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RESEARCH ARTICLE

Research on the hydrographic survey cycle for updating navigational charts

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Abstract

Due to the vast ocean area and limited human and material resources, hydrographic survey must be carried out in a selective and well-planned way. Therefore, scientific planning of hydrographic surveys to ensure the effectiveness of navigational charts has become an urgent issue to be addressed by the hydrographic office of each coastal state. In this study, a reasonable calculation model of hydrographic survey cycle is established, which can be used to make the plan of navigational chart updating. The paper takes 493 navigational charts of Chinese coastal ports and fairways as the research object, analyses the fundamental factors affecting the hydrographic survey cycle and gives them weights, proposes to use the BP neural network to construct the relationship between the cycle and the impact factors, and finally establishes a calculation model of the hydrographic survey cycle. It has been verified that the calculation cycle of the model is effective, and it can provide reference for hydrographic survey planning and chart updating, as well as suggestions for navigation safety.

1. Introduction

The ocean is not only a treasure trove of abundant resources but is also an important strategic space to support future development (Li et al., 2015). In recent years, the rising ocean economy has become a blue engine for the economic development of coastal states. Global maritime transport services account for 70% of total transport services trade, and 90% of China's foreign trade is completed by sea (Zhang, 2018). However, the rapid development of maritime traffic has created great pressure and challenges to the safety of marine navigation. The navigational chart is an important guide to the safety of navigation. Due to the wide range of maritime traffic waters and the complex and changeable environment of coastal ports and fairways, it is necessary to obtain data through hydrographic survey and update navigational charts. If the cycle of navigational chart updating is long, the changes of coastal topography, fairway depth and navigation obstacles cannot be displayed on the chart in time, the effectiveness of the chart cannot be guaranteed, and there is a great potential safety hazard for ship navigation. If the cycle of navigational chart updating is short, it is necessary to carry out frequent hydrographic survey work, which consumes a lot of manpower and material resources. Therefore, a reasonable survey cycle is essential to ensure the effectiveness of the navigational chart.

To solve this problem, coastal states have developed their own hydrographic survey plans for navigational waters. Based on various factors, such as nature, economy and policy, they determined the order and cycle of survey of each navigational water area through different evaluation methods. The National Oceanic and Atmospheric Administration (NOAA) of the United States determined that approximately 500,000 square nautical miles of the Exclusive Economic Zone (EEZ) are 'navigationally significant', and divided the areas into two types, namely critical areas and prioritised areas. The critical areas possess the highest priority, and the prioritised areas have five priority levels, from 1 to 5. The division is based on several factors: shipping tonnage and trends; vintage of surveys in the area (year, equipment and processes utilised) under-keel clearance of vessels; potential for unknown dangers to navigation due to dynamic bottom or human influence; and requests for surveys from pilot associations (NOAA, 2012). In the United Kingdom, an evaluation was carried out after the completion of the hydrographic survey. The evaluation analyses the changing situation of the seabed and the development trend of the maritime traffic, which provides advice for the future survey. The main factors for evaluating the hydrographic survey by the Maritime Management Organization (MMO) included survey history, the special condition of the area, traffic density, the hydrographic results of the area in two years, seabed change, and the influence of maritime traffic etc. Based on these factors, MMO determined the survey cycles for traffic waters (MMO, 2013). The Canadian Hydrographic Service (CHS) conducted assessment of risk area, combining the assessment factors, including the traffic density, the attribute of the area, the timeliness of the documents and the past survey performance (CHS, 2013).

Besides the hydrographic offices, there are also some academic studies on the subject. Michelle and Patrick (1991) proposed a model for determination of cartographic and hydrographic priorities, which consists of three primary layers containing 19 variables. This paper took the Quebec region of Canada as an example and divided the area into multiple rectangular zones to cover all navigable waterways. Then they calculated the priorities of each rectangular zone according to the data collected and the weighted value by using a spreadsheet software. Ling et al. (2002) took the density of bathymetric line, the terrain survey information and the level of application as the most important factors to determine the hydrographic survey cycles. The study took China as example and analysed the submarine terrain of China and the stability of terrain of the coastal waters and its classification. The final output of the paper was a planning scheme for the bathymetric cycle for the coastal waters of China. The result was highly dependent on natural factors, but other factors were less considered. Sang et al. (2015) proposed the main factors affecting the priorities of hydrographic survey as follows: configuration of sea bottom, marine transportation, marine accident, current survey, marine environment and ecosystem, and demand of customer. The study deduced the relative importance ranking of the major ports in South Korea and suggested policy implications and a priority decision model. Christine (2015) took advantage of the under-keel clearance data calculated from the ship draft data of the Automatic Identification System (AIS) to identify hydrographic survey priorities in the study. The study proved under-keel clearances calculated from AIS vary by ports and can be quantitatively used to assign relative risks to ports using draft information. But the attribute data from AIS must undergo significant quality control measures to remove a large amount of erroneous draft information input by the crew.

In summary, hydrographic authorities can allocate hydrographic resources to where needs most by developing a survey plan, maximising the return on investment of the resources and ensuring the timely update of navigational charts. In China, the Maritime Safety Administration (MSA) has developed a corresponding hydrographic survey cycle for each navigational chart. First, the MSA summarised the charts of China's coastal ports and fairways and then compiled the 'Planning Catalogue of Port and Fairway Charts (*Catalogue*)' (MSA, 2017). The chart sequence of all scales in the *Catalogue* is complete and it can continuously cover all kinds of routes along the coast of China, as well as all levels of civil navigation ports and fairways of China's coastal areas. The MSA specifies the hydrographic survey cycle for each navigational chart in the *Catalogue*. The cycles are used to guide the surveying and mapping work of Chinese coastal ports and fairways in the next five to 10 years, which are also used as the basis for the preparation of the annual surveying and mapping plan. The *Catalogue* has a high guiding value, it is based on practical accumulation and expert experience. Since the cycles are derived from a great deal of research, expert consultation and centralised meetings, the flexibility of the cycle update is not enough. In addition, because the circumstantial factors change rapidly, the timeliness of chart updating must be guaranteed.

The maritime navigation waters cover a wide area, and the environment of coastal ports and fairways is complex and changeable. Hydrographic survey is a manpower-intensive, capital-intensive and time-intensive work (IHB, 2017). Based on the cited research, this paper affirms the important practical significance of the scientific hydrographic survey cycles to ensure the effectiveness of navigational charts and navigation safety. This paper takes Chinese coastal ports and fairways as the research object, deeply investigates the current status of hydrographic survey, and comprehensively analyses various factors affecting hydrographic survey. By exploring the relationship between the hydrographic survey cycles of 493 navigational charts and the influencing factors, a back propagation (BP) neural network was used to establish the calculation model of hydrographic survey cycle.

2. Materials and methods

Based on the cited research, this paper analyses and summarises actual investigations, expert consultations and the factors affecting the hydrographic survey cycle in China, and the weights of the factors were assigned using an analytic hierarchy process (AHP). The relationship between these factors is complex and it is difficult to establish a suitable mathematical model. Neutral network is a method of stimulating the human brain thinking and can handle problems with complex changes. Based on these, we aim to model the hydrographic survey cycle by BP neutral network, and use the model to calculate the survey cycles for navigational charts, of which the scale is bigger than 1: 150,000 produced by MSA. The model comprehensively considers natural, social and economic factors, and timely updates the reasonable survey cycles of the navigational charts to maintain the effectiveness of the charts.

2.1. Study area and sample collection

In this study, we take Chinese coastal ports and fairways as examples. The collected research samples are 493 navigational charts (2017) of the *Catalogue*. Navigational chart is one of the most useful tools for mariners, which can provide navigation information for maritime commerce, and also provide basic data for science, industry, environmental protection and other activities. The information and data are mainly derived from hydrographic surveys.

The samples show the Chinese coastal traffic waters completely. We designed a model based on the *Catalogue* to update the survey cycles in a timely manner in response to the changes of circumstantial factors. Generally, coastal states produce navigational charts covering all their territorial water areas. Navigational charts use a sheet line system, dividing the territorial water area into numbers of chart sheets with different scales (Figure 1). Every chart sheet can be called a ‘coastal port and fairway chart’ and has a unique chart number (Gan, 2014). When an area needs to be surveyed, the chart indicating the location of the area must be updated. Considering that the navigational charts with a scale of ≤1: 150,000 only have a publishing cycle, and there is no prescribed cycle for fundamental survey and checking survey, the updated data of chart elements are obtained from the Hydrographic Production Database (HPD). Finally, we selected 493 navigational charts with a scale bigger than 1:150,000 as the samples for this study. The samples cover the Chinese coastal route continuously, and fully cover all civilian ports and fairways in the Chinese coast.

2.2. Cycle factors

2.2.1. Classification of the hydrographic survey

In China, the hydrographic survey requires a long-term plan to execute which can be classified into two types: fundamental survey and checking survey. A fundamental survey means a systematic survey of overall activity, and all the features in a navigational chart must be surveyed. The fundamental survey cycle (FC) generally ranges from two to 12 years. The checking survey is based on the fundamental survey result, and only surveying the features which constantly change, mostly the depth. The checking

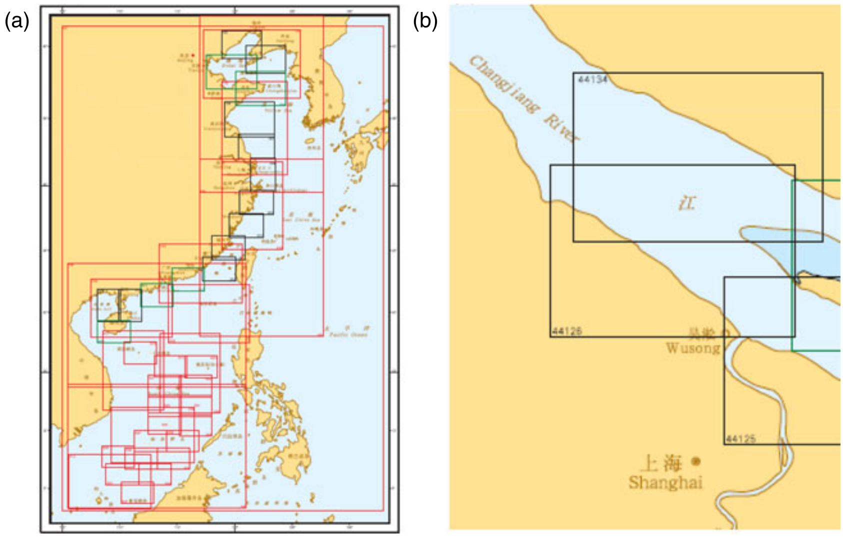

Figure 1. *(a) China Sea area; (b) Shanghai Port (Yangtze River Estuary).*

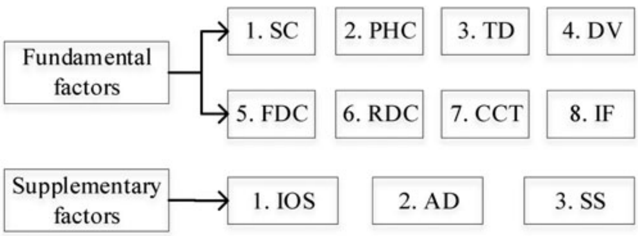

Figure 2. *The fundamental factors and supplementary factors considered in this study.*

survey cycle (CC) may range from a month to several years, dependent on the specific circumstance of the area. There are some other hydrographic survey types which do not require a plan but are based on the demand of the actual requirements, such as emergency survey, navigable scale survey and so on; those are not included in this study.

2.2.2. Selection of modelling factors

To determine the factors affecting the Chinese hydrographic survey cycle, we have studied relevant literature references and foreign cases, as seen previously. At the same time, we consulted experts from the MSA of China, professors of marine surveying and mapping, and related businesses. Finally, the following eight fundamental factors and three supplementary factors were selected to study the hydrographic survey cycles of Chinese navigational charts. Figure 2 shows these factors.

Through objective analysis and expert opinions, we use eight fundamental factors to establish the hydrographic survey cycle model, as follows: the scale of a chart (SC), port handling capacity (PHC), traffic density (TD), depth value (DV), the frequency of the depth change (FDC), the range of the depth change (RDC), the change of coastal terrain (CCT) and important fairway (IF). The instruction of superior (IOS), accident and disaster (AD), and special situation (SS) are also considered as the supplementary factors. IOS, AD and SS can result in a hydrographic survey of an area directly; these surveys are called emergency surveys. Supplementary factors are not included in the hydrographic survey cycle model in this study but can be used to adjust the cycle.

SC is a relatively low impact factor. Generally, the smaller the scale of a chart, the longer the hydrographic survey cycle. If the scale is smaller than 1:150,000, then the data can be captured from the

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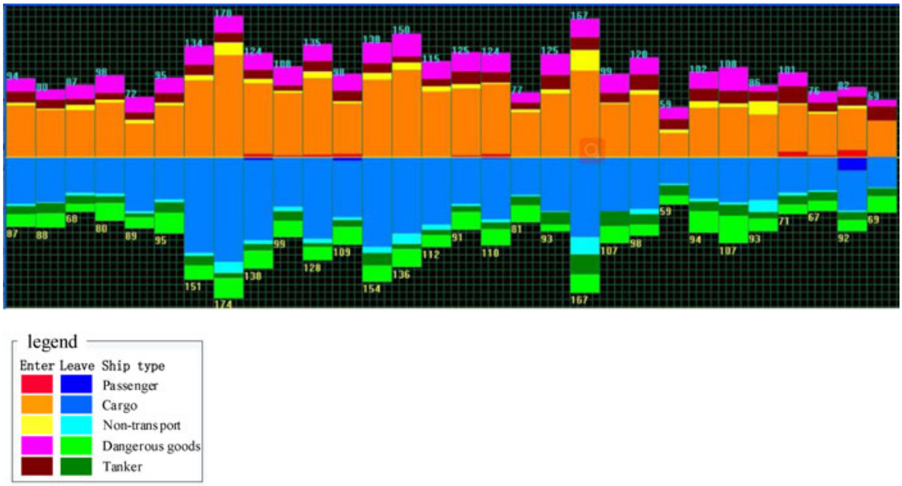

Figure 3. *The monthly data statistics in AIS (ship type and traffic flow).*

larger scale charts or in other ways, without a field survey. PHC and TD data can be collected by using the AIS monitor system developed by MSA, and they reflect the economic status of an area (Figure 3). The bathymetric survey is the main part of the hydrographic survey, so the depth factor should be further detailed and subdivided to determine the survey priority and cycle. DV shows the significance of depth to the hydrographic survey cycle; for example, if the depth is deep enough, it would not threaten to the safety of navigation, so the hydrographic cycle may be longer. FDC indicates the frequency of the depth change in an area; if the change is always obvious since the last survey, then the cycle should be shorter. RDC indicates the range size of the depth change in an area; for example, if it ranges from 2 to 30 meters deep in the same area, then the cycle must be shorter. Coastal terrain should be portrayed exactly on the chart; if CCT is obvious and fast (by natural or human activities), then, likewise, the cycle should be shorter. IF indicates whether an area contains an important seaway; if so, then the cycle should be shorter.

2.2.3. Quantify the weight of fundamental factors

In this study, eight fundamental factors were selected to study their influence on the hydrographic survey cycle. The degree of influence of each factor on the cycle is different, and weights are usually used to describe the degree of influence. AHP is a multi-objective decision analysis method which can quantify the importance of evaluation indicators and determine the weight of each evaluation indicator (Saaty, 1994; Tsubakimoto, 2000). Therefore, the study is based on the AHP and quantifies the weights of fundamental factors.

First, we use the expert evaluation method to compare the fundamental factors in pairs and score them. The experts we invited came from MOT (Ministry of Transport of the People's Republic of China), MSA, WEDCC (Waterway Engineering Design and Consulting Company), CSC (China Shipping (Group) Company) and selected universities. Scores were given by 20 experts whose research directions are closely related to hydrographic surveys. The scores range from 1 to 9. The greater the influence of a factor on the cycle, the greater its score. When the influence is the same, the score is 1. Then, according to the results of expert scoring, a judgement matrix was constructed. On this basis, the program was written to implement the AHP method in MATLAB. Through calculations, we performed a consistency check on the judgement matrix and obtained a consistency ratio (CR) value of 0·029. If CR < 0·1, it means that the consistency of the judgement matrix is reasonable and acceptable. Finally, we got the weights of the eight fundamental factors, which are: 0·02, 0·15, 0·21, 0·09, 0·30, 0·12, 0·05 and 0·07 (Table 1).

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Table 1. *Judgement matrix and weights of fundamental factors.*

Matrix	F1	F2	F3	F4	F5	F6	F7	F8	Weight
F1	1·00	0·17	0·14	0·20	0·11	0·17	0·33	0·20	0·02
F2	6·00	1·00	0·50	3·00	0·33	2·00	4·00	2·00	0·15
F3	7·00	2·00	1·00	3·00	0·50	2·00	5·00	3·00	0·21
F4	5·00	0·33	0·33	1·00	0·33	0·50	2·00	2·00	0·09
F5	9·00	3·00	2·00	3·00	1·00	3·00	5·00	4·00	0·30
F6	6·00	0·50	0·50	2·00	0·33	1·00	3·00	2·00	0·12
F7	3·00	0·25	0·20	0·50	0·20	0·33	1·00	0·50	0·05
F8	5·00	0·50	0·33	0·50	0·25	0·50	2·00	1·00	0·07

Table 2. *The quantitative value for SC.*

No.	SC	Quantitative value	No.	SC	Quantitative value	No.	SC	Quantitative value
1	1:5,000	10	7	1:20,000	4	13	1:60,000	1·2
2	1:6,000	8	8	1:25,000	3·5	14	1:70,000	1
3	1:8,000	7·5	9	1:30,000	3	15	1:75,000	0·8
4	1:10,000	7	10	1:35,000	2·5	16	1:80,000	0·6
5	1:12,000	6	11	1:40,000	2	17	1:100,000	0·5
6	1:15,000	5	12	1:50,000	1·5			

2.3. Cycle modelling

2.3.1. Data collection and processing

The BP neural network is a multilayer feedforward neural network, which is characterised by the forward transmission and the backward propagation of errors (Kung and Hwang, 1988; Sadeghi, 2000). In forward transmission, the input signal is processed from the input layer through the hidden layer to the output layer (Zhang and Lok, 2007). Each layer of neurons affects only the next layer of neurons. If the output layer does not get the desired output, then it goes into reverse propagation and adjusts the network's values of weights and biases according to the forecast errors, so that the BP neural network forecast output keeps approaching the expected output. The model training process actually is a machine learning process. To train the BP neural network, the input layer and output layer should be collected first. With the support of MSA, we collected the following data: 493 navigational charts covering all the coastal ports and fairways of China, AIS statistical data, the natural and social information about the coastal ports and fairways in China, expert scoring data, and the fundamental and checking cycles from the *Catalogue*.

The data processing contained two steps. The first step was to quantify the factors and give them scores, which were given by the experts. There were 493 FC/CC known data samples totally in this experiment, 463 of which were used for training the model, and the remaining 30 samples for model verification. The quantification standards for the factors are shown in Tables 2–6.

The final TD score should be the sum of the three quantitative values in Table 4, including the standards for cargo ships, passenger ships and ships carrying dangerous goods. Table 5 is the quantitative standard for the depth factors. As the depth factor is complex and difficult to be quantified rationally, we adopt the discussion result with the experts who take charge of the hydrographic survey and the analysis of the depth feature on navigational charts. The characteristics of high-level depth factors include fast depth change, the depth varies widely, and/or is less than 10 meters in the area. Small depth factors

Table 3. *The quantitative value for PHC.*

No.	PHC	Quantitative value
1	200 million tons or >10 million TEU	10
2	100 million tons or >5 million TEU	8
3	50 million tons or >1 million TEU	7
4	20 million tons or >500,000 TEU	6
5	10 million tons or >100,000 TEU	5
6	5 million tons or >10,000 TEU	4
7	2 million tons or >5,000 TEU	3
8	1 million ton or >3,000 TEU	2
9	1 million ton or <=3,000 TEU	1

Table 4. *The quantitative value for TD.*

	Cargo		Passenger		Dangerous goods	
SN.	TD (ship/week)	Quantitative value	TD (ship/week)	Quantitative value	TD (ship/week)	Quantitative value
1	>10,000	10	>500	10	>1,000	10
2	>5,000	8	>400	8	>5,000	8
3	>2,000	6	>300	6	>2,000	6
4	>1,000	4	>200	4	>1,000	4
5	>500	3	>10	3	>500	3
6	>300	2	>50	2	>300	2
7	<=300	1	<=50	1	<=300	1

Table 5. *The quantitative value for depth factors.*

SN.	Depth factor (DV/FDC/RDC)	Quantitative value
1	High	3
2	Medium	2
3	Small	1

usually indicate that the depth of the area is relatively steady, and the depth is greater than 20 meters. The rest of charts can be set to medium.

Because the criteria of the factors' quantitative values are different, in order to involve the quantitative values in evaluation and calculation, it is necessary to normalise the quantitative values and map their values to a uniform numerical range through the function transformation. The next step is data normalisation processing, making the data suitable for the hydrographic cycle model.

2.3.2. Model design and training

The hydrographic cycle model is designed based on the BP neural network (Shi et al, 2010). Figure 4 shows the topological structure of BP neural network.

$X_1, X_2 \ldots X_m$ = input values of the BP neural network, $Y_1, Y_2 \ldots Y_n$ = predicted values of the BP neural network, and W_{ij} and W_{jk} = weights of the BP neural network. The BP neural network can be considered as a nonlinear function. The input and predicted values of the network are the independent

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Table 6. *The quantitative value for IF.*

SN.	Important fairway	Quantitative value
1	Yes	1
2	No	0

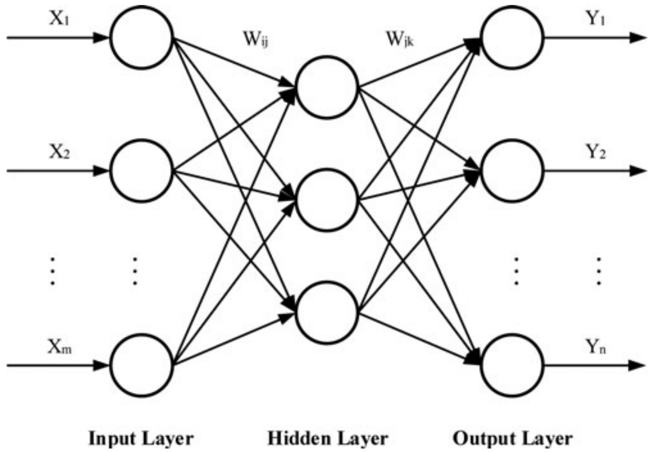

Figure 4. *Topological structure of BP neural network.*

and dependent variables of the function, respectively. When the number of input nodes = *m* and the number of output nodes = *n*, the BP neural network expresses the function mapping relationship from *m* independent variables to *n* dependent variables. Before using a BP neural network to predict values, it is necessary to train the network so that the network has associative memory and prediction capabilities. The training process of BP neural network is a process of machine learning.

In this study, we selected 463 navigational charts as training samples and 30 navigational charts as test samples. There were eight model input layer nodes: SC, PHC, TD, DV, FDC, RDC, CCT and IF, and one output layer node, representing the survey cycle value. When the model is training checking survey, the number of input layer nodes was nine. In addition to the aforementioned influence factors, the influence of the fundamental survey cycle of the chart was also considered. At the same time, we determined the approximate range of hidden layer nodes by referring to the following mathematical formula (Gao, 1998). Through training, we found that with the increase of the number of nodes in the hidden layer, the fitting error presented the trend of decreasing first and then increasing. When the number of nodes was six, the lowest error value appeared. In summary, the number of hidden layer nodes in the survey cycle model of this study is six. Figure 5 shows the BP neural network topology for the survey cycle training in this study:

$$1 = \sqrt{0.43\,mn + 0.12\,n^2 + 2.54\,m + 0.77\,n + 0.35} + 0.51 \tag{1}$$

where l = number of hidden layer nodes, m = number of input layer nodes and n = number of output layer nodes.

Based on the network structures and the data collected, we used the random function in the MATLAB to initialise the BP neutral network weight value and bias value (Zhang and Cao, 2010), then trained the model by establishing a cycle condition, setting the network learning rate to 0·1, the error performance indicator to 0·004, and the maximum number of iterations to 300. Finally, the BP neural network was used to train the fundamental and the checking survey cycle.

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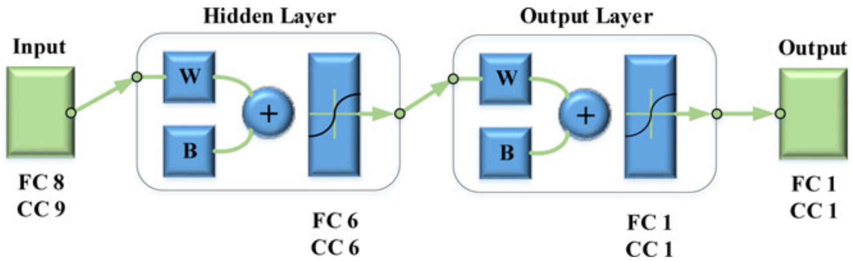

Figure 5. *The BP neural network topology for survey cycle training.*

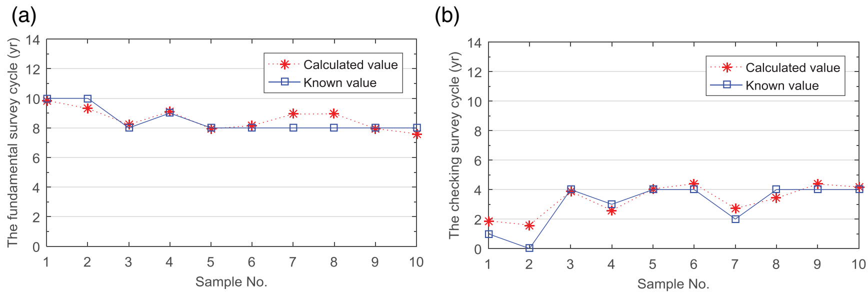

Figure 6. *Model verification results of the North test samples: (a) The fundamental survey cycles; (b) The checking survey cycles.*

Table 7. *Model test samples.*

Area	Chart No.
North	34148, 12312, 13146, 12335, 22113, 23118, 24112, 24113, 36123, 23111
East	44270, 44254, 44264, 41212, 64131, 64111, 54531, 42111, 64221, 52134
South	84248, 81103, 88303, 84224, 81301, 03201, 88402, 88103, 81201, 85101

After many times of training and adjustment, finally we confirmed the model, which has the ability of calculating hydrographic survey cycle. The data processing and model training mentioned were performed using the MATLAB R2016a.

3. Results and discussions

3.1. Cycle calculation

Due to the wide range of sea areas in China and the differences in the marine environment, their hydrographic survey cycles also have their own characteristics.

In the northern sea area of China, such as the Yellow Sea and Bohai Sea, the water depth changes slowly (Liu, 2016) and the area does not require frequent hydrographic survey. However, in the east and south sea areas of China, especially the Yangtze River Estuary and Pearl River Estuary, the depth changes quickly and the traffic density is quite high, so the hydrographic office must survey these areas in a short cycle (Zhang and Chen, 2009; Liu and Xia, 2013). In order to verify the validity of the model, 10 samples were selected from each of the three regions for testing, as shown in the Table 7. The results of using the BP neural network model to predict the hydrographic survey cycle are shown in Figures 6–8, in which the red dotted lines are the calculated values of model prediction, and the blue lines represent the actual known values. Values in the figures represent the hydrographic survey cycle.

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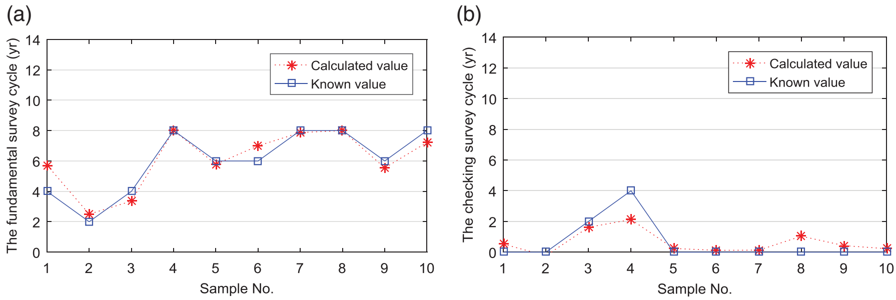

Figure 7. *Model verification results of the East test samples: (a) The fundamental survey cycles; (b) The checking survey cycles.*

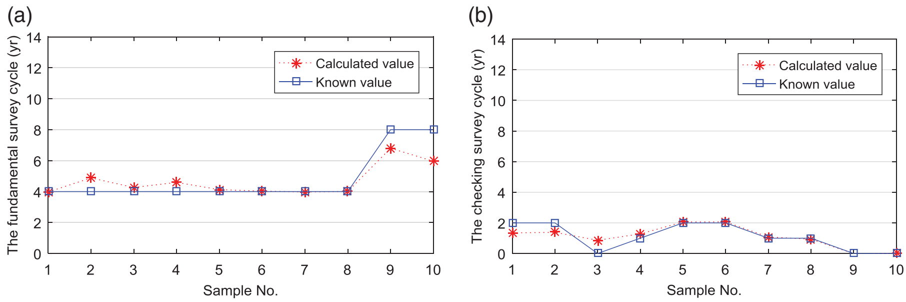

Figure 8. *Model verification results of the South test samples: (a) The fundamental survey cycles; (b) The checking survey cycles.*

Three statistical figures above reflect the fitting of the known result and the calculated result. As can be seen from the figures, the calculated results verify the validity of the model intuitively. Take the seventh sample '54531' in Figure 7 as an example, whose name is Aiwan Bay and Approaches. Calculation of the model found that its FC value is 7·87, and CC value is 0·13. When formulating the hydrographic survey plan, we took their approximate values as 8 and 0, which are the same as the actual known values. Aiwan Bay is located in the south of the Wenhuang Plain and northeast of the Chumen Peninsula in China, which is a semicircle coastal bay. It is 14·8 km long, 14·4 km wide and 124 sq km of sea area. The undersea sediment is mainly silt, and the depth is stable at 5 m more or less (CNKI, 2018). There is no important seaway here and the traffic density is low. Therefore, the hydrographic office does not need to do checking survey in this area and the fundamental survey is relatively longer.

3.2. Error analysis

We further use root mean square (RMS) error to quantify the validity of model predictions. RMS error can be used to measure deviations between predicted values and true values (Freedman, 1983). Tables 8 and 9 are the cycle calculation data of the fundamental survey and checking survey of the three sea areas, respectively. The fitting degree between the calculated results and the known results of the samples from each group of the three sea areas is shown in Table 10. The RMS errors of the fundamental survey cycles of the North, East and South China Sea areas were 0·50, 0·74 and 0·82. The RMS errors of the checking survey cycles of the North, East and South China Sea areas were 0·69, 0·73 and 0·41. By observing Figures 6–8 and Tables 8 and 9, we find that the cycle of fundamental survey and checking survey in different sea areas have their own characteristics.

The change of the eight impact factors summarised in this paper is an important reason to promote the hydrographic survey. The changes of these impact factors can be roughly divided into three types: normal, periodic and accidental. Among them, accidental changes are difficult to predict accurately,

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Table 8. *Model calculation results of fundamental survey cycle.*

Fs	No.1	No.2	No.3	No.4	No.5	No.6	No.7	No.8	No.9	No.10	RMS
V1	10	10	8	9	8	8	8	8	8	8	**0·50**
V2	9·855	9·316	8·231	9·106	7·939	8·158	8·935	8·953	7·951	7·606	(North)
V3	**0·145**	**0·684**	**0·231**	**0·106**	**0·061**	**0·158**	**0·935**	**0·953**	**0·049**	**0·394**	
V1	4	2	4	8	6	6	8	8	6	8	**0·74**
V2	5·727	2·501	3·357	8·005	5·786	6·996	7·871	7·997	5·546	7·219	(East)
V3	**1·727**	**0·501**	**0·643**	**0·005**	**0·214**	**0·996**	**0·129**	**0·003**	**0·454**	**0·781**	
V1	4	4	4	4	4	4	4	4	8	8	**0·82**
V2	3·975	4·880	4·265	4·593	4·125	4·030	3·975	4·008	6·800	5·964	(South)
V3	**0·025**	**0·880**	**0·265**	**0·593**	**0·125**	**0·030**	**0·025**	**0·008**	**1·200**	**2·036**	

Fs: Fundamental survey; V1: Known value; V2: Calculated value; V3: Difference value

Table 9. *Model calculation results of checking survey cycle.*

Cs	No.1	No.2	No.3	No.4	No.5	No.6	No.7	No.8	No.9	No.10	RMS
V1	1	0	4	3	4	4	2	4	4	4	**0·69**
V2	1·878	1·595	3·876	2·585	4·044	4·400	2·722	3·422	4·377	4·174	(North)
V3	**0·878**	**1·595**	**0·124**	**0·415**	**0·044**	**0·400**	**0·722**	**0·578**	**0·377**	**0·174**	
V1	0	0	2	4	0	0	0	0	0	0	**0·73**
V2	0·528	0·000	1·620	2·123	0·218	0·118	0·131	1·038	0·426	0·224	(East)
V3	**0·528**	**0·000**	**0·380**	**1·877**	**0·218**	**0·118**	**0·131**	**1·038**	**0·426**	**0·224**	
V1	2	2	0	1	2	2	1	1	0	0	**0·41**
V2	1·347	1·381	0·865	1·280	2·060	2·067	1·078	0·937	0·012	0·011	(South)
V3	**0·653**	**0·619**	**0·865**	**0·280**	**0·060**	**0·067**	**0·078**	**0·063**	**0·012**	**0·011**	

Cs: Checking survey; V1: Known value; V2: Calculated value; V3: Difference value.

Table 10. *Statistics on model prediction RMS errors.*

Area	Fundamental survey cycle	Checking survey cycle	Average value
North	0·50	0·69	0·595
East	0·74	0·73	0·735
South	0·82	0·41	0·615

and most of them exist in harbours and shallow water areas along the coast. The characteristics of the submarine topography in these areas vary greatly, and the hydrographic survey cycle is quite short. In China, it is mainly distributed in Liaodong Gulf, Huanghekou, Yalujiangkou, North Jiangsu Shoal and Changjiangkou, Zhujiangkou, Qiongzhou Strait, Hainan Island Southwest Shoal and other places. In addition, the underwater terrain of the estuary delta and eroded coast is relatively unstable.

The area of hydrographic survey in China is wide and can be divided into the north China Sea area (Bohai Sea and Yellow Sea area), east China Sea area and south China Sea area. The coastline of the north China Sea area is straight, and the coastal submarine topography is monotonous and changes gently. There are Tangshan Port, Qingdao Port, Tianjin Port and other ports in the sea area. From Figure 6 and Tables 8 and 9, it can be seen that the fundamental survey cycle of the north China Sea area is 8–10 years, and the cycle value is generally large and the curve changes little. The cycle of checking survey is 0–4 years, and the cycle curve fluctuates evenly and changes regularly. Therefore, the cycle prediction accuracy of the north China Sea area is high and the error level is stable.

The east China Sea area has the Changjiangkou and the southeast islands. The coastline is rich and winding, and the submarine topography changes frequently. There are famous Ningbo-Zhoushan Port, Shanghai Port and Suzhou Port in this sea area. From Figure 7 and Tables 8 and 9, it can be seen that the fundamental survey cycle of the east China Sea area is 2–8 years, the curve fluctuation is relatively uniform but the cycle value span is large. The cycle of checking survey is 0-4 years, the cycle value is small on the whole, the curve changes smoothly but there are some large values locally. Therefore, the accuracy of the cycle prediction in the east China Sea area is lower than that in the north China Sea area.

In the south China Sea area, there are some areas with complex submarine topography, such as Zhujiangkou, as well as areas with flat submarine topography, such as Honghai Bay. According to Figure 8 and Tables 8 and 9, the fundamental survey cycle of the south China Sea area is 4–8 years, of which 80% is four years and 20% is two years. The contingency of cycle change is large. The cycle of checking survey is 0–2 years, the cycle span is the smallest and the curve changes steadily. Therefore, the cycle prediction error of the fundamental survey of the south China Sea area is significantly greater than that of the checking survey.

In Table 10, the average values of cycle prediction errors in the north China Sea area, east China Sea area and south China Sea area are 0·595, 0·735 and 0·615, respectively. It can be seen that the prediction accuracy of the north China Sea area is the highest, followed by the south China Sea area and the east China Sea area. Based on the analysis of the natural conditions and port advantages of the three sea areas, the accuracy results predicted by the model in this study are basically in line with them.

The data above can prove the validity of the model, which means the model can be used to update the hydrographic survey cycle of the navigational charts. On the other hand, when a new navigational chart appears without surveying, the model is also applicable. The surveyor only needs to collect relevant information of the new chart, such as the scale, information of the port and the fairway where the chart is located, etc. Summarise the cycle factors of the new chart, combine expert scoring criteria, quantify cycle factors, and use the BP neutral network model to calculate the survey cycle.

4. Conclusions

Hydrographic survey is the work of surveying the marine waters and underwater topography to ensure the safety of navigation. Hydrographic surveys are the main source of navigational charting data. The hydrographic survey cycle involved in each navigational chart is the recommended update cycle for the chart. In order to guarantee the timeliness of navigational charts and marine geographic information, it is essential to establish a hydrographic survey order. This study establishes a hydrographic survey cycle model through a BP neural network, which provides reference for the updating and management of navigational charts. We identify and quantify the fundamental factors affecting the hydrographic survey cycles based on the information collection, data statistics and experts scoring. Then we use the BP neutral network to stimulate the machine learning process and get a hydrographic survey cycle model. Through the model verification and error analysis, it proves the cycle model is valid and applicable.

The hydrographic survey cycle stipulated in the *Catalogue* is not flexible enough, and it is used to guide the surveying and mapping work of Chinese coastal ports and fairways in the next five to 10 years. Based on this research, the surveying and mapping department quickly realised the annual update of the hydrographic survey cycle, which strengthened the guarantee of the validity of the charts. Especially in the case of port construction or fairway expansion and other activities, this study provides a useful reference for maritime department to make hydrographic survey plans and chart compilation plans. Timely cycle updates can help the hydrographic department to allocate the limited survey resources to the places where it is most needed, ensure the timeliness of navigational charts and marine geographic information, and promote the sustainable development of navigation safety. In addition, the Chinese maritime department is the budget executing agency, and must formulate the budget plan for the following year at the end of each year. Based on the change of current situation, this study provides a fast and effective method for the assessment of annual workload and a reliable basis for the formulation of work budget.

There are still unresolved problems in this study, mainly in the following aspects: Add more impact factors to the model, such as resource status, risk area etc, in order to improve the accuracy of the model calculation. The data used to train the model needs to be updated regularly to ensure the effectiveness of the model.

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References

Christine, S. (2015). Crowdsourced Maritime Data: Examining the feasibility of using under keel clearance data from AIS to identify hydrographic survey priorities. Master degree, Faculty of the USC Graduate School University of Southern California, America.

CHS (Canadian Hydrographic Service). (2013). Available at: http://www.charts.gc.ca.

CNKI Knowledge. (2018).Available at: http://xuewen.cnki.net.

Freedman, D. and Mo, C. (1983). Root mean square error of regression. *Mathematical Statistics and Management*, (4), 25–30.

Gan, C. H. (2014). Research on Seamless Multi-Scale Electronic Navigation Charts Data Organization and Its Application. Ph.D. degree, Wuhan University, China.

Gao, D. Q. (1998). On structures of supervised linear basis function feedforward three-layered neural networks. *Chinese Journal of Computers*, **21**(1), 80–86.

IHB (International Hydrographic Bureau). (2017). *International Hydrographic Review*. Monaco: International Hydrographic Organization.

Kung, S. Y. and Hwang, J. N. (1988). An algebraic projection analysis for optimal hidden units size and learning rates in back-propagation learning. *IEEE International Conference on Neural Networks*, **1**, 363–370.

Li, J. K., Zhang, J., Gong, L. T. and Miao, P. (2015). Research on the total factor productivity and decomposition of Chinese coastal marine economy: based on DEA-Malmquist index. *Journal of Coastal Research*, **73**, 283–289.

Ling, Y., Xu, G. J., Lu, X. P., Wang, R. and Su, Z. L. (2002). Research on bathymetric survey cycle. *Hydrographic Surveying and Charting*, **22**(3), 22–25.

Liu, Z. (2016). Research on Risk Evaluation System for Vessels in Yellow Sea and Bohai Sea during Severe Weather. Master of Engineering, Dalian Maritime University, China.

Liu, J. Y. and Xia, F. (2013). Statistical analysis of benefit from regulation engineering in the Yangtze estuary deepwater channel. *Port & Waterway Engineering*, **11**, 29–32.

Michelle, G. and Patrick, H. (1991). Model for Determination of Cartographic and Hydrographic Priorities. Canadian Hydrographic Conference. Canada.

MMO (Marine Management Organization). (2013). Available at: http://www.marinemanagement.org.uk.

MSA(Maritime Safety Administration). (2017). Planning Catalogue of Port and Fairway Charts (Catalogue).

NOAA (National Oceanic and Atmospheric Administration). (2012). Available at: http://www.noaa.gov.

Saaty, T. L. (1994). Highlights and critical points in the theory and application of the Analytic Hierarchy Process. *European Journal of Operational Research*, **74**(3), 426–447.

Sadeghi, B. H. M. (2000). A BP-neural network predictor model for plastic injection molding process. *Journal of Materials Processing Technology*, **103**(3), 411–416.

Sang, G. K., Won, I. L. and Yang, H. W. (2015). An analysis on relative importance and priority of hydrographic survey for major ports in South Korea. *Journal of the Korean Society of Marine Environment & Safety*, **21**(2), 154–163.

Shi, F., Wang, X. C., Yu, L., Li, Y. and Zhang, Y. L. (2010). *30 Cases Analysis of MATLAB Neural Network*. Beijing: Beihang University Press.

Tsubakimoto, T. (2000). Extensions of the analytic hierarchy process: analytic hierarchy process, analytic network process, and neural network process. *Kwansei Gakuin Shogaku Kenkyu*, **46**, 79–102.

Zhang, L. (2018). Forge development synergy across land and over sea. *Maritime China*, **0**(1), 56–57.

Zhang, X. J. and Cao, H. R. (2010). The random function in Matlab. *Artificial Intelligence and Identification Techniques*, **14**(2), 115–116.

Zhang, S. Y. and Chen, H. (2009). Discussion of safe navigation in the winter North-south Route. *Ship & Ocean Engineering*, **38**(1), 71–73.

Zhang, J. R. and Lok, T. M. (2007). A hybrid particle swarm optimisation–back-propagation algorithm for feedforward neural network training. *Applied Mathematics & Computation*, **185**(2), 1026–1037.

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