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Identification of Security Status of Production Logistics System in Coal Mine Based on RS–SVM

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Abstract: Identification of security status of production logistics system in coal mine is important to analyze the weak links and improve the safety level of coal mine safety production. Combining with the particularity and complexity of production logistics system of coal mine, this paper established an identification model of safe state by using the rough set theory (RS) and support vector machine method (SVM). It selected key safety index with the theory of rough set, and used SVM to identify safety status. It showed that identification model of security state based on RS-SVM simplified the computational complexity and improved the identification accuracy of security state.

Key words: Production logistics of coal mine, identification of security state, rough set, support vector machine

INTRODUCTION

Compared with other industries, coal production has its own distinct characteristics. Production process is mainly the change of coal physical form (mining and crushing) and space position (underground and ground transportation), and equipment, material, wind, water and other materials in the process of mining and flow of materials consist of the production logistics system of coal mine. The particularity and complexity of production logistics system of coal mine determine the coal industry is the most serious casualty accidents industry in China's industrial production. However our country coal mine safety production level is not stable and changes over time. Identification of security status of production logistics system of coal mine in a timely manner are of great significance on the analysis of coal mine enterprise safety production status, finding weak links in production safety and developing improvement plan.

At present, literatures are not directly study of coal mine safety state, rather more focused on evaluation index or evaluation index system of coal mine safety, etc. Jing *et al*. (2006) constructed the AHP model of coal mine safety capability with application of analytic hierarchy process from the perspective of systems engineering, and determined the index system of coal mine safety production capacity. Pang (2011), Xu *et al*. (2009), Liu *et al*. (2007), Zhu and Ma (2009) and Tan and Li (2011) built the evaluation index system of coal mine safety from the aspects of man, machine, environment and management, at the same time, they adopted the fuzzy comprehensive judgment method, grey clustering analysis method, extension theory and support vector machine (SVM) method to quantitatively evaluate the system. Hou etc. (Wang *et al*., 2011) constructed expert reliability model based on the similarities and differences of expert decision and got an objective, dynamic weighting from the reliability of the model, to overcome the defects of traditional static weighting method. Wang and Huo (2008) analyzed and sorted the safety evaluation results of eight mines belong to a certain coal enterprises with principal component cluster analysis method, and provided the technical basis for coal enterprise safety production management and decision.

Due to the changeable geological environment and complicated mining method, index which affects the safety status of production logistics system of coal mine are numerous, and they are temporal dynamics, nonlinear characteristics with safety status, the samples of collected data have the phenomenon such as redundancy, omission, conflict. The general regression analysis methods based on polynomial model are difficult to reflect the complicated relation between index and safety state, also are unable to identify significant key security index (Dai and Xu, 2013; Kaneiwa and Kudo, 2011). In addition, due to the particularity of coal mining, the cost of data collection are high, the sample size is small. Through the literature research findings, the rough set method is only

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starting from the data itself, not depend on any prior model, processing the redundancy, omission, conflict between data from the perspective of "rough", and support vector machine (SVM) is now recognized the best tool to set up complicated process global model under the condition of small sample. Scholars have combined the two methods both at home and abroad, and it is used in pattern recognition, fault diagnosis, regression prediction and other fields to effectively improve the model accuracy (Wang and Wang, 2010; Yao and Lu, 2011; Zhang *et al*., 2007; Ren *et al*., 2012; Chen, 2012). Therefore, this paper uses the rough set attribute reduction theory to select key safety index, using support vector machine (SVM) method to select the appropriate kernel function and its parameters, constructing the security status recognition model based on rough sets and support vector machine (SVM).

CONSTRUCTING IDENTIFICATION MODEL OF COAL MINE SAFETY STATE

The basic principle of rough set: The rough set theory is brought up by a polish mathematician named Pawlak in 1982, it is a mathematical tool to portray the incompleteness and uncertainty. Relative to statistical methods, fuzzy theory method and other mathematical methods, the rough set theory do not need to use the apriority knowledge such as probability distribution density, membership function to deal with uncertain information, also do not need other prerequisite constraints. It digs and classifies according to the data itself, revealing inner regularity of data, finding the dependent relationships between data, generating the classification rules, reducing redundant data under the premise of retaining key information, in order to find the minimum expression of knowledge (Thilagavathy and Rajesh, 2011). At present, the rough set theory is widely used in machine learning, pattern recognition, decision analysis, knowledge acquisition, fault diagnosis, etc.

The screening process of key security index of production logistics system of coal mine is shown in Fig. 1 with the basic principle of rough set reduction.

Support vector machine theory: Support vector machine (SVM) method is based on VC dimension theory and structure risk's minimum principle of statistical learning theory. It seeks the best compromise between the complexity of the model (for the learning accuracy of a specific training sample) and learning ability (identification of any samples without error) depending on the limited sample information, in order to get the best generalization ability (Sudheer *et al*., 2013).

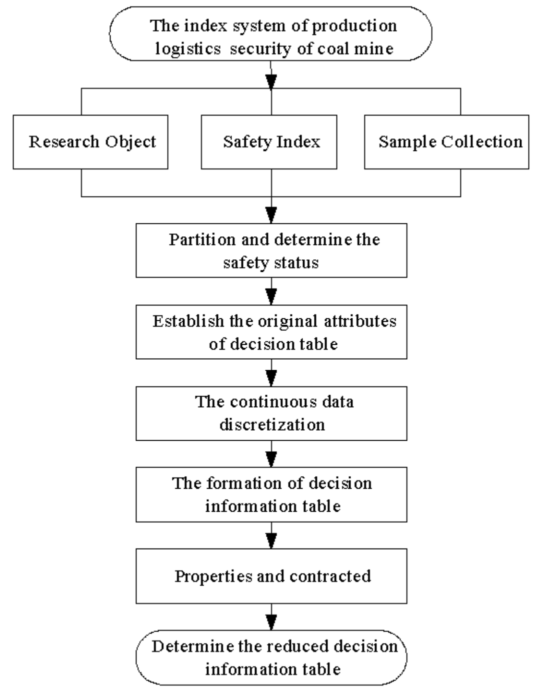

Fig. 1: The selection of key safety indexes based on RS

The SVM algorithm is purposed with the Optimal Hyperplane in the case of linear separable. The Optimal Hyperplane requires classification can not only separate two classes of samples without errors, but also make the classification gap of the two types of space is the largest. It can be represented as a constrained optimization problem:

$$\min\ \phi(w)=\frac{1}{2}\|w\|^2=\frac{1}{2}(w^Tw) \tag{1}$$

$$\text{st.}\ \ y_i(w^Tx_i+b)-1\geq 0, i=1,2,\cdots,n \tag{2}$$

The Lagrange function is defined that the original problem is transformed into the following dual problem of a convex quadratic programming:

$$\begin{cases}\max \sum_{i=1}^{n} a_i - \frac{1}{2}\sum_{i=1}^{n}\sum_{j=1}^{n}\alpha_i\alpha_j y_i y_j\left(x_i^T x_j\right) \\ \text{s.t} \qquad a_i \geq 0, i=1,\cdots,n \\ \qquad \sum_{i=1}^{n} a_i y_i = 0 \end{cases} \tag{3}$$

This is a quadratic function mechanism problem with inequality constraints, there is only one optimal solution. If α^*_i is the optimal solution, then

$$w^* = \sum_{i=1}^{n} a_i^* y_i x_i \quad (4)$$

α_i^* is the support vector as the sample is not zero. Therefore the weight vector of the Optimal Hyperplane is a linear combination of support vector. And b^* can be solved by the constraint condition $\alpha_i [y_i (w^T x_i + b) - 1] = 0$, thus the optimal classification function is obtained:

$$f(x) = \text{sgn}((w^*)^T x + b^*) = \text{sgn}(\sum_{i=1}^{n} a_i^* y_i x_i^* x + b^*) \quad (5)$$

When a hyperplane cannot separate the two class points completely (only a few points are wrong), the slack variable ξ_i can be introduced ($\xi_i \geq 0$, i =l, n), and make the hyperplane ($w^T x+b = 0$) satisfied:

$$y_i (w^T x_i + b) \geq 1 - \xi_i \quad (6)$$

When $0<\zeta_i<1$, sample point x_i is still being classified correctly, but when $\zeta_i \geq 1$, sample point x_i is wrong. Therefore, the following objective function is introduced:

$$\psi(w,\xi) = \frac{1}{2} w^T w + C\sum_{i=1}^{n} \xi_i \quad (7)$$

C is a normal number, where known as the penalty factor. At this moment, the SVM is able to implement with the quadratic programming (the dual program):

$$\begin{cases} \max \sum_{i=1}^{n} a_i - \frac{1}{2} \sum_{i=1}^{n} \sum_{j=1}^{n} \alpha_i \alpha_j y_i y_j (x_i^T x_j) \\ \text{s.t} \quad 0 \leq a_i \leq C, i = 1, \cdots, n \\ \quad \sum_{i=1}^{n} a_i y_i = 0 \end{cases} \quad (8)$$

IDENTIFICATION MODEL OF SECURITY STATE BASED ON RS - SVM

This article screens out the key safety indexes with the attribute reduction methods combined rough sets and support vector machine (SVM) effectively. On the basis of the above, this article begins the sample training with support vector machine (SVM), so as to construct the identification model of security state of production logistics system of coal mine, as shown in Fig. 2 (Wang *et al*., 2013; Yan *et al*., 2008).

- Making the security index data of production logistics system of coal mine into information decision table.
- Using the rough set and boolean reasoning methods to discretize the continuous data.

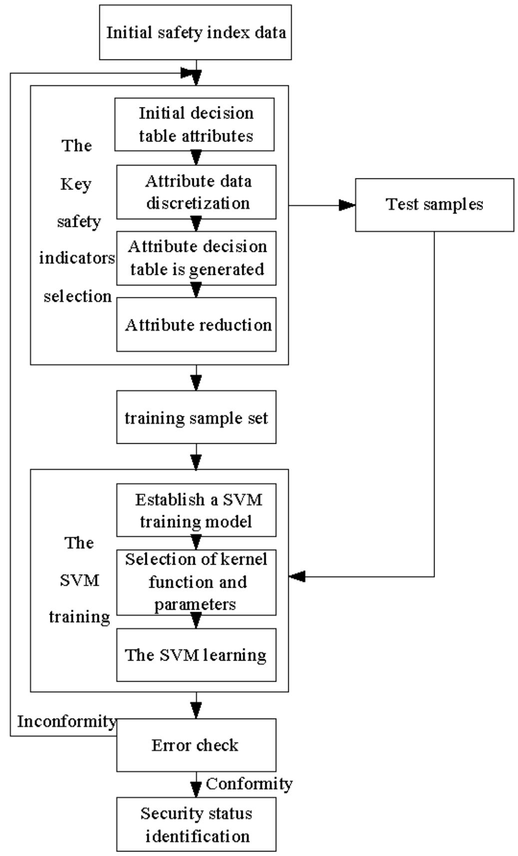

Fig. 2: Identification model of security status

- Under the condition of classification ability of decision table is unchanged, using the attribute reduction algorithm of rough set to deal with the discretized decision table, in order to obtain the reduction of the sample data.
- Selecting training samples and testing samples from the reduction of sample data, determining the kernel functions and parameters, constructing the SVM model, and testing the SVM with test samples.
- Identifying the safety status of production logistics system of coal mine based on the output of SVM. If it cannot meet predetermined requirement, repeating the above steps until the output is satisfactory.

RS - SVM MODEL IN THE APPLICATION OF IDENTIFICATION OF SECURITY STATE OF PRODUCTION LOGISTICS SYSTEM OF COAL MINE THE SELECTION OF INITIAL SAFETY INDEX

Due to the coal mine production is affected by the cross influence of many factors, such as ventilation, energy, materials, equipment, water, in fact production

Table 1: Security index system of production logistics system of coal mine

The target layer	The first level index	The secondary index and the sign
Coal mine safety	Coal mining safety	Upper and lower trough and a security exit design(X1)
		Working surface blasting(X2)
		Roof control(X3)
		Mechanical and electrical equipment(X4)
	Excavation safety	Excavating machinery(X5)
		Road maintenance(X6)
		Tunneling blasting(X7)
	Mechanical and electrical safety	Lifting equipment(X8)
		Power supply system(X9)
		Electrical equipment and maintenance (X10)
	Transportation safety	Inclined roadway and road transport(X11)
		Transportation equipment(X12)
	Ventilation safety	Ventilation facilities(X13)
		Ventilation system design(X14)
		Safety monitoring(X15)

logistics system of coal mine is a complex system characterized by the coexistence of diverse logistics, including seven kinds of logistics forms, such as man, wind, water, power, coal, waste rock, material. According to the characteristics of the seven different logistics forms, this paper constructs the index system of production logistics system of coal mine security from coal mining, excavation, mechanical and electrical, transportation, ventilation, as shown in Table 1 (Lu *et al*., 2003).

According to the requirement of identification of security state of production logistics system of coal mine, the safety degrees are divided into two levels: safe and unsafe, respectively represented by 1 and -1.

THE SELECTION OF KEY SAFETY INDEX

Collection of sample data: Based on the research of the national 50 coal mining enterprises, 50 groups of the sample data of production logistics system of coal mine safety index and safety status are obtained from the historical data. And 40 groups are the training samples, 10 groups are a test samples. For the training sample set, the domain of discourse is U=40,C={X1,X2,X3,X4,X5, X6,X7,X8,X9,X10,X11,X12,X13,X14,X15} is continuous condition attribute set, D={1,-1} is decision attribute set, -1 is not safe, 1 is safe.

Processes of sample data: Applying rough set to deal with decision table requires the data must be discrete, so it is need to do the discrete data preprocessing before attribute reduction. The essence of the data discretization is selecting a group of breakpoints to condition attribute space into a finite number of regions, in order to make the

Table 2: Attribute reduction profile

	REDUCT	SUPPORT	LENGTH
1	{X10, X13, X14}	100	3
2	{X9, X13, X14}	100	3
3	{X5, X7, X15}	100	3
4	{X4, X5, X7}	100	3
5	{X5, X7, X10}	100	3
6	{X5, X13, X14}	100	3
7	{X4, X5, X14}	100	3
8	{X5, X7, X13}	100	3
9	{X3, X5, X14}	100	3
10	{X8, X14, X15}	100	3
11	{X7, X10, X13}	100	3
12	{X4, X10, X14}	100	3
13	{X5, X7, X9}	100	3
14	{X4, X14, X15}	100	3
15	{X10, X14, X15}	100	3
16	{X6, X7, X8, X13}	100	4
17	{X1, X4, X8, X14}	100	4
18	{X4, X6, X8, X14}	100	4
19	{X3, X7, X13, X15}	100	4
20	{X7, X8, X13, X15}	100	4
21	{X1, X7, X10, X15}	100	4
22	{X1, X8, X13, X14}	100	4
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Table 3: The results of RS - SVM model and SVM model

The test sample	RS-SVM Identify Results	SVM Identify Results	Actual value
1	-1.00	-1.07	-1
2	0.97	0.88	1
3	-1.01	-1.09	-1
4	0.82	0.62	1
5	1.00	0.95	1
6	-1.00	-1	-1
7	1.00	0.99	1
8	-1.00	-1.02	-1
9	0.92	0.63	1
10	-1.00	-1.01	-1
The accuracy of model	100%	98.6%	--

objects in each region have the same decision attribute. The software of rough set processing (rosetta) includes boolean reasoning, manual, entropy and naive scale of 9 kinds of discrete algorithm. This article selects a boolean reasoning method to discrete the data, with attribute reduction of decision table based on the genetic algorithm. The results are shown in Table 2.

Screening of key safety index: It's not hard to find from the Table 2, under the premise of safe of production logistics system of coal mine, the original 15 attributes can be reduced to three or four. It significantly reduces the size of the sample set, simplifies the input space of SVM and computational complexity. According to production status of our country's coal mine safety, (X3,X7,X13,X15) is selected from many groups of attribute reduction profile. Namely roof control, the tunneling blasting, ventilation and safety monitoring are selected for critical safety index, as the input vectors of SVM model.

THE MODEL TRAINING AND RESULT ANALYSIS

This article selects Gauss radial basis (RBF) as kernel function of recognition model, its width coefficient isó=10, and model parameters are C = 100, epsilon = 0.001 with the optimal selection. According to the key safety index after reduction, a random sample of 40 sets of training samples are training with libsvm software package, and the other 10 groups sample data are testing. On the premise of the normalized data processing, the results of RS - SVM model and SVM model are shown in Table 3.

It is thus clear that the evaluation results of RS-SVM and SVM are basically identical, in accordance with the actual situation. But the recognition accuracy of safety state has been improved after the attributes reduction. This is due to the attribute reduction removes the redundant attributes of original data and reduces unnecessary condition attribute. It makes the streamlined attribute more representative, and recognition accuracy of RS-SVM method's safety status reaches 100%.

CONCLUSION

The rough set and SVM method can realize the identification of security state of production logistics system of coal mine. The identification by means of using rough set to achieve attribute reduction of safety index, screening key safety indexes and selecting the appropriate kernel functions and penalty factors. The model results show that identification of security state based on RS-SVM model simplifies the computational complexity and improves the identification accuracy of security state compared with the traditional SVM.

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