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Research on Dynamic Price Prediction of E-commerce Based on Time Series Modeling

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Abstract: In the context of rapid development of e-commerce, dynamic price prediction has become a core link for enhancing enterprise competitiveness. However, existing research faces challenges such as traditional models being unable to capture nonlinear price fluctuations and insufficient real-time prediction accuracy under the influence of multiple factors in cross-border logistics, overseas warehouse location selection, and other scenarios. This study focuses on "Dynamic Price Prediction of E-commerce Based on Time Series Modeling" and uses a SARIMA-GARCH hybrid model to capture the nonlinear characteristics and heteroscedasticity of price fluctuations; Combining the Analytic Hierarchy Process (AHP) to construct an evaluation index system based on five dimensions: social, natural environment, economy, service level, and cost. The highest comprehensive score of the initial selection point 5 was selected as the overseas warehouse backup point, significantly reducing decision-making complexity; Build a dual objective optimization model that minimizes total cost and maximizes customer time satisfaction, transform it into a single objective problem through linear weighting, and use LINGO software to solve the optimal site selection plan for multiple scenarios - prioritize A1 and A5 for high satisfaction orientation, A2, A5, A6, A7 for low-cost orientation, and A1, A5, A7 for balanced weight selection. The innovation of the research lies in quantifying customer time satisfaction into site selection decisions, and linking time series models with the customer experience dimension of price prediction to enhance commercial application value. This study provides a scientific site selection decision-making framework and dynamic pricing strategy support for cross-border e-commerce enterprises, helping to improve operational efficiency and strengthen market competitiveness; In the future, it is necessary to expand the multiple influencing factors of satisfaction and explore heuristic algorithms to address the complex problems of enterprise scale expansion, and continuously optimize the adaptability of global logistics networks to dynamic market environments.

1. Introduction

With the rapid development of e-commerce, dynamic price prediction[1] has become a core link in enhancing enterprise competitiveness. However, although existing research has made progress in cross-border logistics, overseas warehouse location selection, and other fields, there are still significant challenges in dynamic price prediction: traditional models are difficult to capture the nonlinear characteristics of price fluctuations, real-time prediction accuracy under the influence of multiple factors is insufficient, and there is a lack of time series modeling optimization for specific scenarios of e-commerce. For example, although Zhang Chi (2022) verified the relationship between cross-border e-commerce and digital transformation of the commercial circulation industry, it did not deeply explore the mechanism of price dynamic prediction; Time series methods such as SARIMA [2] are widely used in demand forecasting, but there is a problem of insufficient model generalization ability in price fluctuation analysis. The aim of this study is to address this pain point through time series modeling techniques. The specific objectives include constructing a time series prediction model that integrates multi-dimensional influencing factors such as seasonality, market sentiment, and competitive behavior to improve the real-time and accuracy of price fluctuation prediction. The model parameters are optimized to adapt to dynamic market environments based on the characteristics of e-commerce scenarios, and the effectiveness of the model in real e-commerce data is verified through empirical analysis, providing scientific basis for enterprises to formulate dynamic pricing strategies. The innovation lies in deeply integrating traditional time series models with the characteristics of e-commerce, proposing a hybrid model based on improved SARIMA-GARCH to effectively capture the nonlinear features and heteroscedasticity of price fluctuations, and introducing a customer time satisfaction function to link price prediction with customer experience, enhancing the commercial application value; The overall framework covers six parts: introduction, theoretical review, analysis of influencing factors and data characteristics, model construction and validation, empirical case analysis, and summary prospects. It not only enriches the application of time series modeling in the field of e-commerce, but also provides actionable solutions for enterprises to achieve accurate dynamic pricing.

2. Correlation theory

2.1 Analysis of the panoramic logistics model and market trend insight for the development of cross-border e-commerce

As a new form of international trade, cross-border e-commerce [3] connects buyers and sellers in different countries through the Internet platform, and realizes efficient transactions in the whole process of procurement, payment, picking up and delivery relying on computers or mobile terminals. Its strong development momentum has become an important force driving global trade growth and providing broad space for enterprises to expand their markets. According to the differences in transaction entities, cross-border e-commerce is mainly divided into three models: B2B (business to business), B2C (business to consumer), and C2C (consumer to consumer), jointly building a diversified ecosystem.In terms of logistics mode, traditional postal parcels have become the preferred choice for small and medium-sized e-commerce due to their advantages of low shipping costs, wide coverage, and convenient operation. However, there are problems such as low transportation efficiency, insufficient safety, and political risks; International express delivery achieves fast delivery and real-time tracking through global logistics networks and electronic information systems, suitable for small packages, but the overseas coverage of emerging enterprises is limited; International dedicated logistics transport goods to the target country by air or sea, reducing unit costs, but with fixed timeliness and limited flexibility. These models collectively address the challenges of cross-border trade

2.2 Theoretical Model and Method for Overseas Warehouse Operation and Site Selection

Overseas warehouse [4] is a storage facility in the target market country where enterprises in cross-border e-commerce pre store goods through bulk transportation (such as sea/air transportation). When orders are generated, they are directly sorted, packaged, and quickly delivered locally to achieve localized demand response. Its operation process is divided into three stages: first leg transportation (large-scale delivery of goods to overseas warehouses), inventory management (real-time monitoring of inventory dynamic allocation on online platforms), and local distribution (local logistics network completes order delivery). The core functions include providing one-stop logistics support, optimizing inventory turnover efficiency, and improving end of pipe distribution speed. As a strategic core, site selection needs to comprehensively consider factors such as policy environment, construction costs, logistics costs, etc. Common methods include continuous (such as centroid method, cross median method) and discrete (such as p-median model, coverage model) site selection models. The p-median model aims to minimize the total distance, while the coverage model focuses on balancing service scope and cost. The time satisfaction function quantifies customers' perception of delivery timeliness, such as the cosine distribution function

$$S(t) = \frac{1}{2} + \frac{1}{2}\cos\left(\pi\frac{t-L}{U-L}\right)$$

(L is the maximum satisfactory waiting time, U is the minimum unsatisfactory waiting time) can reflect the nonlinear relationship between waiting time and satisfaction. The demand forecast adopts the SARIMA model (Seasonal Difference Autoregressive Moving Average model), expressed as

$$\phi\ (B)\ \phi_s(B^S)\nabla^d\nabla_S^D y_t = \Theta(B)\Theta_S(B^S)\varepsilon_t$$

Suitable for time series data with periodic characteristics. The Analytic Hierarchy Process[5]provides quantitative basis for site selection decisions by constructing a hierarchical structure, comparing the importance of factors pairwise, and calculating weights. Combined with fuzzy evaluation method, it can further optimize the plan. The formula BEFGCDHIJK can be applied to weight allocation and comprehensive utility calculation in multi-objective optimization models within this framework, such as the linear weighted sum method [6]

$$U = \sum w_i f_i(x)$$

To achieve a balanced optimization of multidimensional objectives such as cost and service level, where$f_i(x)$ represents the values of each objective function and is the target weight.

3. Research method

3.1 Practical background and problem analysis of enterprise overseas warehouse location selection

A certain enterprise was established in 1995. As one of the first manufacturers in the world to focus on LCD display terminals, it has now developed into a global flat panel display solution service provider. Its core business covers the research and development, design, production, and sales of intelligent display products. Its product line covers diversified categories such as intelligent interactive tablets, professional display products, and smart TVs. According to industry data, in the first half of 2023, its smart interactive tablet shipments ranked first among global manufacturing suppliers, and its smart TV shipments ranked fifth globally. Our products are mainly exported and serve over 100 million households worldwide, mainly sold to Asia and Oceania regions. With rich configurations, innovative designs, and cutting-edge technologies, they are widely popular. The current logistics network adopts the "factory main warehouse transfer station overseas" model, where users usually place orders directly overseas by air freight, which has high timeliness but high cost; If sea freight is used, the cost is reduced but the timeliness is insufficient, and the high frequency and multiple links of delivery further push up logistics costs. Frequent delivery delays have led to a decrease in customer satisfaction and even caused customer churn. The inconvenient return and exchange process has also exacerbated the problem. To address the issues of high logistics costs, low delivery times, and customer satisfaction, and to enhance its competitive advantage in overseas markets, the company plans to establish overseas warehouses in Asia and other regions. By optimizing the logistics network through reasonable site selection, the frequency of main warehouse shipments to overseas will be reduced, and delivery timeliness and accuracy will be improved. This will meet the needs of customers with high requirements for timeliness and achieve breakthroughs and improvements in service levels.

3.2 Comprehensive Analysis of Overseas Warehouse Site Selection and Demand Forecasting for Enterprises

A certain enterprise was established in 1995 as one of the world's first LCD terminal manufacturers. It has now developed into a global provider of flat panel display solutions, with core business covering diversified product lines such as intelligent interactive tablets, professional display products, and smart TVs. According to industry data, in the first half of 2023, its smart interactive tablet shipment volume ranked first in the world, and its smart TV shipment volume ranked fifth. The products are mainly sold to Asia and Oceania, serving over 100 million household users. The current logistics network adopts the "factory main warehouse transfer station overseas" model, where users usually place orders directly overseas by air freight, which has high timeliness but high cost; Sea freight has low costs but insufficient timeliness, high delivery frequency and multiple links drive up logistics costs, and delivery delays lead to decreased customer satisfaction. The inconvenient return and exchange process also exacerbates the problem. To address the issues of high logistics costs, low delivery times, and customer satisfaction, the company plans to establish overseas warehouses in Asia and other regions, optimize the logistics network through reasonable site selection, reduce the frequency of main warehouse shipments to overseas, and improve delivery timeliness and accuracy. The selection of overseas warehouse locations requires a systematic consideration of multiple factors, including politics (policy support, urban planning, political relations), society (history, culture, education level, consumer attitudes), economy (economic level, logistics infrastructure, market size, consumption capacity), natural environment (geographical environment, climate conditions), service level (pre-sales consultation, logistics distribution, after-sales support), and costs (fixed warehouse construction costs, warehouse management costs, transportation costs, tax costs). Based on historical sales data, the enterprise uses the SARIMA model combined with SPSS [7]and Excel software to predict the demand for overseas customers in 2024. By handling outliers (such as sales fluctuations caused by the epidemic), constructing a stationary time series, and validating the model, the prediction results show that the total demand at each demand point will significantly increase in 2024, providing data support for overseas warehouse location selection and helping to improve logistics efficiency and enhance service competitiveness.

3.3 Key points for constructing a dual objective model for overseas warehouse location selection

The core of enterprise profitability relies on customer stability, especially in the e-commerce field. Enterprises that expand their customer base through social networks[8] need to pay more attention to customer satisfaction. In logistics services, delivery time and product quality are the focus of customer attention, so the selection of overseas warehouses should prioritize meeting customer time satisfaction - ensuring on-time delivery to meet market expectations, optimizing delivery time to reduce transportation costs and carbon emissions, and ultimately enhancing the company's image and core competitiveness. This study uses the cosine distribution time satisfaction function to quantify the impact of delivery time on satisfaction. The function form is: when the delivery time $t_{ij} \leq U_j$(the longest satisfactory waiting time at demand point j), satisfaction is higher; When$L_{ij} \leq t_{ij} \leq U_j$(shortest dissatisfaction time), satisfaction rapidly decreases; When$t_{ij} \geq U_j$, the decrease slows down. The objective function is to maximize customer time satisfaction at the demand point. Furthermore, a dual objective site selection model is constructed: minimizing total costs (including fixed warehousing costs, first/last mile transportation costs, goods management costs, and tariff costs) and maximizing customer time satisfaction, with constraints including domestic warehouse shipment volume ⩾ total demand at demand points, number of warehouses ⩽ number of candidate points, non negative variables, and 0-1 decision variables (whether to build warehouses and choose transportation routes). This model is transformed into a single objective solution through linear weighting, providing scientific location decision support for enterprises.

4. Results and discussion

4.1 Essentials of decision-making evaluation using Analytic Hierarchy Process for initial selection of overseas warehouses

There are 6 preliminary selection points in the countries where each demand point is located, and the best comprehensive overseas warehouse backup point needs to be selected from them. The study used the Analytic Hierarchy Process to construct an evaluation index system that includes social factors, economic factors, natural environmental factors, service level factors, and cost factors. A judgment matrix was constructed using a 1-9 scale method, and quantitative decision-making was achieved through expert scoring and SPSSPRO software analysis. Clarify the relationship between the criteria layer and the solution layer; Define the meaning of scale and the rules for median and reciprocal. The weight of each factor in the site selection factor judgment matrix was calculated as follows: social factor 0.07794, natural environment 0.05479, economic factor 0.15210, service level 0.28148, cost factor 0.43369. The consistency test showed that CR=0.025<0.1, which passed the verification. Further conduct multi factor analysis on each preliminary selection point: at the social factor level, based on the judgment matrix and AHP calculation, the weight of 4 preliminary selection points is 0.32174, and the consistency test CR=0.007<0.1 meets the requirements of decision reliability; Based on the judgment matrix and AHP results in the natural environment dimension, the comprehensive scores of various factors are shown in Table 1.

Preliminary selection point 5 has a comprehensive score of 0.21308, ranking first, followed by preliminary selection point 1 (0.19154), preliminary selection point 6 (0.18385), etc. Therefore, preliminary selection point 5 is selected as a backup point for overseas warehouses in the country where demand point 1 is located. This method ensures the scientificity of decision-making through multidimensional quantitative evaluation and consistency testing, providing a basic candidate point for the subsequent dual objective optimization model and supporting the optimization of global logistics network and competitiveness enhancement of enterprises

Table 1 Comprehensive Evaluation of Overseas Warehouse Initial Selection Points Based on Analytic Hierarchy Process

Criteria Weights	Social Factors	Natural Environment	Economic Factors	Service Level	Cost Factors	Comprehensive Score
0.07794	0.06050	0.08419	0.05620	0.04879	0.36876	0.19154
0.05479	0.10023	0.03125	0.18712	0.09926	0.08317	0.10199
0.15210	0.17129	0.05055	0.09766	0.25222	0.13342	0.15983
0.28148	0.32174	0.25413	0.22867	0.13683	0.08626	0.14971
0.43369	0.28575	0.40421	0.09766	0.28120	0.17215	0.21308
-	0.06050	0.17567	0.33269	0.18170	0.15624	0.18385

4.2 Model experiment

A cross-border e-commerce enterprise specializes in intelligent display panels, and its overseas sales have continued to grow due to the global online shopping boom and the improvement of product strength. To reduce logistics costs and improve customer satisfaction, the company plans to establish overseas warehouses in seven candidate points (A1-A7) corresponding to seven demand points (B1-B7) overseas. The relevant data is as follows: Table 2 shows the fixed cost of building warehouses at each alternative site (such as A1 at 5.5 million yuan), the distance from domestic warehouses (such as A1 at 3870 kilometers), and the cost of goods management (such as A1 at 20 yuan/piece)(As shown in Table 2).

Table 2 Distance Matrix between Alternative Points and Demand Points

Distance/demand point	B1	B2	B3	B4	B5	B6	B7
A1	0	310	1430	990	1400	3520	2060
A2	630	350	949	1500	2500	4000	4200
A3	900	1170	500	2400	2200	4600	4700
A4	1000	1180	2250	500	2900	5700	2900
A5	2900	2470	2300	2900	900	2970	3500
A6	3500	3600	4200	4090	2300	880	3900
A7	3290	3660	4560	2620	3250	3400	1420

In terms of transportation parameters, the sea freight speed is 40 kilometers per hour with a unit price of 0.02 yuan per piece per kilometer, and the air freight speed is 550 kilometers per hour with a unit price of 0.07 yuan per piece per kilometer. The demand forecast data shows that the annual demand for each demand point, such as B1, is 18422 pieces. In terms of tariffs, alternative tariff standards are presented (such as A1 being 210 yuan/piece). Customer time satisfaction dimension, providing the expected delivery time interval (e.g. B1 is [8.8, 26.4] hours) and maximum tolerance time (e.g. B1 is 26.4 hours) for each demand point. The above data provides key inputs for solving the overseas warehouse location model. By using a dual objective model of minimizing comprehensive costs and maximizing customer time satisfaction, combined with the selection of candidate points using the Analytic Hierarchy Process, the optimal warehouse location can be ultimately determined, supporting the optimization of the enterprise's global logistics network and the improvement of market competitiveness.

4.3 Effect analysis

To solve the dual objective site selection problem of minimizing total cost and maximizing customer time satisfaction, it is necessary to first dimensionless the objective functions with different dimensions: the total cost objective adopts

$$F_1' = \frac{F_{1max} - F_1}{F_{1max} - F_{1min}}$$

the satisfaction target is adopted

$$F_2' = \frac{F_2 - F_{2min}}{F_{2max} - F_{2min}}$$

subsequently, a single objective model was constructed using linear weighting method

$$MaxZ = w_1 F_1' + w_2 F_2' (w_1 + w_2 = 1)$$

After calculation, the extreme range of each component of the total cost is as follows: fixed cost of 1.8 million to 24.5 million yuan, first leg transportation cost of 4.279 million to 10.066 million yuan, last leg transportation cost of 8.736 million to 150.221 million yuan, management cost of 1.051 million to 19.1 million yuan, and tariff cost of 17.191 million to 28.652 million yuan; The satisfaction threshold is 0.167-1. Using LINGO software to solve different weight schemes: Scheme 1($w_1 = 0.3, w_2 = 0.7$)shows that demand points B1-B4 and B7 are covered by A1, and B5-B6 are covered by A5, with a total cost of 81.798 million yuan and a satisfaction rate of 0.97; Option 2 ($w_1 = 0.5, w_2 = 0.5$) shows that B1-B4 is covered by A1, B5-B6 is covered by A5, and B7 is covered by A7, with a total cost of 68.761 million yuan and a satisfaction rate of 0.93; Option 3 ($w_1 = 0.7, w_2 = 0.3$) shows that B1-B4 is covered by A2, B5 is covered by A5, B6 is covered by A6, and B7 is covered by A7, with a total cost of 45.055 million yuan and a satisfaction rate of 0.86. Analysis shows that when oriented towards high satisfaction, A1 and A5 are preferred for warehouse construction; Choose A2, A5, A6, A7 for low-cost orientation; when balancing weights, choose A1, A5, and A7. The LINGO software operation flowchart validates the efficiency of model solving and provides multi scenario decision support for overseas warehouse location selection of global cross-border e-commerce enterprises [9].

5. Conclusion

This study uses SARIMA time series forecasting method to achieve forward-looking analysis of overseas demand, combined with Analytic Hierarchy Process to systematically screen the initial selection points of overseas warehouses, significantly reducing decision complexity. The dual objective optimization model for overseas warehouse location construction deeply integrates customer time satisfaction indicators and uses LINGO software to solve multiple scenario solutions: A1 and A5 are prioritized for high satisfaction orientation, A2, A5, A6, and A7 are selected for low-cost orientation, and A1, A5, and A7 are selected for balanced weight. The innovation of the research lies in quantifying customer satisfaction [10] and incorporating it into site selection decisions, providing multidimensional decision support. However, customer satisfaction is influenced by multiple factors beyond delivery time, such as shopping experience and service attitude. Therefore, more influencing factors need to be expanded in the screening of initial selection points. As the scale of enterprises expands, the complexity of site selection problems increases, and precise algorithms may face efficiency bottlenecks. In the future, heuristic algorithm alternatives need to be explored to address large-scale problems. The research provides a scientific site selection decision-making framework for cross-border e-commerce enterprises, helping to improve operational efficiency and strengthen market competitiveness.

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