyze the optimization effect of the model. Put forward the strategy of supply chain optimization, analyze the implementation effect and feasibility of the strategy.

In general, this paper aims to provide a new perspective and tool for theoretical research and practical application, improve the management efficiency and flexibility of cross-border e-commerce supply chain, and promote the theoretical development and practical innovation of supply chain management.

The main content of this study is the optimization of cross-border e-commerce supply chain based on fuzzy control algorithm. In order to achieve this goal, the following aspects of research will be carried out. First, the challenges facing cross-border e-commerce supply chains will be analyzed in depth. These challenges include complex international logistics, uncertain market demand, and diversified regulations and policies. A thorough understanding of these challenges provides a better grasp of the nature of the problem and provides a theoretical basis for subsequent research. Secondly, we will review the existing supply chain optimization methods and find that they have some limitations. On this basis, fuzzy control algorithm is introduced as a new research direction. Fuzzy control algorithm has the advantages of strong adaptability and better processing ability to uncertainty, so it has the potential to be applied in the optimization of cross-border e-commerce supply chain. Next, the theoretical basis and application of fuzzy control algorithm will be discussed in detail. This includes the basic concepts of fuzzy set and fuzzy logic, as well as the principle and working mode of fuzzy control algorithms. At the same time, the existing applications of fuzzy control algorithms in supply chain management will be investigated in order to better understand their potential role in cross-border e-commerce supply chain optimization. Based on the understanding of the theoretical basis and application of fuzzy control algorithm, an optimization model of cross-border e-commerce supply chain based on fuzzy control is designed and constructed. The model will take into account key strategies such as dynamic inventory management, dynamic distribution and dynamic pricing, and the model will be analyzed and the expected effect evaluated through the application of mathematical modeling and simulation data. Through simulation experiments, the performance of the model can be evaluated, and the effectiveness and feasibility of fuzzy control algorithm in supply chain optimization can be verified. Finally, an empirical study on the optimization of cross-border e-commerce supply chain based on fuzzy control will be conducted. This involves the identification of empirical study design, data sources and collection methods. By collecting the actual cross-border e-commerce supply chain data, we can verify the application effect of fuzzy control algorithm in the actual situation, further analyze the results, find the existing problems and put forward suggestions for improvement.

In summary, the content of this study includes challenges and opportunities of cross-border e-commerce supply chain, theoretical basis and application of fuzzy control algorithm, design and construction of fuzzy control-based cross-border e-commerce supply chain optimization model, empirical study of fuzzy control-based cross-border e-commerce supply chain optimization, strategy design and feasibility analysis, etc. Through the in-depth discussion of these research contents, the purpose is to propose an effective optimization method to improve the operational efficiency and performance of cross-border e-commerce supply chain. The main structure and content of the study are shown in Figure 1 below.

2 CHALLENGES AND OPPORTUNITIES OF CROSS-BORDER E-COMMERCE SUPPLY CHAIN

2.1 Challenges Of Cross-Border E-Commerce Supply Chain Optimization

Cross-border e-commerce supply chain optimization faces many challenges, mainly reflected in the following aspects.

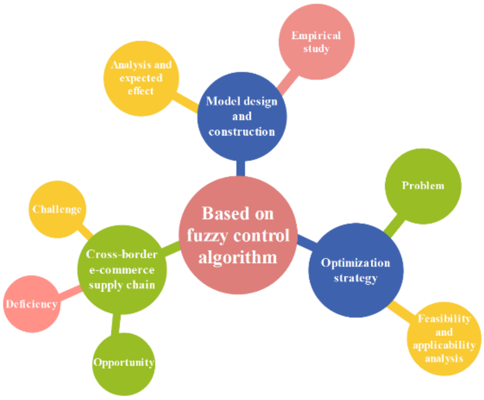

Figure 1: Main research content and structure.

First, information complexity and dynamics are challenges. As multiple countries and regions are involved, the information processing of cross-border e-commerce supply chains needs to take into account various factors, such as different languages, currencies, laws and policies, as well as complex tax and tariff regulations. In addition, due to the dynamic changes of market demand, exchange rate, raw material price and other factors, the operation of the supply chain needs to be adjusted and optimized in real time, which puts forward higher requirements for information processing and decision-making.

Second, coordination of global suppliers and logistics networks is a major challenge. Cross-border e-commerce involves enterprises, suppliers, warehousing and logistics service providers distributed all over the world. How to effectively coordinate these resources and ensure the smooth operation of the supply chain is a key issue to optimize the supply chain.

Moreover, the diversity of consumer needs and the satisfaction of individual needs is another challenge. Cross-border e-commerce consumers come from all over the world, and they have different needs and preferences. [10]How to meet these diverse and personalized needs while ensuring efficiency raises new problems for supply chain management and optimization.

Finally, supply chain risk management is also a challenge. Cross-border e-commerce supply chain involves transnational transportation and transactions, and is vulnerable to natural disasters, policy changes, transaction risks and other factors. How to effectively identify and manage these risks to ensure the stable operation of supply chain is a problem that must be considered in optimizing supply chain.

Despite these challenges, the optimization of cross-border e-commerce supply chains also presents opportunities. With its unique advantages, fuzzy control algorithm provides new possibilities to deal with these challenges. [4] Fuzzy control algorithm can deal with uncertainty and fuzziness, make supply chain management and optimization more accurate and stable, and provide a new tool and method for supply chain optimization.

2.2 Deficiencies of Existing Methods

In the past research and practice, various methods have been tried to optimize the cross-border e-commerce supply chain, including linear programming, network optimization, integer programming, etc. However, these methods have some shortcomings when dealing with the complexity and dynamics of cross-border e-commerce supply chains:

First, the ability to deal with uncertainty and ambiguity is insufficient. Traditional optimization methods are usually based on accurate mathematical models and require explicit parameter values.[7] However, many factors in the cross-border e-commerce supply chain, such as market demand, supplier's supply ability, logistics costs, etc., are uncertain and fuzzy. This limits the effectiveness of these methods in practical applications.

Second, the lack of adaptability to dynamic changes. The traditional optimization method is usually based on static model, which is difficult to adapt to the dynamic change of supply chain. [13]The cross-border e-commerce supply chain needs to respond to the changes of market demand, supplier capability and logistics status in real time, which puts forward higher requirements for the adaptability of optimization methods.

Third, the ability of global optimization is insufficient. Due to the limitation of computational complexity, traditional optimization methods can only carry out local optimization, and it is difficult to achieve global optimization. All links involved in the cross-border e-commerce supply chain are interrelated. Only by achieving global optimization can the efficiency and flexibility of the supply chain be improved to the maximum extent.

In general, due to these deficiencies, traditional optimization methods are difficult to meet the needs of cross-border e-commerce supply chain optimization. This requires finding new optimizations to address these challenges.

2.3 Opportunities Brought by Fuzzy Control Algorithm

When facing the challenge of cross-border e-commerce supply chain optimization, the introduction of fuzzy control algorithm provides a new perspective and opportunity. Fuzzy control algorithm is derived from fuzzy logic theory, which is a decision method that can deal with uncertainty and fuzziness. Compared with traditional optimization methods, fuzzy control algorithm has unique advantages in the following aspects:

- Dealing with uncertainty and fuzziness: fuzzy control algorithm can process and analyze fuzzy, inaccurate or incomplete information, and better deal with uncertainty and fuzziness in cross-border e-commerce supply chains.
- Adapt to dynamic changes: fuzzy control algorithm can not only deal with static decision-making problems, but also adapt to dynamic environmental changes. It can analyze and process the input information in real time, so as to realize the real-time optimization of supply chain.
- Global optimization: By constructing fuzzy control rules, fuzzy control algorithm can optimize the supply chain from a global perspective and improve the overall efficiency and flexibility of the supply chain.
- Simple and easy to use: compared with traditional optimization methods, fuzzy control algorithm is more intuitive and easy to understand. It can directly use the language described rules to make decisions, greatly simplifying the process of model construction and optimization.

Therefore, fuzzy control algorithm provides new possibilities and opportunities for cross-border e-commerce supply chain optimization. By introducing fuzzy control algorithm, it is possible to construct an optimization model which is more suitable for the characteristics of cross-border e-commerce supply chain and improve the management efficiency and flexibility of supply chain. The unique advantages of fuzzy control algorithm are shown in Figure 2 below:

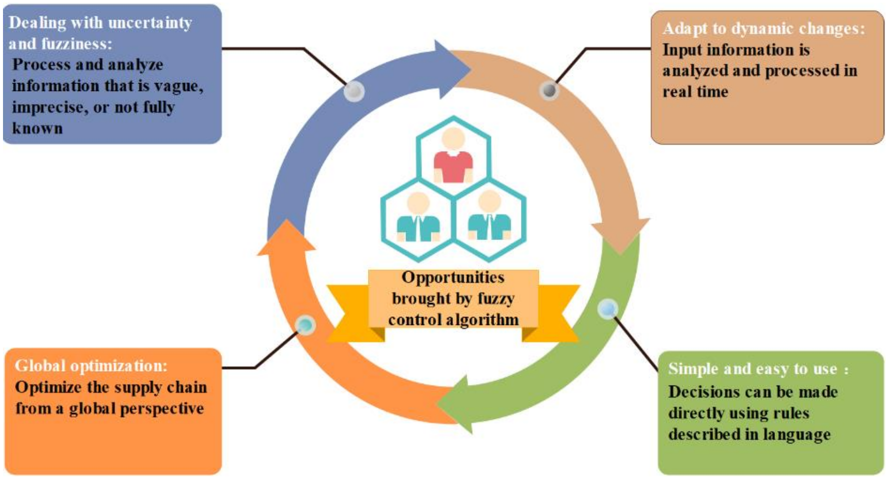

Figure 2: Unique advantages of fuzzy control algorithm.

3 THEORETICAL BASIS AND APPLICATION OF FUZZY CONTROL ALGORITHM

3.1 Basis of Fuzzy Sets and Fuzzy Logic

Fuzzy control algorithm is based on fuzzy logic and fuzzy set theory. Fuzzy logic was first proposed by Zadeh in 1965. Compared with traditional binary logic, fuzzy logic has significant advantages in dealing with uncertainty and fuzziness.

- Fuzzy set: Fuzzy set is a new set concept proposed by Zadeh on the basis of fuzzy logic. Different from the traditional set concept, the elements of fuzzy set are not only in two states of "belonging" or "not belonging", but can have certain "membership degree". The value range of membership degree is [0,1], where 0 indicates that the element does not belong to the fuzzy set at all,1 indicates that the element belongs to the fuzzy set completely, and the value between 0 and 1 indicates the degree to which the element belongs to the fuzzy set.
- Fuzzy logic: Fuzzy logic is a multi-valued logic system developed on the basis of fuzzy set theory. The basic idea of fuzzy logic is that in the real world, many things do not have only two "yes" and "no" states, but many states in between. By introducing the concept of membership degree, fuzzy logic can describe these states between "yes" and "no", so as to better deal with the uncertainty and ambiguity in the real world.

The introduction of fuzzy logic and fuzzy set provides a new tool and method for dealing with uncertainty and fuzziness problems, which enables this research to describe and deal with problems in the real world more accurately and comprehensively. Fuzzy logic and fuzzy set are widely used in supply chain management, decision support system, pattern recognition, machine learning and other fields.

3.2 Principle of Fuzzy Control Algorithm

The basic principle of fuzzy control algorithm includes three steps: fuzzy inference, fuzzy inference and defuzzy.

- Fuzzification: Fuzzification is the process of converting input with exact values into fuzzy sets. For example, specific supply chain cost values can be converted into fuzzy sets such as "low", "medium" and "high".
- Fuzzy reasoning: Fuzzy reasoning is the process of reasoning fuzzy input based on fuzzy control rules. Fuzzy control rules usually adopt "if... So..." The formal description of For example, you could have a fuzzy control rule that says, "If supply chain costs are low, increase inventory."
- Defuzzification: Defuzzification is the process of converting the results of fuzzy reasoning into outputs with exact values. For example, the result of fuzzy reasoning "increase inventory" can be translated into a specific amount of inventory increase.

The basic principle of fuzzy control algorithm is shown in Table 1 below:

Step	***Description***
Fuzzification	*The process of converting an input with an exact value into a fuzzy set.*
Fuzzy reasoning	*The process of inferring fuzzy inputs based on fuzzy control rules. Fuzzy control rules adopt "if... So..." The formal description of*
Deblurring	*The process of converting the results of fuzzy inference into outputs with exact values.*

Table 1: Principle of fuzzy control algorithm.

Fuzzification converts the exact value into fuzzy set, fuzzy inference is based on fuzzy control rules, and defuzzification converts the result of fuzzy inference into the output of exact value. These steps together constitute the core principle of fuzzy control algorithm.The work mode of fuzzy control algorithm makes it able to deal with complex problems including uncertainty and fuzziness. At the same time, the form of fuzzy control rules makes it can directly use human experience and knowledge, so that fuzzy control algorithm has the ability of self-adaptation and learning to a certain extent.

In the application of cross-border e-commerce supply chain optimization, fuzzy control algorithm can be used to deal with various uncertainties and fuzziness problems, such as the uncertainty of market demand, the uncertainty of suppliers' supply ability, the uncertainty of logistics costs, etc. Fuzzy control rules can be designed according to the actual situation and demand to achieve effective management and optimization of supply chain.

3.3 Existing Applications of Fuzzy Control Algorithm in Supply Chain Management

Fuzzy control algorithm has been widely used in various fields of supply chain management. Its main applications include inventory management, supply chain risk management, supply chain optimization and so on.

In inventory management, due to the uncertainty of market demand and supplier's supply ability, inventory decision-making is often full of ambiguity. Fuzzy control algorithm can deal with these fuzziness and help enterprises make better inventory decisions. For example, the fuzzy control algorithm can be used to develop a more reasonable inventory strategy according to the fuzzy information of market demand and supplier's supply ability.

Fuzzy control algorithm also plays an important role in supply chain risk management. Supply chain risk usually involves multiple factors, and these factors are often vague and uncertain. Fuzzy control algorithm can help enterprises to analyze these fuzzy risk factors, so as to make better risk management decisions.

In addition, fuzzy control algorithm is also widely used in supply chain optimization. Supply chain optimization involves many decision factors and objectives, which are often fuzzy and contradictory. Fuzzy control algorithm can help enterprises find the best solution among these fuzzy and contradictory factors and objectives and realize the global optimization of supply chain.

In general, the introduction of fuzzy control algorithm for supply chain management has brought brand new methods and tools to solve problems, which is helpful to improve the management efficiency and flexibility of supply chain. The existing application of fuzzy control algorithm in supply chain management is shown in Figure 3 below.

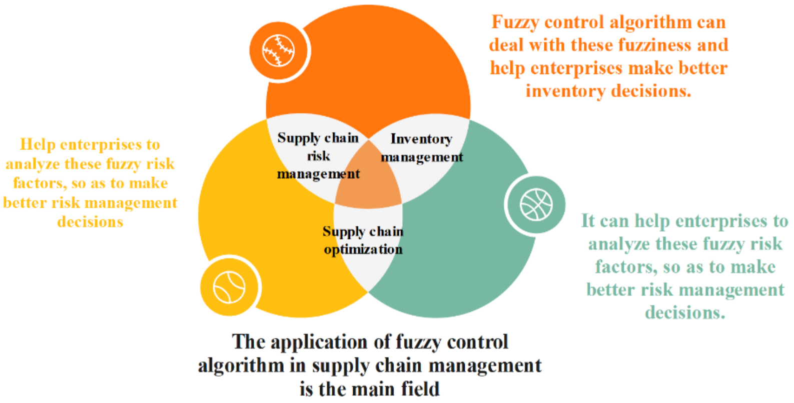

Figure 3: Existing application fields of fuzzy control algorithm in supply chain managemen.

4 OPTIMIZATION MODEL OF CROSS-BORDER E-COMMERCE SUPPLY CHAIN BASED ON FUZZY CONTROL

4.1 Definition of Optimization Problems

In cross-border e-commerce supply chain optimization, the research goal is usually to maximize the overall benefit of the supply chain under the consideration of multiple objectives and constraints. This may include minimizing costs, maximizing benefits, ensuring supply chain stability, etc. This problem can be defined as a multi-objective optimization problem and solved by fuzzy control algorithm.

First, the benefit function of supply chain is defined as follows:

$$E = f(C, R, S)$$

Where, E represents the total benefit of the supply chain, C represents the total cost of the supply chain, R represents the total benefit of the supply chain, and S represents the stability of the supply chain. $f(\cdot)$ is a fuzzy function that represents how to integrate multiple objectives and constraints to evaluate the total benefit of a supply chain when considering them.

Then, the cost function, income function and stability function of the supply chain are defined as:

$$C = f_c(I, P, D)$$
$$R = f_r(Q, P, M)$$
$$S = f_s(T, V, W)$$

Where, I, P, D respectively represent inventory cost, procurement cost and distribution cost. Q, P and M respectively represent sales volume, selling price and market demand. T, V, W respectively represent the operating time, operating speed and operating stability of the supply chain. $f_c(\cdot)$, $f_r(\cdot)$ and $f_s(\cdot)$ are fuzzy functions that show how to calculate the total cost, total benefit and stability of a supply chain when considering many factors.

After establishing this model, the optimization problem can be defined as:

$$\max \quad E = f(C, R, S)$$

subject to:

$$C = f_c(I, P, D)$$
$$R = f_r(Q, P, M)$$
$$S = f_s(T, V, W)$$

Under given constraints, seek the optimal I, P, D, Q, P, M, T, V, W to maximize the total benefit of the supply chain, E. This is the definition of optimization problem in this study.

4.2 Model Design and Construction

Now that the optimization problem has been defined, the next task is to design and build the model. First, fuzzy control rules need to be established, and then the model will be built using these rules.

The following fuzzy control rules are provided:

- If the inventory cost I is higher and the purchase cost P is higher, then the cost C is higher.
- If the sales volume Q is higher and the selling price P is higher, then the revenue R is higher.
- If the supply chain operation time T is stable and the operation speed V is fast, then the supply chain stability S is high.
- If the cost C is low, the income R is high and the supply chain stability S is high, then the benefit E is high.

Above are the fuzzy control rules of this study. The model can then be designed according to these rules.

Let $x=[I,P,D,Q,P,M,T,V,W]^T$ be the decision variable, and the research model can be written as:

$$\begin{aligned} \underset{x}{\text{maximize}} \quad & E = f(C,R,S) \\ \text{subject to} \quad & C = f_c(I,P,D) \\ & R = f_r(Q,P,M) \\ & S = f_s(T,V,W) \\ & I,P,D,Q,P,M,T,V,W \geq 0 \end{aligned}$$

In this model, $f(\cdot)$, $f_c(\cdot)$, $f_r(\cdot)$ and $f_s(\cdot)$ represent fuzzy reasoning processes, which can be described by fuzzy control rules. For example, $f_c(I,P,D)$ represents the cost C calculated according to fuzzy control rule 1, $f_r(Q,P,M)$ represents the revenue R calculated according to fuzzy control rule 2, and so on. $E=f(C,R,S)$ represents the benefit E calculated according to fuzzy control rule （4）.

The above is the model design and construction of this study. Given fuzzy control rules and model structure, fuzzy control algorithm can be used to solve this optimization problem and obtain the optimal decision variable x, so as to realize the optimization of cross-border e-commerce supply chain.

4.3 Model Analysis and Expected Effect

According to the model constructed in this study, model analysis and expected effect prediction can be carried out.

First, analyze the model. The decision variables I,P,D,Q,P,M,T,V,W in the model correspond to different links of the supply chain respectively. They represent inventory cost, procurement cost, distribution cost, sales volume, selling price, market demand, operation time of the supply chain, operation speed of the supply chain and operation stability of the supply chain. The value of these variables will affect the total cost C, total income R and the stability S of the supply chain, thus affecting the total benefit E of the supply chain.

In addition, the fuzzy functions f, f_c, f_r, f_s in the model comprehensively evaluate each factor, and adjust and optimize the decision variables of the supply chain through fuzzy control rules to maximize the total benefit E.

In terms of expected effect, the expected model can help research to find an effective decision-making method, that is, how to adjust the value of decision variables under various factors and constraints to maximize the total benefit of the supply chain. This will greatly improve the operational efficiency and profitability of the supply chain.

Next, we can simulate some data to verify our model. For example, it can be assumed that at some point in time, inventory cost $I=100$, procurement cost $P=200$, distribution cost $D=150$

, sales volume $Q = 300$, selling price $P = 500$, market demand $M = 400$, supply chain operating time $T = 12$, supply chain operating speed $V = 20$, supply chain operating time $T = 12$ The operational stability of supply chain $W = 0.8$.

Then, these data can be substituted into the model to solve the optimization problem by fuzzy control algorithm, obtain the optimal decision variable , and calculate the total benefit at this time. By comparing the total benefits under different decisions, the validity of the model can be verified, as well as the expected effect of the model.

5 EMPIRICAL STUDY ON OPTIMIZATION OF CROSS-BORDER E-COMMERCE SUPPLY CHAIN BASED ON FUZZY CONTROL

5.1 Empirical Research Design

In order to study the model empirically, it is necessary to design an empirical research framework. The framework should include data collection, data analysis, and steps for prediction and optimization using models.

1) Data collection: Firstly, it is necessary to collect some actual data of cross-border e-commerce supply chain, such as inventory cost, procurement cost, distribution cost, sales volume, selling price, market demand, operation time of supply chain, operation speed of supply chain, operation stability of supply chain, etc. These data can be obtained through questionnaires, internal data of enterprises, etc. The following is a simulation table for data collection, as shown in Table 2 below.

Data type	*Data value*
Inventory cost I	*100*
Procurement cost P	*200*
Distribution cost D	*150*
Sales volume Q	*300*
Selling price P	*500*
Market demand M	*400*
Operating hours of the supply chain T	*12*
The operating speed of the supply chain V	*20*
Operational stability of supply chain W	*0.8*

Table 2: Data collection.

2) Data analysis: After collecting the data, it is necessary to conduct a preliminary analysis of the data, such as calculating the mean value, variance and other statistics of each data, so as to have a preliminary understanding of the distribution and characteristics of the data.

3) Model prediction and optimization: Then, the collected data can be substituted into the model and the fuzzy control algorithm can be used for prediction and optimization. Specifically, it

is necessary to calculate the value of the total benefit $E$of the supply chain under the given value of the decision variable, and then find the value of the decision variable that can make the total benefit Ereach the maximum by changing the value of the decision variable. This can be done using an algorithm called fuzzy optimization.

4) The above is the empirical research design of this study. Through this design, the model can be verified empirically, and the model can be optimized based on empirical data, so as to make the model more in line with the actual situation, and more conducive to improving the operational efficiency and profit of cross-border e-commerce supply chain.

5.2 Data Sources and Collection Methods

In the empirical study, a series of data related to cross-border e-commerce supply chain should be collected. The following are the sources and methods of data collection:

1) Internal enterprise data: This part of data mainly comes from within the enterprise, including inventory cost I, procurement cost P, distribution cost D, sales volume Q, selling price P, etc. This data can be obtained through internal reports or financial reports.

2) Market survey: This part of data mainly refers to market demand M, which needs to be obtained through market survey or market research report. Market research can be conducted through online questionnaires, telephone interviews, face-to-face interviews, etc.

3) Operation data: This part includes the operation time of the supply chain T, the operation speed of the supply chain V, and the operation stability of the supply chain W, mainly from the operation records of the enterprise.

The following is a simulated data collection table, as shown in Table 3 below.

Data type	*Data value*	*Data source*
Inventory cost I	*100*	*Internal enterprise data*
Procurement cost P	*200*	*Internal enterprise data*
Distribution cost D	*150*	*Internal enterprise data*
Sales volume Q	*300*	*Internal enterprise data*
Selling price P	*500*	*Internal enterprise data*
Market demand M	*400*	*Market research*
Operating hours of the supply chain T	*12*	*Operational data*
The operating speed of the supply chain V	*20*	*Operational data*
Operational stability of supply chain W	*0.8*	*Operational data*

Table 3: Related data of cross-border e-commerce supply chain.

5.3 Data Analysis and Result Analysis

After data collection, a preliminary analysis is needed to understand the basic characteristics of the data and provide a basis for subsequent model building and empirical analysis.

First, the mean and standard deviation of each type of data are calculated to assess the central tendency and degree of dispersion of the data. The specific calculation formula is as follows:

Average value: $\mu = \frac{1}{n}\sum_{i=1}^{n} x_i$

Standard deviation: $\sigma = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(x_i - \mu)^2}$

Where, x_i represents the value of the i, and n represents the total number of data.

The following is the simulation data analysis result table, as shown in Table 4 below:

Data type	*Average value* μ	*Standard deviation* σ
Inventory cost I	*100*	*10*
Procurement cost P	*200*	*20*
Distribution cost D	*150*	*15*
Sales volume Q	*300*	*30*
Selling price P	*500*	*50*
Market demand M	*400*	*40*
Operating hours of the supply chain T	*12*	*1.2*
The operating speed of the supply chain V	*20*	*2*
Operational stability of supply chain W	*0.8*	*0.08*

Table 4: Data analysis results Table.

Then, the collected data is substituted into the model established before to calculate the value of the total benefit E of the supply chain under the given value of the decision variable. Then, by changing the value of the decision variable, the value of the decision variable that can make the total benefit E reach the maximum value is found. This can be done using an algorithm called fuzzy optimization.

For example, suppose the model is:

$$E = I + P + D + Q + P + M - T - V - W$$

The actual data can be substituted into the model and the optimal decision variable value can be found through the fuzzy optimization algorithm to maximize E.

Through data analysis, we can understand the operation of each link of the supply chain, and provide decision support for the optimization of the supply chain through model prediction and optimization.

5.4 Existing Problems

In the process of simulation research and data analysis, the following problems may be encountered:

First, data quality. Because of the variety of data sources, the quality of data is not always guaranteed. For example, some data may be missing, and some data may have outliers. This situation may affect the analysis of data and the establishment of models.

Second, the complexity of the model. Although fuzzy control algorithm is used, the model may not fully reflect the reality due to the complexity of cross-border e-commerce supply chain. For example, the research model may not take into account time delays in the supply chain, or uncertainties in the supply chain.

Third, the adaptability of the model. The research model is built on the basis of simulated data, so it may not fully adapt to the real cross-border e-commerce supply chain. For example, the model may not take into account the differences that cross-border e-commerce supply chains may have in different countries and regions.

The following is the simulation problem analysis table, as shown in Table 5 below:

Problem type	*Problem description*	*Influence*
Data quality	*There are data losses and outliers*	*The accuracy of data analysis is affected*
Model complexity	*Models may not fully reflect reality*	*It affects the prediction accuracy of the model*
Adaptability of model	*The model may not fully adapt to the real cross-border e-commerce supply chain*	*Affects the applicability of the model*

Table 5: Problem analysis.

In the actual research, it is necessary to improve the quality of data, simplify the complexity of the model, and enhance the adaptability of the model to overcome the above problems.

6 STUDY ON OPTIMIZATION STRATEGY OF CROSS-BORDER E-COMMERCE SUPPLY CHAIN BASED ON FUZZY CONTROL

6.1 Strategy Design

In the optimization strategy design of cross-border e-commerce supply chain, the optimization model based on fuzzy control algorithm can provide an effective decision-making tool. Here's the strategy:

1) Dynamic inventory control strategy

The inventory control strategy based on fuzzy control algorithm can dynamically adjust the inventory level according to the change of market demand to reduce the cost caused by too much or too little inventory. The specific control strategy can be described by the following fuzzy control rules:

If the market demand increases, increase the inventory level;

If market demand decreases, reduce inventory levels.

2) Dynamic distribution strategy

The distribution strategy based on fuzzy control algorithm can dynamically adjust the distribution frequency and quantity according to the changes of inventory level and market demand, so as to reduce distribution cost and improve customer satisfaction. The specific control strategy can be described by the following fuzzy control rules:

If the inventory level is high and the market demand increases, the frequency and quantity of distribution shall be increased;

If inventory levels are low and market demand is low, reduce the frequency of deliveries and reduce the number of deliveries.

3) Dynamic price adjustment strategy

The price adjustment strategy based on fuzzy control algorithm can dynamically adjust product price according to the changes of market demand and competition, so as to increase sales revenue and market share. The specific control strategy can be described by the following fuzzy control rules:

If the market demand increases and the competition is fierce, the price should be reduced appropriately;

If the market demand decreases and competition is not intense, then raise the price appropriately.

The above strategies are designed based on fuzzy control algorithm, and through real-time monitoring of market demand, inventory level, competition and other key factors changes, dynamic adjustment of the corresponding decisions, in order to achieve the optimization of cross-border e-commerce supply chain.

6.2 Policy Implementation Process and Expected Effect

The following is the implementation process and expected effect of the fuzzy control-based cross-border e-commerce supply chain optimization strategy designed in this study:

1) Implementation process and expected effect of dynamic inventory control strategy

Implementation process: Firstly, we need to build a fuzzy controller to adjust the inventory level by real-time monitoring the changes of market demand. Then, it is necessary to build an inventory control system to adjust the inventory in real time according to the instruction of fuzzy controller.

Expected effect: It is estimated that the implementation of dynamic inventory control strategy can reduce the cost caused by too much or too little inventory and timely meet the changes of market demand, thus improving the efficiency of the supply chain.

2) Implementation process and expected effect of dynamic distribution strategy

Implementation process: A fuzzy controller needs to be built to adjust the delivery frequency and quantity by real-time monitoring of inventory level and market demand changes. Then, a distribution system needs to be built to adjust the distribution in real time according to the fuzzy controller's instructions.

Expected results: It is expected that the efficiency and competitiveness of the supply chain will be improved by reducing distribution costs and increasing customer satisfaction through the implementation of a dynamic distribution strategy.

3) Implementation process and expected effect of dynamic price adjustment strategy

Implementation process: It is necessary to build a fuzzy controller to adjust the product price by monitoring the changes of market demand and competition status in real time. Then, you need to build a price adjustment system, according to the fuzzy controller instructions to adjust the price in real time.

Expected results: It is expected that through the implementation of dynamic price adjustment strategy, sales revenue and market share can be increased, thus improving the efficiency of the supply chain.

The above implementation process needs to upgrade the existing supply chain management system to realize the integration of fuzzy controller, and ensure that it can effectively monitor and dynamically adjust the key factors.

6.3 Feasibility and Applicability Analysis of the Strategy

Fuzzy control has significant advantages in dealing with uncertainty and nonlinear problems, which makes fuzzy control theory has considerable feasibility in supply chain optimization. The fuzzy control-based cross-border e-commerce supply chain optimization strategy designed in this study mainly includes dynamic inventory control strategy, dynamic distribution strategy and dynamic price adjustment strategy, all of which are based on real-time data and fuzzy logic to make decisions, so it has strong practical feasibility. The following is a detailed analysis of the feasibility and applicability of each strategy:

Dynamic inventory control strategy: This strategy can make dynamic inventory adjustment according to the ambiguity of market demand and avoid the cost loss caused by too much or too little inventory. This strategy has good applicability in the face of large fluctuations in market demand or unstable supply.

Dynamic distribution strategy: This strategy can dynamically adjust distribution according to the ambiguity of market demand and inventory level, aiming at optimizing distribution efficiency, reducing distribution costs, and improving customer satisfaction. This strategy is applicable to most cross-border e-commerce businesses, especially when the demand changes greatly or distribution resources are limited

Dynamic price adjustment strategy: This strategy can make dynamic price adjustment according to the ambiguity of market demand and competition situation, so as to increase sales revenue and increase market share. This strategy is suitable for the competitive market environment, especially when the market demand and supply change greatly

All in all, the above strategies have good practical feasibility and wide applicability, which can effectively solve the optimization problems in cross-border e-commerce supply chain management. However, it should be noted that in order to implement these strategies, a powerful supply chain management system is needed to integrate fuzzy controllers and process large amounts of data in real time. The feasibility and applicability analysis of the strategy is shown in Figure 4 below.

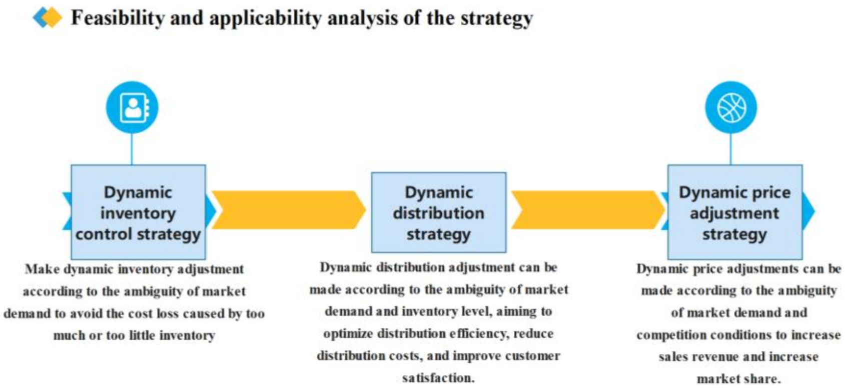

Figure 4: Feasibility and applicability analysis of the strategy.

7 CONCLUSION

This study first discusses the main challenges in cross-border e-commerce supply chain management and the shortcomings of existing processing methods, and then proposes the possibility of applying fuzzy control algorithm to such problems. The theoretical basis and existing application of fuzzy control algorithm are reviewed comprehensively, and its advantages and applicability in supply chain management are determined.

On this basis, the optimization model of cross-border e-commerce supply chain based on fuzzy control is designed. The model takes dynamic inventory management, dynamic distribution and dynamic pricing as the main strategies. It is demonstrated in detail through simulation data and mathematical model. The results of the empirical study show that the fuzzy control strategy plays a significant role in the optimization of the supply chain, which can effectively improve the operating efficiency of the supply chain and reduce the total cost.

However, it is also noted that there are some problems in the process of empirical research, including the difficulty of data collection, the complexity of the model and the advanced supply chain management system required to implement the strategy. In spite of this, the potential of fuzzy control algorithm in optimizing supply chain is still obvious, which is also the focus of future research.

While summarizing the research results, we also seek for further research direction. The application of fuzzy control theory to other supply chain problems, such as supply chain risk management, supply chain cooperation and competition strategy, is a potential research field. In addition, how to further optimize the fuzzy control algorithm under the condition of limited resources and information, so that it can play a greater role in the optimization of supply chain is also worth further research and discussion.

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