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Prediction Model of Salary Dynamic Fluctuation Trends Incorporating Multivariate Time Series

Abstract: - With the continuous development of human resource management, salary management has emerged as a crucial area of enterprise focus. To better predict the dynamic fluctuation trends of salaries, the establishment of a rational prediction model is of paramount importance. To this end, a prediction model for salary dynamic fluctuation trends is constructed based on multivariate time series and the BP neural network model. Data spanning from 2006 to 2015 are selected to forecast salary fluctuations during the period from 2021 to 2025, and the prediction results are comparatively analyzed with actual index data. The research findings indicate that residents' salary income approximately synchronizes with national economic growth levels and aligns with real-world scenarios. However, significant salary fluctuations are observed, which can be attributed to adjustments in national fiscal policies and the enhanced development of the national economy, leading to an upward trend in employee salaries.

Keywords: multivariate time series; BP neural network; salary fluctuation; ARIMA(0,1,0)

1 Related Work

According to reports published by the All-China Federation of Trade Unions, the proportion of China's labor force in GDP has shown a declining trend year by year, resulting in a phenomenon known as the "labor shortage." As salary income is a fundamental source of concern for individuals, enhancing workers' salaries has garnered significant attention. Generally, numerous factors influence salary fluctuations, necessitating real-time adjustments based on the actual national economic development to ensure salary rationality [1]. Especially against the backdrop of rapid market economic growth, industrial structures are undergoing transformation. However, research on salaries tends to focus on salary management, encompassing salary formulation, performance management, and related aspects, with relatively limited studies on salary fluctuation prediction.

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One study targeted gender factors, utilizing a multivariate regression method to predict salaries from both male and female perspectives, yielding an R2 value of 0.80 [2]. Another study improved upon the traditional K-nearest neighbor (KNN) algorithm by addressing its shortcomings, refining feature attribute weighting and K-value selection, and applying it to salary prediction. The results demonstrated the effectiveness and relatively good prediction performance of this approach [3]. A third study analyzed factors influencing salary levels and designed a prediction classifier based on the KNN algorithm, utilizing sample sets of different salary levels to forecast salary levels. The study found that the classifier achieved the highest prediction accuracy of 88.10% when K=7 [4]. Further, a salary prediction model was constructed using algorithms such as Naive Bayes, Decision Trees, and Bagging, with a comparative analysis of prediction results from different algorithms. The results indicated that Bagging and Naive Bayes algorithms performed relatively better, achieving a prediction accuracy of 85.20% [5]. Another study built a salary prediction model incorporating regression analysis, Decision Trees, SVM, and Random Forest algorithms, comparing their prediction effects. The study revealed that the Random Forest algorithm demonstrated higher prediction accuracy, with MSE and R2 improved to 0.027 and 0.921, respectively, after parameter optimization [6]. Moreover, research has introduced traditional salary features into deep learning algorithms for salary prediction in vertical industries, demonstrating relatively good prediction performance [7]. Additionally, Doc2vec was trained into corresponding text vectors, upon which Random Forest and Support Vector Machine algorithms were introduced to predict salaries in a specific industry. While this method considered the influence of textual features on salaries, it focused more on the effectiveness of machine learning prediction models and did not delve deeply into textual feature extraction during prediction [8].

Based on the aforementioned research, this paper constructs a prediction model for salary dynamic fluctuation trends incorporating multivariate time series, aiming to achieve accurate prediction of salary fluctuation trends.

2 Salary Adjustment Model Based on BP Neural Network

In this study, we analyzed the trend of salary fluctuations based on the standard of wage growth rates for laborers. To achieve this, we introduced the BP (Back Propagation) neural network and utilized data from 2006 to 2015 to predict salary fluctuations for the period 2021 to 2025. Furthermore, we conducted a comparative analysis between the predicted results and the actual values [9].

The BP neural network is a type of feedforward neural network capable of achieving multi-layer precise predictions. Its network structure is illustrated in Figure 1. During the learning process of this neural network, there are two main phases: the forward propagation of signals and the backward propagation of errors. The objective function of the BP neural network is the sum of squared errors of the network, which is minimized through gradient descent. This can be expressed as:

$$\min S = SEE^2 \quad (1)$$

In Equation (1), SEE^2 represents the sum of squared errors of the network.

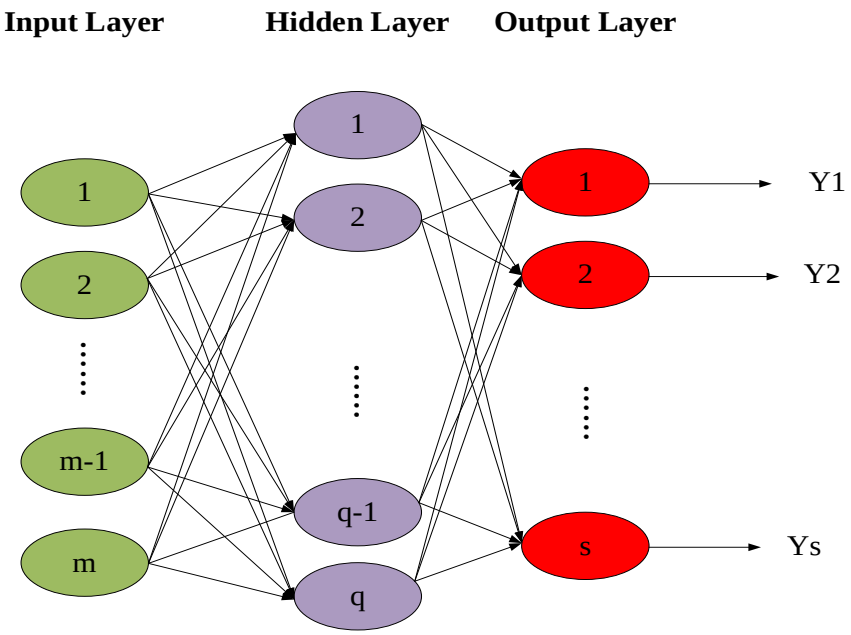

Figure 1: Structure Diagram of BP Neural Network

It is clearly illustrated in Figure 1 that the input layer comprises m inputs, denoted as $X_1, X_2, \cdots, X_m$, and the hidden layer contains q neurons. Among these, $W_{11}, W_{12}, \cdots, W_{sq}$ represents the weights connecting the neurons to the s neurons in the output layer. The output layer, in turn, comprises s outputs, denoted as $Y_1, Y_2, \cdots, Y_m$.

2.1 Forward Propagation of Signals

Given that the threshold for each node in the hidden layer is θ, and the threshold for each node in the output layer is α, the activation functions for the hidden layer and the output layer can be represented as $h(\varepsilon)$ and $f(\delta)$, respectively. Thus, the input N to the m-th node in the hidden layer can be expressed as:

$$\begin{cases} f(\delta) = \dfrac{1}{1+e^{-\delta}} \\ h(\varepsilon) = \varepsilon \end{cases} \quad (2)$$

Thus, the input N_m to the m-th node in the hidden layer can be expressed as: $N_m = \sum_{i=1}^{q} W_{mi} X_m + \theta_m$ (3)

By integrating the above formula, the input r_m to the m-th node can be obtained as:

$$r_m = h(N_m) = h(\sum_{i=1}^{q} W_{mi} X_m + \theta_m) \text{ (4)}$$

After obtaining the input of the node, it is used as the input node for the output layer, from which the output M_s of the output layer can be derived:

$$M_s = \sum_{i=1}^{q} W_{si} r_i + \alpha_s \text{ (5)}$$

Substituting M_s into the activation function f of the output layer, we have:

$$Y_s = f(M_s) = f(\sum_{i=1}^{q} W_{si} r_i + \alpha_s) \text{ (6)}$$

2.2 Backward Propagation of Errors

For the model constructed above, the calculated result represents the actual value. Consequently, the weights and thresholds need to be adjusted through the error gradient descent method, as follows:

Assuming the error is denoted as e_s, we have:

$$e_s = T_s - Y_s \text{ (7)}$$

In Equation (7), e_s represents the error, and T_s represents the desired output.

Based on the above formula, we construct a mean squared error function, which is given by:

$$E_1 = \frac{1}{2} \sum_{i=1}^{m} e_i^2 \text{ (8)}$$

After constructing the mean squared error function for a single sample, the training criteria can be achieved through Equation (9), leading to:

$$E = \frac{1}{2} \sum_{i=1}^{m} \sum_{j=1}^{s} (e_j^i)^2 \text{ (9)}$$

After the corresponding adjustments to the thresholds and weights, the corrected values can be obtained as follows:

$$\begin{cases} \Delta W_{mp} = -\eta \dfrac{\partial E}{\partial W_{mp}} = \eta \sum_{i=1}^{m} \sum_{j=1}^{s} e_j^i f'(N_s) W_{sq} h'(N_m) X_m \\ \Delta \theta_p = -\eta \dfrac{\partial E}{\partial \theta_p} = \eta \sum_{i=1}^{m} \sum_{j=1}^{s} e_j^i f'(N_s) W_{sq} h'(N_n) \\ \Delta W_{sp} = -\eta \dfrac{\partial E}{\partial W_{sp}} = \eta \sum_{i=1}^{m} \sum_{j=1}^{s} e_j^i f'(N_p) k_p \\ \Delta \alpha_s = -\eta \dfrac{\partial E}{\partial \alpha_s} = \eta \sum_{i=1}^{m} \sum_{j=1}^{s} e_j^i f'(N_p) \end{cases} \quad (10)$$

In Equation (10), ΔW_{mp}, and $\Delta \theta_p$ represent the correction values and thresholds of the hidden layer, respectively; ΔW_{sp}, $\Delta \alpha_s$, and represent the correction values and thresholds of the output layer, respectively; η is the learning rate of the network.

Through the above-constructed salary prediction model based on the BP neural network, preliminary salary prediction can be achieved.

3 Hybrid Horizontal and Vertical Salary Prediction Model Integrating Time Series Analysis

3.1 Model Construction

To achieve effective prediction of salary fluctuations, this paper integrates multiple time series to conduct a vertical prediction of the influencing factors of salary fluctuations. Simultaneously, through the BP neural network model constructed above, a horizontal prediction of workers' salaries is conducted. Here, time series refer to numerical sequences arranged in chronological order of observations of a variable, primarily reflecting the changes of the research object within a specific time frame.

(1)Vertical Perspective: By incorporating time series analysis, the magnitudes of the primary factors are predicted. In this research process, the ARIMA(Z,V,O) model is primarily utilized for vertical prediction. This model not only boasts high prediction accuracy but also offers convenience in operation during the prediction process, making it commonly used for short-term predictions. Prior to prediction using this model, data preprocessing is required to differentiate the data, effectively transforming it into a stationary time series to facilitate subsequent data analysis. After differentiating the data, indicators such as national economic level, fiscal revenue, and Renminbi (RMB) exchange rate are selected for prediction analysis through the ARIMA(Z,V,O) model. The constructed ARIMA(Z,V,O) model is as follows:

① AR(z) Autoregressive Model:

$$X_{7t} = \tau_0 + \tau_1 X_{7(t-1)} + \cdots + \tau_2 X_{7(t-z)} + \varepsilon_t \quad (11)$$

In Equation (11), τ_1 represents the horizontal smoothing coefficient; ε_t represents the variance white noise sequence of the data.

② MA(O) Moving Average Model:

$$X_{7t} = \varepsilon_t + S_1\varepsilon_{t-1} + \cdots + S_O\varepsilon_{t-O} \quad (12)$$

In Equation (13), S_1 represents the trend smoothing coefficient.

After integrating Equations (11) and (12), we obtain:

$$X_{7t}^{'} = \tau_0 + \varepsilon_t + \sum_{i=1}^{Z}\tau_i X_{7(t-i)}^{'} + \sum_{i=1}^{O} S_i\varepsilon_{7(t-i)} = \Delta^V X_{7t} = (1-L)^V X_{7t} \quad (13)$$

In Equation (13), L represents the lag operator, and it has the property that:

$$L^i X_{7t} = X_{7(t-i)} \quad (14)$$

In this research process, the selected prediction indicators are national economic level and fiscal revenue. Therefore, the prediction model is organized as follows:

$$(1-L)X_{7t} = \tau_0 + \varepsilon_t \quad (15)$$

(2) Horizontal Perspective: Based on the BP neural network model constructed above, the salary fluctuation is predicted. In the actual prediction process, it is necessary to conduct corresponding training using the BP neural network based on the analysis results of the time series to obtain the fluctuation trend of salaries [10].

3.2 Model Solution

(1) Vertical Prediction

Based on the time series model constructed above, a horizontal prediction is conducted for the Renminbi (RMB) exchange rate, government purchases, national economic level, and fiscal revenue. The prediction results are detailed in Table 1.

Table 1 Prediction Results for Four Major Factors from 2021 to 2025 (Unit: Billion Yuan)

Year	National Economic Level	Renminbi (RMB) Exchange Rate	Government Purchases	Fiscal Revenue
2021	1075177	6.89	264824	213720
2022	1134367	6.89	280238	225372
2023	1193558	6.89	295653	237046
2024	1252749	6.89	311067	248710
2025	1311940	6.89	326482	260373

(2) Horizontal Prediction

Based on the BP neural network model constructed above, a horizontal prediction of salary income is conducted, and the results are detailed in Table 2.

Table 2 Prediction Results of BP Neural Network (Unit: Billion Yuan)

Year	Salary Income
2021	34040
2022	36409
2023	38980
2024	41440
2025	43910

Through analyzing Tables 1 and 2, it can be observed that as the national economic level rises, the residents' salary income also increases, which is consistent with the actual situation. However, during the period from 2021 to 2025, there are significant fluctuations in salaries. This can be attributed to the adjustments in fiscal policies by the government and the improvement in the development level of the national economy, leading to an increasing trend in the salaries of enterprise employees.

3.3 Model Validation and Analysis

To verify the prediction effectiveness of the model constructed in this paper, the residual analysis method is adopted to examine the training status of the model, as shown in Figure 2.

From Figure 2, it can be observed that when the fourth data point is input, the residual is relatively large, indicating an anomaly at this point. In contrast, the residuals of other data points are relatively small and exhibit a symmetrical pattern. Furthermore, upon analyzing the anomaly, it was found that the appreciation of the Renminbi (RMB) exchange rate is the primary factor contributing to this anomaly. Comprehensive analysis reveals that the distribution trend of residuals is relatively stable, indicating that the model has good prediction performance and exhibits excellent stability during the training process.

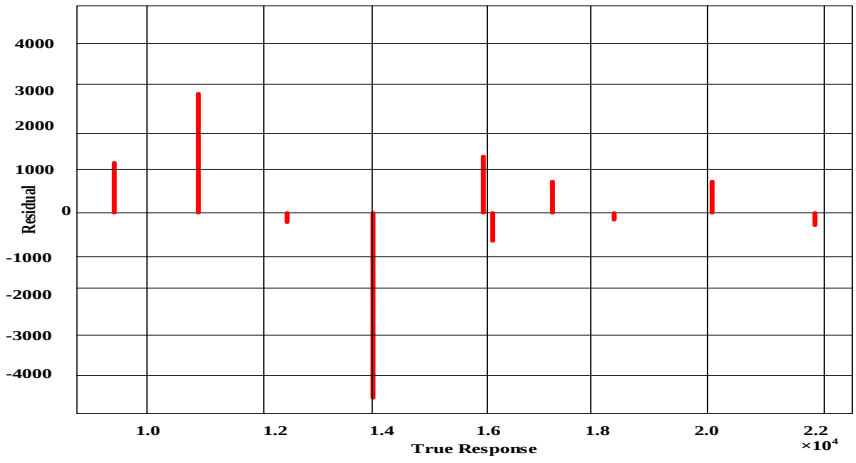

Figure 2: Residual Analysis of BP Neural Network Model Training Results

4 Countermeasures and Suggestions

Salary fluctuations are a common phenomenon in modern enterprise compensation management. They are not only influenced by multiple factors such as market conditions, corporate strategies, and employee performance but also directly related to employee motivation and the stable development of enterprises. In response to salary fluctuations, the following suggestions are offered:

5.1 Establishing a Flexible Compensation System

(1) Dynamic Adjustment Mechanism

As the market continuously evolves, corporate strategies undergo ongoing adjustments, and employee performance varies, the compensation system of an enterprise should also undergo corresponding dynamic adjustments [11]. This is not only the enterprise's response strategy to market changes but also an incentive for employee performance. Firstly, enterprises should recognize that compensation is not merely a reward for employees' work but also a crucial tool for attracting and retaining talent. Therefore, establishing a dynamic compensation adjustment mechanism is vital. This mechanism requires timely and appropriate adjustments to employees' compensation levels based on changes in market compensation levels and the enterprise's own strategic development goals. In the dynamic adjustment mechanism, market changes are significant factors influencing compensation levels. Enterprises should regularly conduct market compensation research to understand compensation levels in the same industry and region, ensuring that their compensation system remains competitive in the market. Simultaneously, adjustments to compensation levels for key positions should be made according to changes in corporate strategic goals to better align with the enterprise's strategic development needs. Additionally, employee performance is also a crucial factor in the dynamic adjustment mechanism. By establishing a comprehensive performance appraisal system, enterprises can objectively and fairly evaluate employees' work performance and adjust their compensation levels accordingly. Employees with outstanding performance should be rewarded with higher compensation levels and promotion opportunities to incentivize them to maintain their excellent performance. For employees with average performance, adjustments to compensation or the provision of training opportunities can help enhance their work capabilities. In summary, enterprises should establish a dynamic compensation adjustment mechanism that regularly or irregularly adjusts compensation levels based on market changes, corporate strategic adjustments, and employee performance. This can not only attract and retain talent but also stimulate employees' work enthusiasm and promote the sustainable development of the enterprise [12].

(2)Constructing a Diversified Compensation Structure

In the diverse modern enterprise environment, traditional compensation structures no longer suffice to meet the varied needs and expectations of employees. To better motivate employees, beyond basic salaries, it is advisable to introduce a diversified compensation structure. Within this framework, bonuses play a significant role. Based on employees' work performance, achievements, and contributions, corresponding bonus incentives can be granted. This not only boosts employees' work enthusiasm but also stimulates their creativity, encouraging them to work harder to create value for the company. Stock options are also an integral part of the diversified compensation structure. By granting employees stock options, making them shareholders of the company, they

are incentivized to grow alongside the company. This not only enhances employees' sense of belonging and loyalty but also ignites their work passion and motivation. Furthermore, benefits form a crucial component of the diversified compensation structure. Companies can offer various benefits such as medical insurance, housing subsidies, paid vacations, among others, to cater to employees' diverse needs. These benefits assist employees in addressing practical issues in their lives, enhancing their quality of life, and thereby enabling them to focus more intently on their work. Additionally, this diversified compensation structure possesses flexibility, enabling companies to adjust the structure according to employees' specific circumstances, market demands, and the company's strategic objectives, thereby aligning it more closely with the company's actual situation.

5.2 Focusing on Market Changes

(1) Market Research

Market research is paramount for enterprises, particularly in the realm of compensation management. Conducting regular compensation market research enables enterprises to acquire information on salary levels within the same industry and region, thereby assisting them in formulating reasonable compensation strategies. Firstly, the purpose of compensation market research is to grasp changes in the external market environment and comprehend the competitive landscape of salaries within the same industry and region [13]. By analyzing these data, enterprises can ascertain their position in the market regarding salary levels and subsequently decide whether adjustments are necessary. Secondly, this research also reveals salary levels across different positions and levels, which aids enterprises in scientifically setting job salaries, benefits, and bonus systems, ensuring the rationality and fairness of their compensation systems. Additionally, during the research process, enterprises should pay attention to employee satisfaction and expectations. Through surveys, employee interviews, and other methods, they can understand employees' perspectives and expectations on compensation, thereby better meeting their needs and enhancing their satisfaction and loyalty.

(2)Formulating Reasonable Compensation Strategies

Enterprises should formulate reasonable compensation strategies based on research findings. In the formulation process, it is crucial to integrate the enterprise's actual situation, development strategies, and employee needs to ensure that the compensation strategy attracts and retains outstanding talents while maintaining the enterprise's competitiveness. Simultaneously, enterprises need to regularly evaluate and adjust their compensation strategies to adapt to changes in the market environment and the enterprise's growth needs [14]. In conclusion, conducting regular compensation market research serves as a vital basis for enterprises to formulate reasonable compensation strategies. By understanding the actual needs of the market and employees, enterprises can better develop compensation strategies that align with their development requirements, thereby attracting and retaining talents and enhancing their core competitiveness.

5.3 Enhancing Communication and Feedback

(1) Establishing a Rational Communication Mechanism

To create an effective communication mechanism, enterprises must adopt a series of measures to ensure that employees fully comprehend and accept their compensation policies, the reasons for adjustments, and their

subsequent impacts. Firstly, enterprises should regularly organize employee meetings where they can elaborate on current compensation policies, encompassing salary structures, performance evaluation criteria, and promotion pathways. This fosters an understanding of the enterprise's overall planning and design philosophy for the compensation system. Secondly, establishing internal communication channels such as employee hotlines and internal forums enables employees to raise questions or suggestions promptly. These channels enhance employees' sense of participation and belonging while facilitating the enterprise's timely understanding of employee feedback and needs. When adjusting compensation policies, enterprises should communicate with employees in advance, explaining the reasons and objectives of the adjustments. This not only mitigates employees' doubts and misconceptions but also strengthens their trust and identification with the enterprise. During explanations, enterprises should strive to use simple and comprehensible language, avoiding overly technical or complex terminology. Furthermore, enterprises should convey the impacts of adjustments, both individual and team-wise, enabling employees to understand how their work outcomes contribute to team performance and corporate strategic goals. This also offers employees an opportunity to appreciate the value and significance of their work. Lastly, enterprises should periodically evaluate and adjust their communication mechanisms to ensure their continued effectiveness and efficiency, encompassing regular feedback collection, satisfaction assessments, and communication strategy optimization.

(2)Establishing a Rational Feedback Mechanism

In enterprise management, establishing an effective feedback mechanism is crucial for the continuous optimization of the compensation system. To better comprehend employees' perspectives and needs regarding the compensation system, enterprises must adopt measures to gather their opinions and suggestions. Firstly, enterprises should set up dedicated feedback channels, including internal surveys, employee forums, and anonymous suggestion boxes, ensuring that all employees, from grassroots to senior management, feel encouraged to participate. Secondly, regular satisfaction surveys on the compensation system should be conducted to gauge employees' satisfaction levels, identify issues, and gather improvement suggestions. These surveys provide insights into the system's operational status and changes in employee needs. Additionally, establishing an anonymous feedback mechanism is vital, allowing employees to express their opinions and suggestions freely without fear of negative consequences for voicing dissent [15]. Upon collecting employee feedback, enterprises should promptly analyze and organize it to understand employees' specific needs and expectations regarding the compensation system. Based on this, enterprises can adjust compensation policies according to actual conditions, such as modifying salary structures or introducing additional incentives, to meet employee needs and enhance satisfaction. Furthermore, enterprises should regularly communicate with employees to understand their career development aspirations and provide more development opportunities and promotion paths. This not only boosts employee satisfaction and loyalty but also provides strong talent support for enterprise growth.

Conclusion:

The predictive model for dynamic fluctuations in salary trends integrating multiple time series is a comprehensive forecasting system that can effectively enhance the scientificity and effectiveness of salary

management. However, it also exhibits corresponding limitations, which are specifically manifested in the following aspects:

(1)In the process of data selection, there are significant subjective factors involved, and the impacts of geographical distribution, industrial structure, and other factors on salary fluctuations have not been fully considered.

(2) Regarding the constructed BP neural network, its weight linearity is relatively poor, which may lead to training failures during the training process, and the training time can be lengthy.

To address these issues, in subsequent research, factors such as industrial structure and geographical distribution should be incorporated into the model. Additionally, appropriate improvements should be made to the BP neural network to effectively reduce the likelihood of model failures during the training process.

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