Research Article

Research on the Prediction of Port Economic Synergy Development Trend Based on Deep Neural Networks

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After entering the new century, along with the further deepening of global economic and trade cooperation, the industrial division of labor has been newly developed globally, which brings the cooperation among countries in the international logistics chain more and more closely. As the core node linking domestic and foreign water transportation, ports play a very key role in the international logistics chain and have an extremely central position in the national logistics planning. The coordinated development of port economy is an important part of the economic development planning of port cities, and it is also the premise and basis for the comprehensive planning of port logistics infrastructure construction scale, logistics space layout, and port city logistics development direction and function positioning. Therefore, according to the availability of realistic data, this paper establishes a deep neural network prediction model for the collaborative development of ports and uses various port logistics indicators to predict the economic development trend, so as to realize a nonlinear mapping relationship between the level of port economic development and the side of port logistics demand. Meanwhile, the research of this paper will provide theoretical basis and corresponding practical tools for the coordinated development between regional economy and port logistics industry.

1. Introduction

With the renewal of management concept and the deepening of the change of production and manufacturing mode, modern logistics industry is getting more and more attention in the world [1]. Especially after China’s accession to WTO, foreign trade has been further enhanced and the prosperity of the market economy has accelerated the rapid development of its distribution industry, which has gradually developed into an important part of the national economy and an economic growth point. In coastal ports and some large central cities, the port economy has even leaped to become a local pillar industry, while a logistics boom has been set off nationwide [2].

The history of port development shows that the port has gradually changed from being a single transportation transit point to a modern logistics service center and it plays an increasingly important role in the economic development of the port city and the region radiated by the port [3]. As a key node connecting the outside world in a country or region, ports naturally have the advantages of clusters in terms of geographical conditions. In recent years, theoretical research and practical development of port-related industrial clusters have made great progress [4]. The development of port-side industry economy brings great influence on the development of port logistics. At present, the more mature division of port-side industries divides port-side industries into port-side core industries, port-side related industries, port-side hinterland industries, and port-side derived industries. The related industries are mainly the logistics creation, storage, processing, and transportation industries directly connected with the port, which is the port logistics industry [5]. There is a close relationship between the port logistics industry and the port economy. The cluster development of the port logistics industry provides a new power engine for the port economy, while the development of the port economy provides a solid foundation for the cluster development of the port logistics industry [6].
With the continuous progress of technology, especially the breakthrough of AI technology, deep learning has been widely used in various fields and industries, promoting industrial innovation and breakthrough development [7]. In the economic and financial fields, people are also increasingly aware of the importance of economic data to the industry, which is an important basis for policy makers and industry practitioners to effectively feel the changes in industrial and economic development. As the volume of economic data increases dramatically and the forms of data become more and more diverse, the approach of deep learning provides a new research idea of finding patterns in big data and learning the potential features behind the data through deep learning models [8]. Therefore, it is of great importance to apply deep learning to the industrial economy.

The purpose of this article is to adapt the port logistics supply to the needs of coordinating with the actual development of the regional economy of the port hinterland and to conduct a prediction study of the port logistics demand from the perspective of port cities’ planning of port logistics combined with the economic development of the port. By analyzing the economic influencing factors of port logistics demand, the strong correlation between the level of port economic development and logistics demand is pointed out. According to the availability of realistic data, a deep neural network prediction model of port economic development trend is established to realize a nonlinear mapping relationship between the level of port economic development and port logistics demand. Meanwhile, it is also hoped that this paper can provide a new research direction and a reference for the development of port economy.

Furthermore, Section 2 of this paper proposes a comprehensive review of the related work and literature. It analyzes the port economy and its correlation with hinterland regional economy, drivers of economic growth in ports. This section also presents the steps for the economic development of the ports. In Section 2, the existing methods and the proposed methods are explained. It deeply discusses the RNN, GRU, and LSTM. Furthermore, it proposes the attentional model and a recurrent neural network model on the basis of dual attention mechanism and trend adjustment. Section 4 performs the experiments and analyzes the achieved results. The conclusion of the paper is given in Section 5.

2. Related Work

2.1. Port Economic Analysis. Port economic synergy development analysis refers to the process of correlating the logistics demand of the port and its hinterland with the socioeconomic activities of production and consumption demand [9]. As port logistics activities increasingly penetrate into the whole process of socioeconomic activities such as production, circulation, and consumption, they are closely related to the development of the social economy, especially the port hinterland, and are an important part of the socioeconomic activities of the port and the hinterland. Therefore, there is a close correlation between the synergistic development of port economy and socioeconomic development, and the socio-economic development of port cities and hinterland is the main factor affecting the economic activities of ports [10]. Port economic synergistic development analysis is to understand the demand intensity of port and hinterland socioeconomic activities for the supply of port logistics capacity with the help of qualitative and quantitative analysis tools and to carry out effective demand management. Guiding social investment into the service areas radiated by the port in a purposeful manner will be conducive to rational planning, construction of port logistics infrastructure, and improvement of the supply system of port logistics.

2.2. Analysis of the Correlation between Port Economy and Hinterland Regional Economy. There is an interactive relationship between the port economy and the economic development of the hinterland [11]. The prosperity of the hinterland promotes the demand for port logistics that relies on the hinterland. In turn, the development of the port logistics economy will also promote the development of the hinterland that depends on the port. The development of ports and hinterlands is interdependent and mutually reinforcing. The port not only provides transportation services for the hinterland, but more importantly, it has a strong radiation effect on the hinterland, and there seems to be a natural blood relationship between it and the hinterland region. The hinterland of the port can absorb and gather landward economic energy through the land transportation network, and it can more easily transcend the spatial boundaries of geography through the sea channel and directly participate in the international economic cycle in a large span, absorbing and gathering the factors of productivity in the world. Using the advantages of port transportation, we can vigorously develop import and export trade and processing trade, promote the integration of the hinterland and the world economy, drive the development of the hinterland economy, and make the development of the hinterland economy more vital. While the port promotes the economic development of the hinterland, the development of the hinterland also provides support and guarantee for the development of the port. The hinterland provides financial, trade, consolidation, and distribution services for the port. The development of the hinterland economy constantly makes changes in the types of goods in the port and also makes corresponding changes in the function strategy, service scope, production characteristics, and status role of the port.

2.3. Analysis of the Drivers of Economic Growth in Ports. The total economic volume of the port and hinterland, the regional industrial structure, and the spatial distribution of the port and hinterland economies have a huge impact on the port economy [12]. Port logistics demand is an important driving force for port economic development, and it can be said that the factors affecting port economic development also potentially affect the growth or reduction of port logistics demand [13]. There is an inherent and implicit mapping relationship between the economy and logistics demand. But, this relationship is not a simple linear relationship, because there are many economic factors and each factor may cause a certain degree of impact on logistics demand, so it is difficult
to use a simple and clear model to describe this relationship. However, this intrinsic determining and driving relationship between the regional economy and port logistics demand can be described abstractly by a mathematical expression, as shown in the following:

\[ Y = Af(x_1, x_2, x_3, \ldots, x_n) \]  

(1)

where \( Y \) indicates the logistics demand, including logistics demand scale, logistics demand structure, logistics demand main body, etc. \( x_1, x_2, x_3, \ldots, x_n \) represent a series of regional economic factors such as total regional economy, industrial structure status, regional economic spatial distribution, etc. From this functional relationship, we can see that the economic influence of port logistics is multifaceted and each economic factor may have an impact on all aspects of logistics demand, while the impact of each economic factor on the growth of logistics demand is not equally important and the focus of the impact on logistics demand is not the same, so this intricate internal linkage determines the multifaceted nonlinear complex mapping relationship between the economy and logistics demand.

2.4. Forecasting Steps for Port Economic Development

2.4.1. Determining the Purpose of Forecasting. Clearly defining the goal of forecasting is the premise of effective forecasting with a clear forecast objective to collect information in a targeted manner; otherwise, it is impossible to determine what to investigate, to whom to investigate, and not to mention how to make forecasts. At the same time, the forecast target is determined as detailed and quantitative as possible, which is conducive to the smooth development of forecasting work.

2.4.2. Analyzing the Factors Influencing the Market Demand of the Logistics System. The analysis of controllable and uncontrollable factors in the system is crucial. For different systems, controllable and uncontrollable factors are different. The same type of system has different controllable and uncontrollable factors depending on its geographical, social, and political environment, and often some factors are controllable in one system while it is uncontrollable in another system. Objective analysis of the main elements of the port logistics system and the main factors affecting market demand is the basis for forecasting.

2.4.3. Determining the Content of the Forecast. Forecasters must recognize the potential impact of different factors on logistics demand and be able to deal with them appropriately. For a particular project, significant components must be identified, analyzed, and combined with appropriate forecasting techniques. The information from the research should be analyzed statistically. The information is analyzed statistically to understand whether the information is complete. Then, the characteristics of the information and data are analyzed, and the sample data are corrected.

2.4.4. Establishing Mathematical Models for Forecasting. In the forecasting of economic systems, the use of quantitative forecasting methods is a necessary means to achieve objective and scientific forecasting. The establishment of forecasting models is not only related to historical data but also to the level of modeling of the forecaster. Both traditional forecasting methods and deep learning-based forecasting methods require a thorough understanding of forecasting theory and forecasting models. The nonlinear nature of the economic system often increases the difficulty of the mathematical model building work, and the determination of the fitting curve is difficult. To overcome the difficulties in building the model, a deep neural network forecasting model is used for forecasting in this paper and the model is modified accordingly.

2.4.5. Calculating the Results and Making Error Analysis Correction. Error analysis is an important part to ensure the prediction accuracy, and the error between the predicted value of the model and the value of the sample data is often used to measure whether the prediction model is good or bad in the prediction process. There are always errors in systematic forecasting, and the errors are caused by various reasons. Some are caused by the model itself, for example, the model always lags the actual value, so the forecast results should be added to the lag amount to make the forecast more accurate. Some errors are caused by changes in the external environment, so we should analyze the future economic and political situation in depth, analyze the future impact factors and give their quantitative values, and use the quantitative values to correct the model’s prediction values.

3. Method

3.1. Existing Recurrent Neural Network Models

3.1.1. Recurrent Neural Networks (RNNs). For traditional neural networks, there is no temporal association between inputs, whereas for human thinking, economic forecasting, etc., temporal association is crucial.

But, traditional neural networks and machine learning methods are unable to do this, and recurrent neural networks solve this problem.

The full name of RNN is recurrent neural network [14], which allows information to be passed from one step of the network to the next step of the network, as shown in Figure 1. This chained structure has a natural advantage for data with certain temporal connections, and as you can see from the figure, the output of the current moment can be influenced by all previous moments. If imagined as a reading comprehension problem, this means that the understanding of this text when reading the current position is influenced by the previous fragments and this structure is able to represent this influence.
Traditional neural networks have several obvious limitations [15]: one is that the input and output of traditional neural networks are too limited, requiring a fixed length of input and a fixed length of output. Second, these models use a fixed number of computational steps, such as the number of layers in traditional neural networks, and third, the learned knowledge of traditional neural networks is not shared. However, recurrent neural networks change this limitation by allowing us to operate on sequences of vectors, with variable-length sequences for both input and output, and a portion of the learned information can be quickly generalized to the entire network. The recurrent neural network scans the data from left to right and the parameters are shared at each time step. The forward propagation algorithm of the recurrent neural network is shown in equation (2). Forward propagation is done from left to right as shown in Figure 2:

\[
a^{(t)} = g_1(W_{aa}a^{(t-1)} + W_{ax}x^{(t)} + b_a), \\
h^{(t)} = g_1(W_{ha}a^{(t)} + b_h).
\]  

(2)

Although recurrent neural networks have good performance for sequential models, there is a big problem with recurrent neural networks, which is the problem of gradient disappearance. To solve this problem, gated recurrent units that change the propagation structure inside the RNN are available.

### 3.1.2. Gated Circulation Unit (GRU)

The purpose of GRU is to solve the problem of gradient disappearance and to allow the model to have long-time memory [16]. The internal structure of the simplified gated neural network is shown in Figure 3, and its formula is shown in equation (4). The GRU introduces a new variable \( c \), which means memory cell, to provide the memory capability of the model. The core idea of the GRU is to have an update gate, and the output of the update gate has a value between 0 and 1 due to the use of the sigmoid activation function. But, its probability of being close to 0 or close to 1 is higher, so that \( \Gamma_u \) acts like a gate to decide whether the current input needs to be remembered or not.

\[
\bar{c}^{(t)} = \tanh \left( W_c [c^{(t-1)}, x^{(t)}] + b_c \right), \\
\Gamma_u = \sigma \left( W_u [c^{(t-1)}, x^{(t)}] + b_u \right), \\
c^{(t)} = \Gamma_u \cdot \bar{c}^{(t)} + (1 - \Gamma_u) \cdot c^{(t-1)}.
\]

(3)

### 3.1.3. Long Short-Term Memory Network (LSTM)

LSTM is another more common type of recurrent neural networks [17] and a more powerful and general version than GRU. In LSTM, there is still an update gate \( \Gamma_u \). A new feature of LSTM is that instead of having only one update gate for control, a
new gate called forgetting gate is added, denoted by $\Gamma_f$ and then a new output gate $\Gamma_o$. At this point, the update value of the memory cell is changed to $c^{(t)} = \Gamma_u \ast c^{(t-1)} + \Gamma_f \ast c^{(t-1)}$ and the complete equation of LSTM is shown as follows:

$$
\bar{c}^{(t)} = \tanh \left( W_c c^{(t-1)} \ast x^{(t)} + b_c \right),
$$

$$
\Gamma_u = \sigma \left( W_u c^{(t-1)} \ast x^{(t)} + b_u \right),
$$

$$
\Gamma_f = \sigma \left( W_f c^{(t-1)} \ast x^{(t)} + b_f \right),
$$

$$
\Gamma_o = \sigma \left( W_o c^{(t-1)} \ast x^{(t)} + b_o \right),
$$

$$
e^{(t)} = \Gamma_u \ast \bar{c}^{(t)} + \Gamma_f \ast c^{(t-1)},
$$

$$
a^{(t)} = \Gamma_o \ast e^{(t)}.
$$

### 3.2. Attentional Model

#### 3.2.1. Code-Decoder Architecture.

For the encoder-decoder model, it is most common to get a fixed dimensional vector $c$ given the input sequence $x = (x^{(1)}, \ldots, x^{(T)})$, as shown in

$$
h^{(t)} = f(h^{(t-1)}, c^{(t-1)}),
$$

$$
c = q \left( h^{(1)}, \ldots, h^{(T)} \right),
$$

where $h^{(t)} \in \mathbb{R}^n$ is the hidden layer output at moment $t$. $c$ is obtained from $T$ hidden layer outputs by some transformation. Both $f, q$ denote nonlinear methods, and there are also various choices. For example, $f$ can be chosen as the internal structure of RNN or the internal structure of LSTM, and $q$ can be chosen directly as the last hidden layer output, or all outputs can be stitched.

The encoder stage is an RNN that reads the input sequence sequentially, and the state of the hidden layer is updated after each reading of the current input. When the input sequence is read at the end, the hidden layer of the RNN finally encodes the whole input sequence as a c-vector. The decoder is another recurrent neural network, and $y^{(t)}$ and $h^{(t)}$ are determined not only by $y^{(t-1)}$ but also by the final output $c$ of the encoder. Therefore, the hidden layer of the decoder stage at moment $t$ is calculated as shown in equation (6) and the conditional distribution probability when the result $y^{(t)}$ is obtained in the decoding stage is shown in equation (7). The encoder-decoder model diagram is shown in Figure 4, where $f$ and $g$ are the activation functions and the output of the $g$ activation function is the probability value.

$$
h^{(t)} = f(h^{(t-1)}, y^{(t-1)}, c),
$$

$$
P(y^{(t)} | y^{(t-1)}, y^{(t-2)}, \ldots, y^{(1)}, c) = g(h^{(t)}, y^{(t-1)}, c),
$$

The encoder has to compress the whole input sequence into a c-vector, which means that some part of the information must be missing in the compression process and therefore the accuracy is somewhat affected. To reduce this impact, the attention mechanism is introduced [18]. The difference between the attention model and the classical encoder-decoder model is that the encoding stage is not compressed into just a c-vector but generates a sequence of vectors, as shown in Figure 5.

#### 3.3. A Recurrent Neural Network Model Based on Dual Attention Mechanism and Trend Adjustment.

The goal of port economic trend forecasting is to forecast future economic trends by means of diverse eigenvalues (influencing factors) and known economic indicators. The formula for port economic forecasting is much like that for autoregressive forecasting, where the input is defined as the entire set of features $\{x_t\}_{t=1}^T = \{x_1, x_2, \ldots, x_T\}$ with the corresponding set of economic indicators as $\{y_t\}_{t=1}^T = \{y_1, y_2, \ldots, y_T\}$. At time $t$, $x_t \in \mathbb{R}^n$, where $n$ is the dimension of the feature and $T$ is the entire time stage. The output of the economic trend forecast is the next $\Delta$ values of economic indicators after $T$ time stages, which can be expressed as follows: $\{\tilde{y}_t\}_{t=T+\Delta} = \{\tilde{y}_{T+1}, \tilde{y}_{T+2}, \ldots, \tilde{y}_{T+\Delta}\}$, where $\Delta$ is determined by the target of the economic trend forecast, assuming that $\Delta \ll T$ and $\{x_t\}_{t=T+1}^T$ are unknown factors in the forecast stage.

The difference between the attention model and the classical encoder-decoder model is that the encoding stage is not compressed into just a c-vector but generates a sequence of vectors, as shown in Figure 5.

$$
\{\tilde{y}_t\}_{t=T+\Delta} = F \left( \left\{x_t\right\}_{t=T+1}^T, \left\{y_t\right\}_{t=T+1}^T \right).
$$

The structure of the encoding phase of the recurrent neural network model based on the dual attention mechanism and trend adjustment is shown in Figure 6.
We use \( h^{\text{int}}_1 \) and \( h^{\text{ext}}_1 \) to denote the final representation learned from \( \{x^{\text{int}}_t\}_{t=1}^T \) internal feature input and \( \{x^{\text{ext}}_t\}_{t=1}^T \) external feature input, respectively. Thus, the encoder for multitasking can be expressed as

\[
\begin{align*}
\{h^{\text{int}}_t\} &= \text{LSTM}^{\text{int}}(x^{\text{int}}_t, h^{\text{int}}_{t-1}), \\
\{h^{\text{ext}}_t\} &= \text{LSTM}^{\text{ext}}(x^{\text{ext}}_t, h^{\text{ext}}_{t-1}), \\
\{h^{\text{con}}_t\} &= \text{LSTM}^{\text{syn}}(x^{\text{syn}}_t, h^{\text{con}}_{t-1}).
\end{align*}
\]

(10)

The internal feature-encoded LSTM, the external feature-encoded LSTM, and the joint LSTM encoder are different LSTMIs that do not share weights and offsets, but each trip of the LSTM can learn its own weights and offsets.

The decoding stage diagram of the recurrent neural network model with dual attention mechanism and trend adjustment is shown in Figure 7.

The formula for decoding based on the attention mechanism is shown in
hidden layer output of the external feature LSTM and the two. It is calculated as shown in Figure 7: Demonstration of attention mechanism for weighted input mapping.

\[
\begin{align*}
    x_{t}^{\text{dec}} &= W_{\text{dec}} \left[ \sum_{t'=1}^{T} a_{tt'}^{\text{int}} h_{t'}^{\text{int}} + \sum_{t'=1}^{T} a_{tt'}^{\text{ext}} h_{t'}^{\text{ext}} \right] + b_{\text{dec}}, \\
    e_{tt'}^{\text{int}} &= v_{\text{int}} \tanh \left( M_{\text{int}} a_{tt'-1}^{\text{con}} + H_{\text{int}} h_{t'}^{\text{int}} \right), \\
    e_{tt'}^{\text{ext}} &= v_{\text{ext}} \tanh \left( M_{\text{ext}} a_{tt'-1}^{\text{con}} + H_{\text{ext}} h_{t'}^{\text{ext}} \right), \\
    a_{tt'}^{\text{int}} &= \frac{\exp(e_{tt'}^{\text{int}})}{\sum_{s} \exp(e_{ts}^{\text{int}})}, \\
    a_{tt'}^{\text{ext}} &= \frac{\exp(e_{tt'}^{\text{ext}})}{\sum_{s} \exp(e_{ts}^{\text{ext}})},
\end{align*}
\]

where \(e_{tt'}^{\text{int}}\) and \(e_{tt'}^{\text{ext}}\) correspond to the correlation scores of the hidden layer output of the internal feature LSTM and the hidden layer output of the external feature LSTM and \(a_{tt'}^{\text{con}}\) at moment \(t'\), respectively. Among them, \(v_{\text{int}}, v_{\text{ext}}, M_{\text{int}}, H_{\text{int}}, \) and \(H_{\text{ext}}\) are the parameters to be learned by the model.

4. Experiments and Results

The port logistics subsystem is divided into input and output indicators, and we have selected container throughput, cargo throughput, length of production quay, and number of production berths as sequential parameters. The regional economic subsystem is divided into total indicators, structural indicators, trade indicators, and investment indicators, as shown in Table 1.

The degree of synergy between port logistics and regional economic system at time \(t\) is expressed by \(Y_{t}\). Here, \(Y_{t}\) is between 0 and 1. The closer the value of \(Y_{t}\) is to 1, the higher the degree of synergy between the regional economic subsystem and the port logistics subsystem. On the contrary, the closer \(Y_{t}\) is to 0, the lower the degree of synergy between the two. It is calculated as shown in

\[
C = 2 \frac{\sqrt{X_{1}^{1} X_{2}^{1}}}{\sqrt{\left( X_{1}^{1} + X_{2}^{1} \right)^{2}}} + \Delta \\
F = \frac{X_{1}^{1} + X_{2}^{1}}{2}, \\
Y_{t} = \sqrt{C \times F}.
\]

\(X_{1}^{1}\) and \(X_{2}^{1}\) are the orderliness of the regional economic system and the port logistics system at moment \(t\). The combined level of coordination between the development degree of the port logistics system and the regional economic system is represented by \(C\). The combined level of the port logistics system and the regional economic system at the moment \(t\) is expressed by \(F\).

The criteria for classifying the grade of synergy between port logistics and regional economy are shown in Table 2. This paper is based on publicly available data from a port and the hinterland city where it is located. Using the proposed recurrent neural network model based on the double attention mechanism and trend adjustment, the weights of the sequential covariates of the port logistics system and the hinterland economic system and the orderliness of the sequential covariates are trained. The trend of a port logistics and its hinterland economic orderliness and the integrated synergistic trend are obtained, as shown in Figures 8–10.

The comprehensive synergy degree of port logistics and regional economy is largely on the rise, and when the orderly degree of port logistics develops in the same direction as the orderly degree of regional economy, the comprehensive synergy degree is also on the trend of development. The prediction model presented in this paper is generally consistent with the real data trend.
5. Conclusion

The foundation for logistics planning and construction in port area cities is the port logistics [19]. Therefore, the development trend of port regional economy and its research are practically significant [20]. Thus, in this paper, the analysis was carried out for the characteristics and main contents of port logistics forecasting and economic forecasting of the region where the port is located. This analysis was based on the basic theory of port regional economy and forecasting theory. Hence, we proposed a prediction method based on deep neural network to establish a neural network prediction model that meets the needs of the port regional economy. The results proved the applicability of the model and the feasibility of the method. Because there are many factors influencing the port economy, we have selected a few important indicator factors with focus and the follow-up can be done from improving the network model or adding more indicator factors to study the synergistic development of the port regional economy in depth.
Data Availability
The datasets used during the current study are available from the corresponding author on reasonable request.

Conflicts of Interest
The authors declare no conflicts of interest.

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