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Risk Prediction of LNG Power Vessel Filling Operation in RS-SVM Combined Model

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Abstract

In view of the reliability and efficiency of risk prediction for the filling operation of LNG-fueled ship, a risk prediction model for filling operation of LNG-fueled ship based on rough set-support vector machine (RS-SVM) is constructed. Under the condition of not changing the sample classification quality, the RS method was used as a feature parameter to reduce the pre-processor, and then the classification modeling was performed based on the SVM method. Taking the LNG power boat filling operation process as an example, the personnel, the environment, and the equipment were used. The establishment of risk indicators system. Genetic algorithm is used to reduce the RS rough set attributes. The initial risk factor is removed from 12 items to 5 items. The obtained reduction set is taken as a new domain, and the SVM is used for sample training based on the reduction set. The calculation results of 20 training samples are verified by the back-test method, and the SVM model is accurate and reliable. Furthermore, using the five prediction samples to obtain the risk prediction results of the accident, which is in good agreement with the actual situation, indicating that the RS-SVM combination forecasting model established in this paper has a good guiding role in the prediction of the risk of the LNG-fueled ship's filling operation.

Keywords

Rough set; genetic algorithm; attribute reduction; RS-SVM; risk prediction; LNG-fueled ship.

1. Preface

Liquefied Natural Gas (LNG) is mainly composed of methane. It burns less air and emits a lot of heat. It is a relatively advanced clean energy source. Therefore, LNG power vehicles and ships have developed rapidly. The LNG power boat is an emerging industry. LNG gas tanks are placed on the LNG power boat, and the pipes and related metal parts may be broken and contracted due to ultra-low temperature LNG, resulting in gas leakage. LNG power ship leakage is most likely to occur in its filling operation. Therefore, this paper conducts a deep analysis of the safety of the filling operation process, studies the risks existing in the filling process, and identifies the risk factors in the filling process. The rough set is simplified, the most critical risk factors are screened out, and the risk prediction is carried out through the SVM model, which provides the risk decision for the LNG power ship filling process.

In recent years, there have been some progress in the risk research of LNG power boats at home and abroad. Wei Wei made quantitative predictions for the gas storage pipes and pipelines of special LNG-diesel dual fuel ships, and analyzed the probability of accidents. And proposed a prevention plan; Yu Ting'an [1] mainly analyzes the possible consequences of the ship's leakage, and develops the heat radiation absorption rule for the crew, hull structure and storage tank; Shim Kumar Debnath

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[2] compares three quantitative analysis The calculation model of fire and explosion occurred in the tank leakage, and deeply analyzed the degree of impact of the risk of leakage caused by wind and leakage; Goerlandt Floris [3] system analyzes the explosion of the tank, the cause of the fire, and draws the accident tree. The minimum cut set of the fixed event is generated, and the influence factors of the degree of danger are determined by the degree of structural importance, and an optimization scheme is proposed for its reliability and safety capability. Luo Jianqiang [4] optimized the catastrophe progression method at the level of science, which played a crucial role in the risk assessment of the LNG power boat filling process. Zhang Haihong [5] mainly discusses the mutation phenomenon of the system, and applies the catastrophe theory to the analysis cybernet for the first time, and sorts out the mutation control theory and extends it to the development of the ship navigation system. Qi Ji [6] used the fuzzy mutation theory to explore the degree of risk in the evolution of maritime traffic safety system; Chen Yupin [7] analyzed the theory of the impact mechanism of the risk of marine accidents on human, machine and ring systems.Organization of the Text

2. The basic principle of the RS-SVM combined prediction model

2.1 Rough set reduction principle

Rough Set (RS) is a data analysis and processing tool that was introduced by Polish mathematician Professor Pawlak in 1982 to quantify inaccurate, inconsistent and incomplete information and knowledge. Attribute reduction is the unrelated or unimportant attribute under the condition of keeping the database classification ability unchanged, which is the core of the rough set theory. A rough set decision system is generally expressed in the form of a four-tuple:

$$S=(U,A,V,F) \tag{1}$$

Where the domain U={U1, U2, U3,...U[u]} is a non-empty finite set of objects;

Where Va is the value range of A;

f: Vx A→V is an information function,

It assigns an attribute value to each attribute of each object, ie a∈A, X∈U, f(X, a)∈Va. When the attribute A=C∪D, C∩D in the information system, C is the condition attribute, D is the decision attribute, and the knowledge expression system with the condition attribute and the decision attribute is generally called the decision system [8]. Attribute Reduction For a given decision system S = (U, C ∪ D, V, f), the reduction of condition attribute C is a non-empty subset P of C, and must satisfy the following two conditions:

1)a∈P,;

2)POSP(D)＝POSC(D)

Then, P is a reduction of C, and all the reduction sets in the condition attribute C are denoted as RED(C), which is defined as RED(C)={RC|γb(D)=γC(D), BR, Гb(D)≠γC (D)}, ie Ind(C)=Ind(C-Xi), then the attribute Xi is said to be omissible; otherwise the attribute Xi is indispensable for C, ie it cannot be omitted.

If the attribute set is not independent, then all possible minimum attribute subsets can be found, thus getting the basic set (reduction) of the same number of attribute sets and finding all the indispensable attribute sets (cores). There are many algorithms for reduction, such as genetic algorithm, Jhonson algorithm and information algorithm.

2.2 SVM classification prediction principle

Support Vector Machine (SVM) is a statistical method based on the principle of structural risk minimization and the construction of optimal hyperplane [9-10]. Specifically assume a problem of binary classification of a given training data set using a hyperplane of a feature space. For a given sample point (xi; yi), i=1,...,n;y∈{+1,-1 }xi is a support vector, and yi is a category index. The goal of learning is to construct a decision function that separates the two types of patterns as correctly as

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possible. The structural decision function can be transformed into a typical quadratic programming problem, that is, the minimum value of equation (2) is obtained under the constraint shown in equation (1).

$$y_i [(\omega \text{ x i}) - b] + \xi i - 1 \geq 0, \xi i \geq 0, \quad (1)$$

$$\varphi(\omega) = 12\|\omega\|2 + C\sum ni = 1\xi_i, \quad (2)$$

$$(i = 1,2,\ldots, n),$$

ω is the classification surface weight coefficient vector;

b is the classification domain value;

ξi is the deviation of the training sample with respect to the separation plane;

φ(ω) is the objective function;

C is the penalty coefficient, C>0. Using the Lagrange multiplier method, the decision function can be finally obtained.

$$f(x) = \text{sgn}\sum ni = 1 [aiyi\cdot(x\cdot xi) + b], \quad (3)$$

ai is a Lagrange multiplier. For the nonlinear case, the separation surface can be introduced, and the input space Rd is mapped to the high-dimensional inner product space by the nonlinear mapping φ(ω): Rd→F.

By constructing the optimal hyperplane, then classifying it using a linear classifier. According to the theory of functional analysis, under the condition of Mercer, this nonlinear mapping can be realized by defining an appropriate kernel function, introducing the kernel function K(xi, x), then the decision function of equation (3) can be written as

$$f(x) = \text{sgn} \sum ni=1[aiyiK(xi,x)+b]. \quad (4)$$

Equation (4) is a support vector machine, in which a vector corresponding to ai with a non-zero value supports the optimal classification plane and thus becomes a support vector. In a nutshell, the support vector machine is a linear classifier determined by the support vector. First, the input space is transformed into a high-dimensional space by the nonlinear transformation defined by the kernel function, and then the optimal classification surface is solved in this space.

3. Construction and application of RS-SVM prediction model

The outstanding advantage of RS is to achieve knowledge reduction, but its weakness is unable to capture the nonlinear mapping relationship between variables, and the advantages and disadvantages of SVM are just opposite to RS. Although it can not simplify the input vector space dimension, it is better. It captures nonlinear features in the data and has good nonlinear modeling capabilities. If the input information space has a large dimension, it will lead to long SVM training time and low efficiency. Therefore, combining RS and SVM, the accuracy and efficiency of the combined model in predictive applications will be significantly improved [6-8].

The main idea of the RS-SVM risk prediction combination is to divide the whole prediction process into two stages [9-12]; a.RS is used as the pre-system of SVM, and reduce the LNG power ship filling operation process through RS knowledge reduction. The number of risk prediction explanatory variables can reduce the complexity of SVM model and shorten the training time of SVM model. b. SVM as a post-information identification system has strong fault tolerance and anti-interference ability. The basic flow of predicting the risk of LNG power ship filling operation process using RS-SVM model is shown in Fig. 1. This paper takes the safety risk of the LNG power ship filling process as an example to comprehensively analyze the relevant risk factors affecting the safety of the LNG power ship filling process. These factors are the number of elements in the RS-SVM observation sample into the vector. According to these risk factors, relevant historical observation data are collected, and the composition of SVM can be determined according to the criteria of classification prediction [13]. In this paper, y=±1, +1 means no risk (no accident), and -1 means there is risk (an accident will occur). Through the RS-SVM combination model to predict the LNG power ship filling

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process risk, the key factors leading to the LNG power ship filling process risk can be determined, and the risk of accidents can be effectively pre-controlled.

3.1 Establish an indicator factor system

LNG power ship filling process

The LNG powered ship adds a set of LNG fuel system to the ordinary pure diesel engine power ship. The LNG fuel system includes fuel gas tanks, fuel supply systems, etc. Due to the special risk of LNG fuel, the filling operation [8] is The risky part of the daily operation of LNG fuel-powered ships. The ship currently operated is mainly completed by the filling party (filling station or tank truck). In the LNG ship filling operation, it can be divided into three stages, namely, the preparation stage, the filling operation stage, and the completion stage.

LNG power boat filling process risk and its causes

LNG power boat filling process ---- risk of leakage

An accident often occurs due to the combined effects of multiple system couplings. The LNG power boat filling process risk system is a complex system with many factors. The three systems of ship risk system, environmental risk system and human factor risk system interact and influence each other. This paper considers the coupling relationship between multiple systems to better reflect the safety status of the LNG power boat filling process risk.

LNG power boat fuel leakage mainly includes: gas tank damage, valve failure, liquid or gas phase pipe cracks, connection flange failure, instrument cracks. Leakage of the pipe section is usually caused by weld defects, pipe corrosion, erosion, vibration, cracking, and external force; flange leakage is mainly caused by improper structural selection, abnormal stress due to thermal stress of the pipe system, etc. Or bolt damage, uneven thermal expansion, poor bolt parallelism, insufficient bolt strength, etc.; valve leakage is mainly the leakage of the connecting flange and the gland flange, the welding defects left in the welding process, the wire in the threaded connection Leakage of the packing caused by buckle leakage and aging of the filler.

The most fundamental risk in the process risk of LNG filling comes from the risk of the ship system. The risk of the ship system comes from the structural strength of the ship itself, the design defects at the time of production, and it is inevitable with the use of the ship. It will cause certain corrosion damage, and its structural strength, sealing and integrity will be affected. For ships that have been in use for more than 15 years, this problem is more pronounced, with equipment aging, deterioration, spalling, and abnormal wear.

For LNG powered ships, the risks of their gas supply systems and protection systems need to be considered. The gas supply system is mainly composed of a gas supply double-layer pipeline, an LNG detector, and an LNG gas storage tank. The pressure of the gas tank will affect the gas supply double-layer pipeline and the gas storage tank, and the pressure is too large, the pipeline and the gas storage tank A rupture will occur, resulting in a fuel leak. The service life of the pipeline affects the safety of the gas supply double-layer pipeline. Safety valves also affect the gas storage tank, and the tightness of the valve also affects fuel leakage. The working state of the LNG detector indicates that the function of the LNG detector is normal. Once a leak occurs, if the LNG detector works normally, early detection can better suppress the accident. At the same time, the environment also affects the state of everything.

Study the impact factors of environmental risks in the LNG power boat filling process risk. First consider the effects of wind, tides, waves and cyclones. The greater the wind, the greater the drift and the greater the risk of shipping. Tidal waves have a direct impact on the navigation of ships. At low tides, the depth of the ship's berthing may be insufficient. At high tides, the traffic density of ships entering and leaving the port may be too large. Secondly, considering the traffic environment of the port, the width of the moored waters and the frequency of the vessels coming and going will affect the risk of the filling process.

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When analyzing the risk of LNG filling process, it is divided into three parts for analysis. First, in the preparation stage before the operation, the ship is berthed, the information exchange between the ship and the shore, and the safety of the staff to the ship and the filling station. Inspection of the facility and protective equipment will affect the risk value, as well as the connection of the filler hose. A large part of the leakage of LNG comes from the piping problem. In the LNG filling operation phase, the pipeline is first pre-cooled. This factor is characterized by the piping temperature, followed by the liquid inlet operation, which is characterized by the flow rate of the dosing pump. The most important thing is the monitoring of the working conditions by the staff, monitoring the pressure and liquid level in the gas tank, and carefully checking the safety of the valve. After the final refilling inspection phase, pay attention to whether the valve is closed, whether the equipment is in place, and the purging operation. The purging operation is mainly to purify and inertize the piping system and characterize it through the LNG balance in the pipeline.

Table -1 Risk factors for LNG power ship filling process

Factor hierarchy	Factor name and symbol	Variable setting	Factor description
Environmental factors	Wind	C1	Wind power
	Tidal	C2	The classification of tidal size
	Visibility	C3	The level of visibility affects of of work
	Traffic density	C4	Density of ships docked at ports
Human factors	Information exchange	C5	Information exchange during the filling process
	Security check	C6	Safety check before and after filling
	Working condition supervision	C7	Rating according to the degree of supervision of the working conditions
	The level of Operators	C8	Operator's education level
Ship factors	LNG detector	C9	Detector status
	Gas storage tank	C10	Gas tank type
	Protection system	C11	Protective system integrity
	The age of Ship	C12	Classification of ships according to ship age

Therefore, this paper refers to relevant research, and divides the security level of each risk factor into five levels: low security, low security, general security, high security and high security. The internationally accepted method, the ALARP framework, is chosen to express acceptable risk criteria. The risk is divided into three areas using acceptable standard lines and negligible standard lines: unacceptable risk areas (unacceptable areas), acceptable areas (ALARP areas), and negligible areas. According to the safety level of the LNG power boat, the order from high to low is I, II, III, IV, V. The higher the safety level, the higher the safety index of the system, which indicates that the system is more stable and safe.

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Table 3-2 LNG power boat filling safety level membership function table

Safety Level	I	II	III	IV	V
Safety status interval	More danger	Danger	General	Safety	More Safety
(scores)	[0,0.72)	[0.72,0.83)	[0.83,0.90)	[0.90,0.96)	[0.96,1.00)

4. RS-SVM model establishment

4.1 RS reduction processing

Some attributes in the decision table sometimes have similar knowledge representation ability, there is redundancy between attributes, and the rough set attribute reduction of redundant elimination can be performed by genetic algorithm. The algorithm is based on the heuristic algorithm of attribute importance, which is effective for solving relative attribute reduction in decision system.

According to the genetic algorithm flow, the genetic algorithm is applied to the data reduction by MALTAB software, that is, the decision table S=(U, A, V, F) is input in the programming process, and the non-empty finite set of attributes A=C∩D, where C It is a conditional attribute, D is a decision attribute, and finally the attribute reduction R of this decision table is output. It should be noted that the number of iterations of the genetic algorithm in this paper is 150 times.

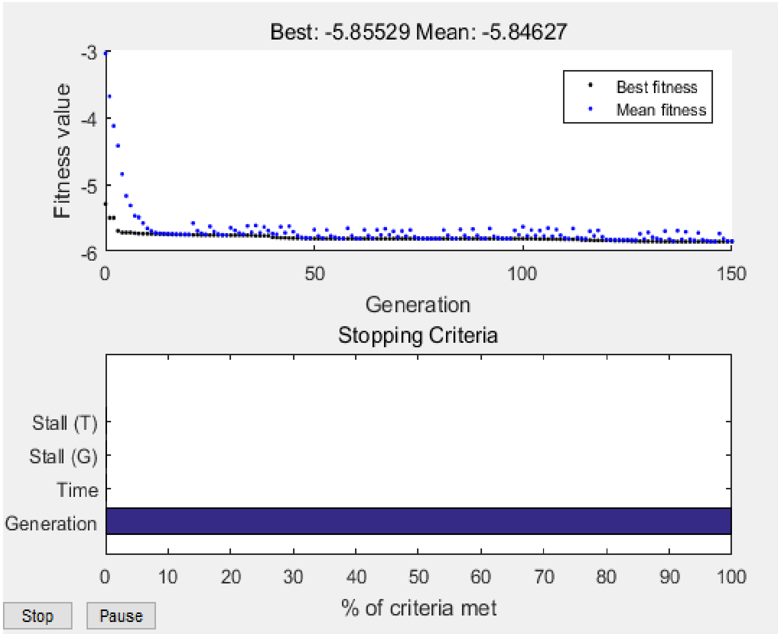

Figure 3. Genetic algorithm iterative calculation of fit results

The reduction result C_reduct = [C1, C5, C6, C8, C11], the objective function optimal value target Value = -5.8553, after RS pre-processing, the initial risk factor can be eliminated from 12 items into 5 key factors, namely wind , information exchange, security inspection, operator level, protection system. In turn, the dimension of the sample data space is reduced, the number of SVM training samples is reduced, and the training efficiency is improved.

4.2 Application and verification of SVM

According to the RS-SVM combination model, the basic process of LNG power ship filling process risk prediction is known. SVM is used as the post-information identification system of the prediction model. The prediction result is calculated by the recognition of the training sample operation results to obtain the prediction result. . In fact, SVM is a linear classifier determined by support vectors. It

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applies a nonlinear transformation that requires kernel function definition to transform the input space into a high-dimensional space. Therefore, in the SVM prediction application, the kernel function needs to be determined first.

4.2.1 Selection of SVM kernel function

Commonly used kernel functions are:

The polynomial kernel function K(x,xi)=[(x·xi)+1]q.

The radial basis kernel function K(x,xi)=exp(-γ‖x-xi‖2). γ is the nuclear parameter, γ>0.

The Sigmoid kernel function K(x,xi)=tan h(v(x·xi)+c).

Among the three kinds of kernel functions, the most widely used is the radial basis kernel function. It has a wide convergence domain, which is an ideal classification function [8], and only contains one parameter, which is easy to optimize. Therefore, the radial basis kernel function is chosen in this paper.

4.2.2 Training of the SVM model

The attribute set C={C1, C5, C6, C8, C11} obtained from the RS attribute reduction in the 20 sets of training sample data is input as the condition attribute in the SVM model, and the corresponding gas security risk status is set to y=. +1 (no risk) or y=1 (risk) and enter y as the decision attribute of the model. The SVM model was sampled by using 20 sets of training sample data obtained from RS object reduction (Tables 2~4). After the training, the 20 sets of samples in Tables 2~4 are back-calculated by the back-embetic estimation method, and the discriminant result is consistent with the actual situation of gas risk occurrence. The false positive rate of the judgment is 0, indicating the training of the predictive model. The result is a high correct rate and can be used in practical engineering practice.

5. Conclusion

The application of the RS-SVM combination model has important decision support functions for coal mine safety risk pre-control, which helps to improve the safety risk pre-control efficiency. After RS pre-processing, the initial risk factor can be eliminated from 12 items into 5 key factors, namely wind, information exchange, safety inspection, operator level, and protection system. On the one hand, the dimension of the sample data space is reduced, the number of SVM training samples is reduced, and the training efficiency is improved; on the other hand, the design of the risk pre-control of the LNG filling process, the investment of the pre-control capital, and the pre-control scheme are Provide a scientific basis for the development and implementation of pre-control decisions.

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