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Optimizing Back Propagation Neural Network with Genetic Algorithm for Man-hour Prediction in Chemical Equipment Design

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This papers sets to address the low accuracy of man-hour prediction, and proposes modeling based on optimizing back propagation neural network with genetic algorithm (AG_BP) for quantitative predictions. We conduct research on the management process of chemical equipment design, based on historic data in the user database, analyze the relevance of parameters and obtain the parameters, construct and improve models using the AG_BP algorithm. The results show that this approach is a good solution for predicting man-hours required for chemical equipment design. The models designed in this paper can help improve the prediction accuracy and can be promoted for broader use.

1. Introduction

The chemical projects are technique-intensive and requires a great amount of man-power in implementation. Since manpower is a important factor in project construction, it is increasingly important to have accurate prediction and planning on man-hours. As early as in 2008, Sinopec launched the Pricing Measures on Petroleum and Chemical Project Design to align with the international bidding and pricing practices. In earlier research, some have proposed to use statistical methods in analyzing and assessing the man-hours in project designs, and provided technical assurance with management systems. But from a practical point of view, man-hour calculations are still focused on prediction and need improvement on accuracy. To find the proper method in predicting man-hours is directly relevant to the future work. The allocation of work in the chemical project design should be balanced, therefore in lack of accurate prediction, the unbalanced coordination between the personnel will impede the progress of project. In recent years, China has seen greater investment on chemical projects, which also poses higher requirements for the human resources planning of the design institutes on large scale chemical projects.
To realize accurate prediction of man-hours for chemical project design, this paper first analyzes the design management flow and design features. Then it establishes proper model based on analysis on parameters and offer application standards.

2. Literature review

The design of the chemical construction project belongs to the typical technology intensive and knowledge intensive work. The most important cost is the manpower cost, which can be measured by the time of manpower consumption. Artificial time is an important basis for an enterprise to make a tender offer at the initial stage of a project, to make a work plan in the early stage of design development, and to optimize the arrangement of human resources. Therefore, the prediction of artificial time is very important. The importance of artificial time in chemical engineering projects has been gradually concerned. In 2008, Sinopec group introduced *The Method of Designing Cost for the Design of Petrochemical Engineering Construction Project*, to adapt to the trend of international design project bidding according to the design consumption time. Afram and so on also introduced several artificial time calculation methods (Afram et al., 2017) which are convenient for international project investment quotations. Huang and others used statistical techniques to estimate and make statistics of engineering design projects (Huang et al., 2015). Momeni and others embedded statistical

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technology into artificial time management software to master real-time human load data in project operation and provide a reliable basis for scientific and rational arrangement of human resources (Momeni et al., 2015). However, the artificial time in these studies is still in the stage of statistical and empirical estimation, and the accuracy is not high. In consequence, it is imperative to find an effective artificial time prediction method.

In general, the design of chemical engineering is composed of technique process design, equipment design, piping layout design and civil design. The working methods of these designs have their own characteristics. The equipment design of the main body of the chemical engineering design refers to the design and selection of the construction drawings of non-standard equipment, the type selection and design of the setting equipment, as well as the inquiry design of the package unit system equipment which is responsible for the performance of the manufacturing plant. The project management mode is mainly the responsibility matrix generated based on the work decomposition structure (WBS) and the organization decomposition structure (OBS). The work items are arranged to a specific person, and the quota time for assignment of work items becomes the design manual time of the work. Because of the lack of accurate prediction method of artificial time, the work arrangement is easy to cause the unbalanced distribution of work load among the staffs, the disharmony of the personnel distribution among the work roles and the mismatch of the human load allocation among the various projects. In recent years, with the rapid expansion of the investment and construction of China's chemical project, the human resources of the design unit are very tense. It is becoming more urgent to realize the optimal allocation of human resources in the design department when predicting the artificial time. The quantitative prediction of the working hours is different from the prediction method used in the general time series problem. At present, the relationship between the prediction variables and the related variables in the historical data is mainly analyzed by the factor analysis method to predict the artificial time.

The technology of working time quantitative prediction has been developed in the product design time of the machinery manufacturing industry and the prediction of the processing time of the product, but it is seldom used in the field of chemical engineering design, and the literature about the artificial time prediction of the chemical equipment design is rare. Chou and Pham quantitatively analyzed the impact of factors such as project complexity on development time by regression analysis theory (Chou and Pham, 2015). Lee and so on set up a working time estimation model for machining center of mechanical manufacturing industry (Lee et al., 2014). The expression of the regression analysis modeling is not accurate enough for the actual problem, and the prediction deviation is large. For the systems difficult to establish an accurate mathematical model with multiple nonlinear systems, Yadav and Chandel applied back propagation (BP) neural network for modeling to predict the working time, which has achieved good results (Yadav and Chandel, 2014). At present, the research of back propagation neural network has made remarkable progress. At the same time, the application of neural network in the prediction of time series is also getting more and more attention. Because the neural network has the characteristics of nonlinear, high dimension, unpredictability, attraction and its large-scale parallel processing, it is obviously superior to the traditional linear prediction method in predicting the nonlinear time series with high complexity, and has been applied to the capital stock market, the weather factor time series, and the prediction of population and insect, showing its application prospect.

Because BP neural network can easily generate local minimum value and have slow convergence speed during training, Betiku et al. used genetic algorithm to optimize BP neural network (Betiku et al., 2015). Genetic algorithm is an optimization method proposed in 1975 by Professor J H Holland who was inspired by the theory of biological evolution and natural selection. It simulates the phenomena of reproduction, mating and mutation occurring during natural selection and natural genetic processes. The solution of the problem is expressed as a chromosome (generally expressed in binary), thus forming a group of chromosomes. And they are placed in a problem environment, and the chromosomes adapted to the environment are selected according to the principle of survival of the fittest. Three genetic manipulations of reproduction, crossover and mutation are carried out to produce a new generation of chromosomes which are more adaptable to the environment, so that the generation can evolve continuously, and finally converge to a most adaptable individual to obtain the optimal solution of the question. Aghbashlo and other scholars used the kernel approximation algorithm and the Support Vector Machine (SVM) algorithm for working time prediction, and achieved good results (Aghbashlo et al., 2015). In view of the characteristics of the manufacturing industry, the design time or processing time of a single mechanical product is much different from that of the chemical equipment design table, the variety of equipment and design, the minimum size of the machine and the characteristics of the process composition system, but the research methods are of reference significance for the prediction of artificial time for the chemical equipment design.

To sum up, the above research mainly introduces the knowledge of the chemical equipment design process, the main body, and the artificial time, and does not have much research to link the neural network with the genetic algorithm and the artificial time prediction. Therefore, based on the above research status, in order to realize the artificial prediction of chemical equipment design, this paper mainly studies the artificial time prediction of chemical equipment design based on genetic algorithm optimization back propagation neural network. Firstly, the relationship between the management process of chemical equipment design and the design characteristics and artificial time is analyzed, modeling method is put forward, and the selection of input and output parameters of the model is realized through parameter analysis. Then, it is modeled with different algorithms, and a suitable model is selected by comparison. Finally, an application example is given. In a word, the research has certain practical value and innovation.

3. Method

The man-hours required for chemical project design is closely related to the management flow and design features. This paper conducts analysis on chemical equipment design project management flow based on integrated WBS and OBS as well as quota management method. Then it conducts analysis on the differences between chemical equipment design and other machinery designs and their implications on the man-hours needed. It then proposes modeling plans for man-hour prediction. See Figure 1 for an example.

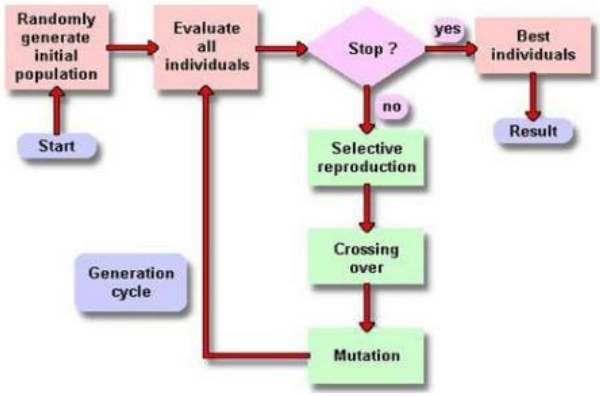

Figure 1: Genetic algorithm flow chart

3.1 Flow Analysis

A project flow chart based on integrated WBS and OBS is in Figure 1. The technique designer should, based on WBS, perform preliminary decomposition of the project, i.e. in a decomposition sequence of project→facility→main item→sub item→equipment, while the person in charge should conduct detailed WBS decomposition that categorizes the work items. A work item means the work needs to be completed for project design, and each equipment may have multiple work items, such as construction drawings, engineering drawings, data sheets, and supplier information. Eventually, full WBS is set up, including facility→main item→sub item→equipment→work item.

The design agency is typically an organizer of multiple undergoing projects. When conducting OBS decomposition, the equipment department of the agency should appoint a person in charge for each project, who under the guidance of the department head and project managers, takes up overall responsibility to the design projects. The person-in-charge then appoints one or more members from his team to take on different designing roles (main roles include designer, mapper, checker and approver) as decomposed by WBS. The OBS decomposed tree-like relations is shown in Figure 2.

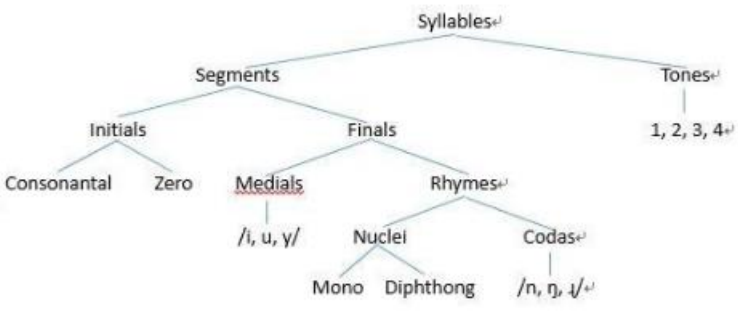

Figure 2: Chemical equipment design project responsibility matrix

The work item and design members mapped as work task (see the black dots in Figure 1) forms a matrix, which is the responsibility matrix that multiplies WBS decomposed results with the OBS decomposed results. When the person-in-charge allocates work, he determines the work type and relevant parameters based on the content under work items, identifies the man-hour quota using the quota management technique, and further allocates the man-hours to different roles based on the responsibility matrix. The members with different roles and responsibilities should not perform work under the same work item. The work should proceed in the sequence of design, drawing, checking, examining and approving in the same flow indicated in the responsibility matrix in Figure 1.

The design agency should perform quota management on the man-hours, where man-hour quota needed for completion of a work item is the product of the number of drawings, difficulty factor, reduction factor, specified man-hour under a work type, and total allocation ratios of responsibilities (which might not be 1). The total man-hours needed for the design project equals the total man-hours under all work items. Normally, a chemical project requires designs of detailed drawings for dozens and even hundreds of non-standard equipment and appearance design for prototype equipment, which is very time-consuming. So it is an effective approach to realize improved human resources allocation through quantitative prediction of man-hours with WBS decomposition results, and further determination of number of roles for each group using OBS decomposition results.

3.2 Modeling Plans

When selecting the output parameters, specific considerations should be given to analyze the work features of chemical equipment design and speciality of the work types. In order to have a clearer understanding on the man-hours needed for each work type, the predictive variable is set as the corresponding man-hour to each work type, and the addition of all man-hours under all work types is the total man-hour needed for the project.

When determining the input parameters, a calculation should be conducted on the man-hours needed for the work types recorded as the historic data in the database, and conduct parameter contribution degree and relevance analysis on the calculation results (in Table 1 and 2). At the same time, use the parameters (mostly from WBS decomposition) to predict the difficulty factor of prediction, and select proper a model for parameter input. Then adopt BP, GA_BP, and SVM for modeling. The prediction results are compared to determine a proper algorithm for man-hour prediction for chemical equipment design.

Table 1: Features parameters of the project

Parameter	Instructions	The determinants
HR	When a work type is rated manually	Type of work
NE	The number of equipment in a work type	The process flow
NF	Number of working type files	Equipment complexity
ND	The number of drawings of a work type	Equipment complexity
CD	The difficulty factor of a certain type of work	How easy is it

Table 2: Item information parameter

Parameter	Instructions	The determinants
T1	The product type	None
T2	The project type	None
Y	Production	None

When conducting the calculation on the initial data in the database inventory, to eliminate impacts of the highly reusable projects, non-standard (initial design, technological update, and expansion or supplementary) projects, and projects with incomplete information, we consider projects with average difficulty parameter below 0.3 as highly reusable projects, projects with total number of equipment below 20% of average total number of equipment under the same product category as non-standard projects, and projects with total man-hours below 20% of average total man-hours under the same product category as projects with incomplete information. The judgement logical expression is:

$$CD\_A < 0.3 \| (N1\_T1)$$

4. Results and Discussion

Considering there are many factors influencing man-hours needed for chemical equipment design, and the relationships among the factors are complex, it is a highly non-linear issue. Historic data reflects the inherent

pattern of change within the system, and a certain inventory of historic data tells the pattern and the underlying mechanism. Machine learning algorithm is a way that enables the machine to automatically learn the patterns and mechanisms from historic data, output the physical quantities with complex causal relationships after proper training, and use the patterns to predict future information. This paper adopts the algorithms of BP, GA_BP and SVM to construct non-linear models for calculating man-hours needed for chemical equipment designs, to understand the complex relationship between man-hours and the factors, and to select a proper model for the prediction that outputs the best results.
BP neural network is a gradient descend algorithm based on empirical risk minimization, a widely-adopted artificial neural network known for being able to realize non-linear function mapping. In addition, BP neural network has advantages in simple structure and easy operation. The input parameters for the model based on BP algorithm is HR (specified man-hours for work type), ND (number of drawings), CD (difficulty factor), and the output parameter for a certain work type is MH (man-hour). The BP neural network algorithm can have different numbers of hidden layers. This model selects a three-layered network structure based on the Kolmogorov Theorem. The determination of number of neurons is also highly relevant. Preliminarily, it is scoped using 2N+1 as number of neurons based on Hecht-Nieisen, and further tested for a number of times using the test-and-error method. When the hidden layer number of neurons is 7, the model has the optimal training results. Hence the topology structure for the prediction model of man-hours in chemical project design in Figure 3 and 4.

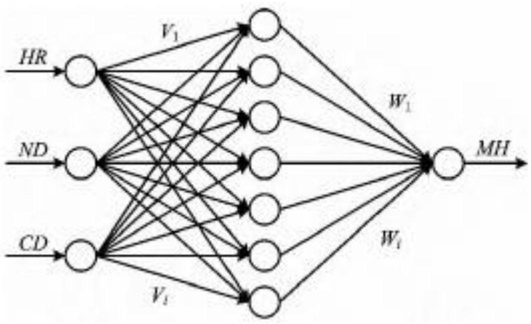

Figure 3: Topology of prediction model based on BP algorithm.

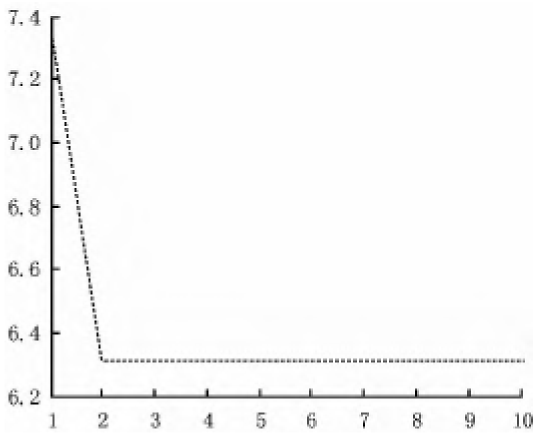

Figure 4: GA average fitness curve

5. Conclusion

Prediction of project man-hours needed at an early phase is an important baseline for setting the investment price, project schedule, and human resources allocation. But currently the man-hours prediction is heavily reliant on empirical experiences and has high error rates. This paper adopts the GA_BP algorithm for modeling. First, we prepare the historic project data from previous chemical equipment projects, conduct analysis in line with the parameter relevance to select proper parameters for further testing of relations among parameters, and implement controls on the key parameters. Then prediction models are set up to predict man-hours for each work type. Compared to the traditional BP algorithm, the GA_BP algorithm has low error rates, higher accuracy and stable performance. The method advocated in this paper provides good support for overall project management, and facilitates human resources allocation by utilizing the prediction results. Project managers can allocate human resources in line with the work type categorization, and reduce the potential shortage or over-staffing with the help of this method, which is going to play a significant role in future chemical projects and other types of designs.

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