A CASE-BASED ENTERPRISE INFORMATION SYSTEM FOR THERMAL POWER PLANTS' SAFETY ASSESSMENT

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Abstract: Security assessment of Thermal Power Plants (TPP) is one of the important means to guarantee the safety of production in thermal power production enterprises. Modern information technology may play a more important role in TPP safety assessment. Essentially, the evaluation of power plant systems relies to a large extent on the knowledge and length of experience of the experts. Therefore in this domain Case-Based Reasoning (CBR) is introduced for the security assessment of TPPs since this methodology models expertise through experience management. This paper provides a case-based approach for the management system security assessment decision making of TPPs (MSSATPP). A case matching method named CBR-Grey is introduced in which Delphi approach and Grey System theory are integrated. Based on this method, we implement a prototype of enterprise assessment information system (CBRSYS-TPP) for the panel of experts.

1 INTRODUCTION

Thermal Power Plants (TPPs) equip numerous industrial departments and their productive process is very complicated. In TPPs, the frequency of accidents with serious consequences is extremely high. When operating TPPs, the safety of people's lives and work conditions is a major concern. There are numerous TPPs all over the world. Taking China as an example, there are over 1200 coal-fired thermal plants (Yang, Guo and Wang, 1999). As one of the strongest nations in electric power generation, due to various limitations and causes, China produces its electric power mainly from coal (Williams, 2001). In Turkey as well, 80% of the total electricity is generated from thermal power plants (Oktay, 2009). For the purpose of reducing major and extraordinarily large accidents in TPPs and ensuring the security of electric power production, an increasing number of thermal power enterprises in China pay more attention to the security assessment issue.

Security assessment of TPPs mainly concerns three different aspects: Production Equipment Systems (PES), Working Circumstance Systems (WCS), and Management Systems in production. The latter is also referred to as the Management System (MS) in current research. By the analysis and evaluation of these three subsystems, the TPPs establish the necessary corrective, remedial, and preventive measure, and finally realize the aim of controlling the accidents in advance. As one of modern management ladders, safety assessment of TPPs is one of powerful tools for automatically diagnosing safety issues. However, numerous evaluations for production safety are irregular, unscientific, and capricious, as well as lacking

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powerful information and knowledge support. Along with the increasing perfection of security assessment rules and the development of information technologies, new techniques are being applied to almost all aspects of power systems to improve efficiency (Zhao, Wang, Nielsen, Li and Hao, 2010). It is of both major significance and profound social consequences for TPPs to make their security assessment process progress toward the quantification, scientization, and automatization. MS security represents an important part of the security issue in the production of TPPs. Numerous facts show that a large part of safety accidents in TPPs occurred due to the managerial inadequateness and not for the equipment malfunctions.

First, common evaluation issues concerning the power industry have been reported in the literature. In view of the special importance of production security for TPPs, it is important to study scientific approaches that fit the characteristic features of the production and management of TPPs for security assessment. However, few research studies focus on the safety assessment of TPPs in production - the inside security itself. Most of the literature focuses on the operational performance (Liu, Lin, Sue and Lewis, 2010), energetic and exergetic performance analyses (Erdem, Ali, Burhanettin, et al, 2009), the selection of an optimum power plant (Garg, Agrawal and Gupta, 2007), air quality impact (Kumar, Mahur, Sengupta, Prasad, 2005; Petkovšek, Batič and Lasnik, 2008), and ecological efficiency (Lora, Salomon, 2005). Second, as far as content assessment is concerned, few studies concern safety evaluation of management work. In terms of evaluation approaches, few approaches are actually able to solve the problems of providing powerful and helpful information support for experts' decision making and the reuse of domain knowledge. Until now, rare contributions have been made to the assessment approaches for management security of thermal power plants. As an important technology in artificial intelligence, CBR can provide an information support for the whole process of MSSATPP decision making. Part of its advantage lies in that it can capture expert knowledge, provide methods for knowledge management, and give suggestions for fast problem-solving. Different from ANNs and decision trees, CBR can address the problem of over fitting.

In the area of evaluation research, there are also many articles concerning CBR, such as the applications of CBR to software cost estimation (Zhuang, Churilov, Burstein and Sikaris, 2009), software effort estimation (Mukhopadhyay, Accordingly, there is a sizable margin of error. Vicinanaza and Prieutula, 1992), risk assessment in audit judgment (Chang, Lai and Robert, 2006) , risk analysis for electronic commerce (Jung, Han and Shu, 1999), web break sensitivity evaluation in a paper machine (Ahola and Leiviskä, 2005), safety risk analysis in information security systems (Bang, Kim and Hwang, 2008), safety evaluation of process configuration (Gu, Liang, Li, et al, 2010), and so forth. In this article, we apply CBR to MSSATPP, and propose a whole evaluation approach integrating weight derivation approaches and case retrieval algorithms for MSSATPP. The research novelty of our work lies in that by taking the management system of whole power systems as an example, we integrate Grey System Theory and Delphi method into case-based reasoning, and then apply the optimized CBR to enterprise information system for MSSATPP (CBRSYS-TPP).

2 BACKGROUND

Power plant safety evaluations are performed by panels of experts through investigation, discussion, and negotiation. This process is explained in this section, as well as the motivations for building the CBRSYS-TPP system.

2.1 TPP Safety Evaluation Process

Security assessment is one of the important measures and safeguards for enforcing the electric security basis in TPP production and for guaranteeing safe, stable, and economical TPP operation. As an important part of the whole security assessment work of TPPs, MSSATPP is an all-around examination and evaluation of the safety management work in the production of TPPs. Two different parts are involved in the security assessment of TPPs: inside evaluation and outside foreign expert evaluation, respectively. The former is operated by a thermal power plant itself. Power companies organize expert groups with relevant personnel to evaluate their safety status, identify issues, and then propose revision suggestions according to the evaluation index, standard, or criterion. The latter is generally organized by the electric power company responsible for a group of TPPs. To do so, the electric power companies organize audits in which relevant experts complete their evaluation work. To prepare for the actual audits performed by the electric power companies, most of the electric power incorporations currently complete their internal thermal power plants safety evaluation work through external experts' evaluation. The complete evaluation steps are approximately as follows:

Step1: organize an experts' group to conduct the assessment. The experts can come from a technical layer, a management layer of the electric power companies, the institutes of the electric power, or universities or government departments related to electric power.

Step2: determine the weights associated with the evaluation index or the total score of each index by DELPHI method (Kayacan, Ulutas and Kaynak, 2010);

Step3: organize the experts' visit to the thermal power plants and their scoring through the fact-finding inspection;

Step4: gather the score, conduct group discussions, and finally make decisions. Usually, the evaluation can end in one of two ways: qualified with minor correction and remedy or unqualified with major correction and remedy.

One detail deserves to be paid attention to here: the conclusion is not obtained simply by the direct addition of the scores from the experts. The real decision making process is that the experts' group draws the final conclusions through discussion and consultation. The rule of "who gets a high score, who passes" is not necessarily clear-cut. This process is understandable because evaluating the security on basis of the scores only is not reasonable. Different thermal power plants are evaluated by different experts' groups, and the scoring measures of experts may be different due to their diverse characters, moods, and knowledge background. Therefore, electric power enterprises come to conclusions through comprehensive group evaluation. In this practice, historical or antecedent cases are very valuable for the decision making process of these experts.

Several limitations of in the evaluation process described above can be highlighted as follows. First, the evaluation approach presents too much subjectivity. It generally requires high costs, a long time, and hard labour, but lacks efficiency. In practice, most of this kind of evaluation work is too time consuming with respect to the quality and reliability of conclusions drawn. A second limitation is the lack of knowledge and information available to support the experts' evaluation and decision making process while historical data and information could be resorted to. For the past ten years or so, thermal power enterprises have accumulated a decent number of SATPP evaluation reports. An evaluation report can be regarded as a case. The cases represent the intelligence gathering activity of experts' and permit to trace their wisdom and knowledge. As an important information resource, a large amount of cases is very valuable for reference. Unfortunately, these MSSATPP cases are left unused and not managed, analyzed, or utilized. During the evaluation process of new thermal power plants, the information resource is hard to be utilized because these evaluation reports have not been organized and analyzed. Some of them have not been standardized nor made electronically available yet. More than that, due to the lack of support of information system in which the cases are effectively organized and analyzed and the knowledge extracted from the case data, Enterprise information resource and the historical knowledge of experts cannot be communicated to the experts' group during the decision making process of MSSATPP. The third limitation is the difficulty of self evaluation and day-to-day real-time evaluation.

Therefore, it is vital for a group of experts to have intelligent information and knowledge support during decision making. Following, one important purpose of our current research is to present a more effective case matching method different from those commonly used in case-based reasoning for the safety assessment issue of thermal power plants. Another aim of our current study is to develop a case-based intelligent enterprise information system based on historical knowledge to assist the panel of experts in reaching a right decision making for MSSATPP. In the next sections, a novel case matching method combining Delphi method and Grey System theory is presented.

2.2 Evaluation Indexes

On the basis of actual investigations of coal-fired thermal power enterprises, currently, the safety evaluation of thermal power plants mainly concerns the following six aspects, which are generally regarded as evaluation indexes.

In CBRSYS-TPP, the cases represent actual historical evaluation reports which have been structured. Not only the attributes (i.e. Goal, ResponsSys, Supervision, BasicWork, SafeEdu, and IntergratedM) are included as evaluation indexes, but also other important attributes, such as the Number of Items with Deducted Marks, the Number of Major Problems, the Assessment Result, the Suggested Amendment Opinions, are represented. In Fig.1, the six indexes on the left are input variables, and four extra attributes on the right are the output variables. The values of input variables are acquired by expert group scoring. Then, the similar cases including ten rather than six attributes are able to be acquired by case matching.

The four extra attributes on the right in Fig.1 are extremely important and valuable. The former three items, i.e. Number of Items with Deducted Marks (IDM), Number of Major Problems (MP), and Assessment Result, are influential for the decision results of the current evaluation problem. The last one, i.e. Suggested Amendment Opinions, is extremely helpful as reference for the expert group to derive their suggested corrective and remedial measures based on the specific conditions of the thermal power plant. Accordingly, CBRSYS-TPP is able to be used by all the expert group members to effectively acquire their knowledge and decision support. The entire safety evaluation procedure of thermal power plants will be eventually completed with the powerful aid and support of CBRSYS-TPP.

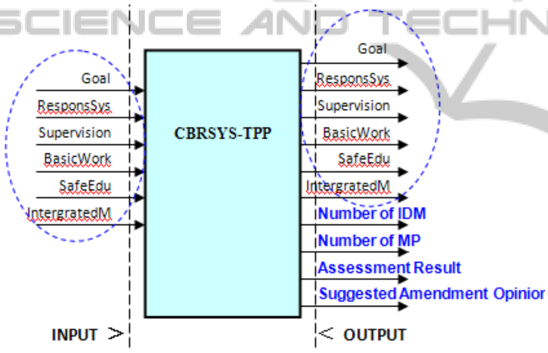

Figure 1: Evaluation indexes and four extra output attributes in CBRSYS-TPP.

3 RESEARCH METHODOLOGY

Our research methodology is presented in three parts. Part one proposes the retrieval method based on grey system theory and our improvement on it combining Delphi approach. Part two describes two statistics for performance evaluation of our proposed method. Part three presents our implemented enterprise information system and data set for as experiments.

3.1 Decision Information Acquiring Method

In our study, we use grey system theory combining Delphi approach to complete the acquisition of decision information. In CBR systems, the information acquisition is also called case matching or case retrieval. The most famous case matching method is the traditional CBR retrieval algorithm which is based on Euclidean distance. Besides, other methods such as neural networks, genetic algorithms and fuzzy logic are also studied in previous literature (Aamodt and Plaza, 1994; Mántaras, McSherry, Bridge, Leake, et al, 2005; Bichindaritz and Marling, 2006).

However, there still exists a gap between the abilities of these techniques and the real requirement to improve their accuracy and to provide more detailed decision information. In this article, grey system theory and Delphi method are integrated into case-based reasoning technology and CBR-KNN is introduced as a novel case matching method.

Grey System Theory was first built by Ju-Long Deng in 1982 (Deng, 1982). All systems with incomplete information can be regarded as grey systems (Liu and Wang, 2008). The case retrieval algorithm for knowledge acquisition of MSSATPP has been based on grey relationship analysis. As one of the system analysis techniques, grey relationship analysis is an approach for analyzing the degree of association among different factors. Here, we integrated it into CBR for MSSATPP and proposed CBR-Grey. The fundamental steps using grey relationship analysis for case retrieval in MSSATPP are as follows (Lu, He and Du, 2008).

Step1. Determine the evaluation index system according to the evaluation purpose, and then collect evaluation data.

Suppose there are m data series which form the following matrix:

$$(X_1, X_2, \wedge, X_m) = \begin{pmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mn} \end{pmatrix}$$

where n denotes the number of evaluation indexes, and m is the number of historical MSSATPP cases in the case base.

Step2. Use Delphi method and obtain all weight values of the indexes. The Delphi method is a systematic, interactive forecasting method which relies on a panel of experts. This technique is based on the principle that forecasts from a structured group of experts are more accurate than those from unstructured groups or individuals (Harman, 1992).

Step3. Determine the reference data series. The reference data series should be an ideal contrast standard. They can be composed of the optimal value or worst-case value of the indexes as well as other reference values that are selected according to the evaluation purpose. In our current research, the reference data series is the target case to be solved and the attribute values are those of the objective case to be solved. Let X_0 denote the reference data series, $X_0 = \left(x_0(1), x_0(2), \cdots, x_0(m)\right)$.

Step4 Normalize the data.

Step5 Compute the absolute differences between the corresponding elements of reference data series and comparisons from the case base, namely $|x_{0k} - x_{ik}|$, i=1, 2, …, m ; k=1, 2, …, n., where k denotes the number of attributes, and i denotes the number of evaluation objects.

Step6 Derive the values of $\min_i \min_k |x_{0k} - x_{ik}|$ and $\max_i \max_k |x_{0k} - x_{ik}|$.

Step7 Compute the correlation coefficient. By Formula (1), respectively compute the correlation coefficients between each comparative series and reference series. In Formula (1), ρ denotes the resolution ratio, and its values range from zero to one. The smaller ρ is, the bigger the differences among correlation coefficients are, and the stronger the separating capacity is. Generally, the value of ρ is 0.5. *i* denotes the case number in the case base. $\zeta_i(k)$ represents the correlation between the target case and case *i* in the case base for index k.

$$\zeta_i(k) = \frac{\min_i \min_k |x_{0k} - x_i| + \rho \cdot \max_i \max_k |x_{0k} - x_{ik}|}{|x_{0k} - x_{ik}| + \rho \cdot \max_i \max_k |x_{0k} - x_{ik}|} \tag{1}$$

Step8. Compute correlative series. Respectively compute the average value of the correlation coefficients between the corresponding elements of the reference series and every evaluation object (comparative series). This average value, named correlation series, can reflect the correlation relationship between the reference series and the comparative series denoted by i. We mark it as follows.

$$r_{0i} = \frac{1}{\mathrm{n}} \sum_k \zeta_i(k) \quad \text{(k=1, 2… n)} \tag{2}$$

Step9 When the indexes have different roles and importance in comprehensive assessment, we can compute weighted means which can be shown as follows.

$$S_{global}(\mathrm{i}) = \frac{1}{\mathrm{n}} \sum_k \mathrm{w}_k \cdot \zeta_i(k) \quad \text{(k=1, 2 … n)} \tag{3}$$

where w_k denotes the weight of index k.

Step10 Derive the comprehensive assessment result on the basis of the correlation series of all the objects of observation: $S_{global}(1)$, $S_{global}(2)$, … $S_{global}(\mathrm{m})$.

In the above descriptions, the local similarity is represented by the grey association degree of the characteristic attributes. The global similarity is derived by the weighted addition of all the local similarities. For the different importance of the evaluation indexes of thermal power plants, the weight can be integrated into the computing process of a comparative environment when the local similarities are being computed. Therefore an improved local grey association algorithm is derived and further expressed as follows in equation (4).

$$\zeta_i^{'}(k) = \frac{\min_i \min_k \mathrm{X(i,k)} + \rho \cdot \max_i \max_k w_k * \mathrm{X(i,k)}}{(w_k * \mathrm{X(i,k)}) + \rho \cdot \max_i \max_k w_k * \mathrm{X(i,k)}} \tag{4}$$

Where $\mathrm{X(i,k)} = w_k |x_0(k) - x_i(k)|$. The local grey similarity of the index k between the objective case and historical evaluation case can be defined as follows.

$$\zeta_i^{dist}(k) = \frac{1}{\zeta_{\mathrm{i}}^{'}(k)} - 1 \tag{5}$$

According to the definition of the Euclidean distance, the global similarity between two cases can be defined as follows.

$$\zeta_{\mathrm{i}}^{\mathrm{global}} = \sum_{k=1}^{m} (\zeta_i^{\mathrm{dist}}(k))^2 \tag{6}$$

Thereby, the global similarity of two cases can be derived by the following formula. The case chosen for reuse is the one maximizing the global similarity.

$$S_{\mathrm{i}}^{\mathrm{global}} = \frac{1}{\zeta_i^{\mathrm{global}} + 1} \tag{7}$$

3.2 Performance Evaluation Statistics

In this research, to evaluate the performance more fully, two statistics are used to evaluate the performances of different case matching methods.

One is the accuracy, the most commonly used index for the evaluation of performance.

Another is the $F_{-\mathrm{value}}$. In the fields of statistics and information retrieval, the sensitivity and specificity are generally used for evaluating an algorithm (Rowe and Wright, 2001). Sensitivity and specificity are complementary of each other. The simple improvement in sensitivity will lead to a decreasing specificity, and vice versa. Thereby, a good retrieval system should demonstrate both high sensitivity and specificity, but in reality a retrieval system performance tends to be a tradeoff between them avoiding too low sensitivity or specificity. The combined effect can be evaluated by the F–value.

3.3 Data Set

The data set for our experiments are mainly collected from a mega electric power enterprise group, GreatT Power Generation Group of China (GreatT). As one of the largest power generation corporations in Asia, she owns over one hundred power plants, most of which are coal-fired thermal power plants. The data set are mainly the historical security assessment data of TPP of GreatT over the years. Most of the data are the newest assessment reports of SATPP occurring between 2007 and 2009. Since these TPPs vary in their degree of informatization and electronic data were not even available in parts of them, the task of collecting the data was hard. The current project team collected a total of 120 MSSATPP records, and 106 complete and valid cases were acquired after displaying and analyzing. Among them, the number of positive cases is 56, and the number of negative cases is 50. The assessment reports from the same thermal plants but occurring in different years will be regarded as two different records. Taking LuoHo' Power Plant for example, its two reports in 2008 and 2009 are two different records of the data set. In these data, there are at most three data records occurring for the same thermal plant. These three data records are for three different years.

In this research, we conducted the experiments by 10-fold-cross-validation. The test data are extracted randomly. For each test, 96 cases will be used as historical data in the case base, and the remaining 10 cases represent the testing data (five positive cases and five negative cases respectively). For each experiment, the tests will be repeated ten times. Although the data set is not very large, since there are only six attributes in the cases, according to the usual requirement: number of attributes / number of data should equal 1:10~1:20, it can satisfy the experimental requirements (6 / 106 = 0.057).

4 SYSTEM IMPLEMENTATION AND EXPERIMENTS

We implemented a prototype of CBRSYS-TPP and used it to complete the following experiment regarding the performance of information acquisition. In this section, we completed two different experiments. The first one is to test the accuracy, sensitivity and specificity as well as calculate the F_{macro}-Value of our proposed case matching methods which combines Delphi method and grey system theory. And the second one is to test several common classification methods using the same data set. 10-fold-cross-validation tests were conducted. The performance of the methods is evaluated by accuracy, F_{macro}-value and several statistics. In each 10-fold-cross-validation, the data set was divided into ten mutually exclusive subsets with the same distribution using Matlab R2008a. Each fold should be used only once to test the performance of the retrieval algorithms. The most similar cases were generated from the remaining nine folds.

4.1 Comparison Tests with KNN

In the first experiment, tests compare different case matching methods: the traditional case retrieval method and our proposed approach. By the tests, the accuracy of CBR-Grey is 94%. The average sensitivity, average specificity, recall and F_{macro}-value are 96%, 92%, 92.3%, 96%, and 94.11% respectively. Meanwhile, the traditional KNN based on Euclidean distance algorithms is used as the second retrieval method to acquire similar cases. In this experiment, the value of K selected is seven. The accuracy of CBR-KNN is 90%. The average sensitivity, average specificity, precision, recall and F_{macro}-value are 91%, 90%, 91%, 91.07%, and 90.03% respectively. The results are still acceptable. But by comparison, CBR-Grey has significantly higher accuracy and better comprehensive performance.

4.2 Comparison with Other Methods

Neural networks (especially RBF Network), decision trees and logistic regression are also common methods for different assessment issues, especially binary classification evaluations (Boyen and Wehenkel, 1999; Kim and Singh, 2005; Amjady, 2003).

In the current study, comparative experiments were conducted between CBR-Grey and the other two methods: RBF Network and logistic regression. The first tool for this experiment is Weka 3.6.2 in which RBF Network is integrated. The second tool is SPSS15 which is the platform for logistic regression analysis. The data set used here are still the GreatT TPP data set.

Table 1: The comparative experimental results of four different approaches (based on Great TPP dataset)

Method	Accuracy	Precision	Recall	F-value	Exp. Tool
CBR-Grey	94.00%	92.30%	96.00%	94.11%	CBRsys-TPP, Matlab R2008a
Logistic Regression#	91.50%	91.07%	92.73%	91.89%	SPSS15
RBF Network	84.90	80.00%	89.30%	84.39%	Weka3.6.2

#: the cut value is .500;

10-fold-cross-validation tests were conducted. The experimental results are shown in Table1. Among them, CBR-Grey has the best accuracy (94%) and F-value (94.11%). Logistic regression has 91.50 % of accuracy and 91.89% of F-value. Nevertheless, RBF Network only has 84.90% of accuracy and 84.39% of F-value. Accordingly, RBF Network is not recommended for real applications in MSSATPP.

In our proposed approach, Delphi method is also regarded as part of the case retrieval method. Our experimental results highlight that, as far as practical aspects of decision support for expert panel members are concerned, in comparison with KNN based on Euclidean distance algorithm, the most popular retrieval algorithm, our proposed approach seems to present the advantage of combining the strength of Delphi method and grey system theory to complement the weaknesses of traditional case matching approaches. Meanwhile, we completed the comparative experiments among our proposed approach and three other common methods for binary classification evaluation issues. The conclusion is that CBR-Grey is the best both in accuracy and F_{macro}-value. This further illustrates the validity and high performance of CBR applied to MSSATPP. At the methodological level, the potential advantage of CBR-Grey is in its ability to acquire and reuse the historical knowledge whenever the available information is complete or incomplete.

5 CONCLUSIONS

Our proposed method integrating grey system theory and Delphi method into CBR methodologies and intelligent enterprise information system may provide intelligent decision support for MSSATPP, and the evaluation cycles of experts may be reduced with an improved efficiency. This paper provides a novel and effective way for the security assessment of thermal power plants as well as a new perspective on the use of prototypes through case aggregation which is one of the popular trends of CBR systems in recent years (Nilsson and Sollenborn, 2004). From a practical perspective, this approach can not only provide the suggested conclusion but also a whole set of evaluation and improvement alternatives for both expert panel members and TPPs.

By further trials in Luodian, one of high-power stations in China, the practical results have verified its availability and high performance again. The computerized system works well in providing the knowledge and decision making support for experts during the process of MSSATPP. According to an anonymous survey of 32 assessment experts, 29 of them (90.6%) replied that they were mainly satisfied with the effects of the CBRSYS-TPP system. All the experts expressed that they got valuable information support during the decision making and the conclusions are more scientific and acceptable than those without the support of CBRSYS-TPP. This further inflects the application values of CBR in the safety assessment of TPPs.

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