Design and Implementation of Safety Expert Information Management System of Coal Mine Based on Fault Tree

WANG Cheng-gang
QingDao Technological University Computer Engineering Institute Qingdao,China
qdjnbj@gmail.com
WANG Zi-zhen
DONGHUA University College of Information Science and Technology
Sanghai, China
shdhwzz@gmail.com

***Abstract*—Using the principle and method of fault tree and combining computer information system, the safety information closed-loop control system is formed with the characteristics of automatic control and automatic conversion. It has very important significance for coal mine safety to predict and deal with the hidden danger automatically, rapidly and timely. Based on this, we develop a safety information processing system according to fault tree of coal mine, which runs under the way of WEB. In this paper, we firstly introduce the overall structure and the component of the expert system, illustrate the fault tree analysis method in detail; then describe the key technologies and implementation method of software development and the program is given; finally, explain the important role of system implementation in solving the safety information management problem of coal mine.**

***Index Terms*—Safety Information, Closed-loop Control, Expert System, Accident Tree, Workflow**

I. INTRODUCTION

Coal is a high-risk industry, coal mine safety accidents caused heavy losses to enterprises, so reducing safety accidents become national great demand and the main task of coal enterprises. Facing the complex coal mine safety factor, we develop this project to control the hidden trouble of coal mine by safety management, and automatically predict accidents and controllable plans by expert system [1].

Current situation of information security management basically has the following questions:

A. The safety management is a complex dynamic system with various influence factors, information is processed mainly with artificial or record，needs long time to input information and print out report forms, a large number of hidden information cannot be tracked and supervised automatically.

B. he traditional mode is passive and lagging behind, lessons can be summed up only after the accident, can not analyze, evaluate and predict the potential danger existing in every production process, let alone to guide to adopt prevention plans and measures, eliminating hidden dangers ahead of time.

C. People can not analyze and evaluate the equipment and environment rapidly before accident. Due to lack of scientific analysis and prediction, they can not timely judge the form, development and rigger conditions of accident.

With the development of computer technology and national attention to safety work, we already have the basis to development. Through the development of coal mine safety information expert system, the goal of the paper is to make a significant drop of major hidden danger and accidents and form a stable situation of production safety [2].

Accident tree is a kind of reliability analysis method which is firstly proposed by H A Walson of Bell laboratories. Fault Tree Analysis (FTA), also called Decision Tree, is a kind of method which ratiocinates the possible consequences by the initial event according to time sequence, thus identify the hazard source [3]. Mine accident is commonly the result of the successively occurrence of hidden danger, and some accidents happen with the occurrence of other hidden danger. There is a cause-and-effect logic relationship in the time and sequence of the hidden danger existence[4]. The situation is analyzed with tree diagram, so called fault tree. It can qualitatively understand the dynamic changes of the whole incident, and quantitatively compute the probability of each stage of development, in order to understand the process and state of the accident, and the probability of various states [5].

According to the principle of fault tree and the hidden danger examined every day, we analyze all stages step by step through time development and mutual relationship. On the basis of the possible subsequent events of each hidden danger, we select the two opposite states and find out the interrelated subsequent events. Then we analyze the safety or risk of these events, gradually advancing, until find out the major hidden dangers or the results of accidents [6]. If there is danger, indicate it and call out response plans for leadership and stuff to refer and make decision. The automatical workflow engine software of the computer will inform the relevant responsible persons, and keep tracking until the safety control personnel to review and verificate. The

WANG Cheng-gang（1963-）qdjnbj@gmail.com

doi:10.4304/jsw.5.10.1114-1120

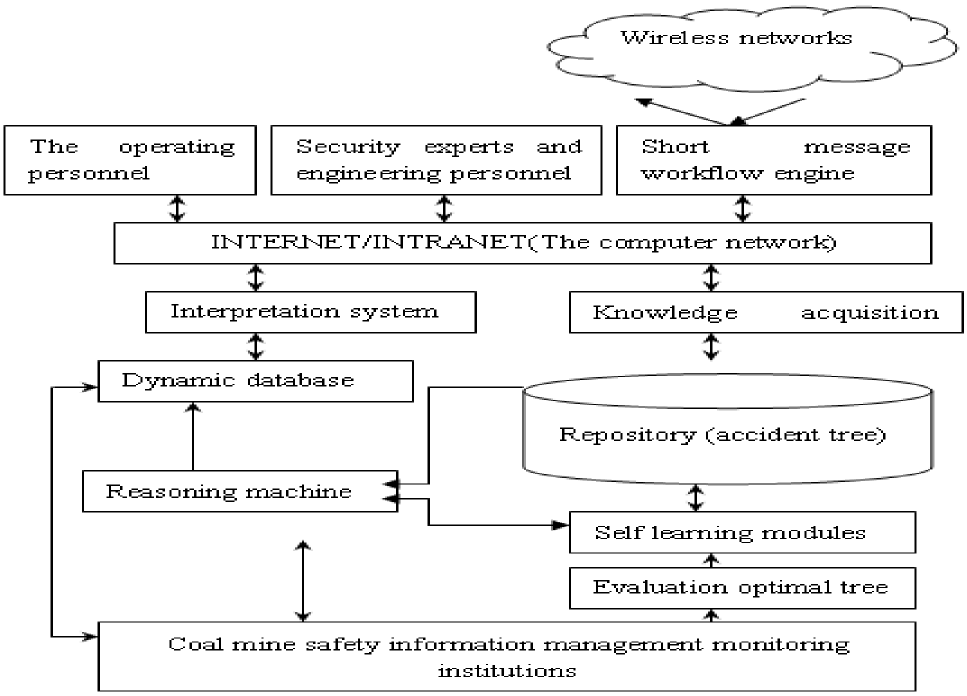

Figure 1: Overall structure of coal mine safety accident tree expert system

closed-loop control system of coal mine hidden dangers will be formed [7].

II. Overall Design of Information Management Expert System of Coal Mine Safety Accident Tree

Information management expert system of coal mine safety fault tree is a computer software system with automatic conversion of workflow as the center .After the collection of hidden danger information of three classes, based on the comprehensive use of expert experience and logic knowledge, we find out the eventually accident point and the cause of the accident by computer computing. If confirmed by control safety personnel, it will return to the relevant responsible persons, finally remove the hidden dangers automatically or artificially [8].

The framework of mine accident tree expert system contains nine parts: the automatic classifying information network platform based on computer network and workflow engine, the explaination institutions, the knowledge acquisition management institution, the dynamic database, the fault tree knowledge base, the inference engine, the evaluation optimizing institution, the self learning module and safety management and the safety management information system[9]. System structure is shown in figure 1.

The functions of each part are described as follows:

A. Computer network and workflow engine of automatic classifying information transmission platform

Taking the company's LAN or INTERNET as platform, the coal mine safety information management system, which is based on workflow, automatically transfers the security information to different role in the form of workflow. Operators can put the problems and hidden dangers forward through computer or short message, the system will answer them and output the results into computer or mobile phone. And when there is error between the results and the system, system can revise the parameters artificially form self learning mechanism according to experience through computer or short message [10].

B. System interpretation institutions.

The possible cause and result of accidents could be explained and reasonable solution will be provided, accident treatment plan will be provided to the accident with dangerous consequences. Interpretation system mainly explains the behavior and results to the user, how the reasoning result comes from.

C. Knowledge acquisition management institution.

The safety administrator, The professional management staff and security experts input the questions, the hidden dangers, the accident experience knowledge and logical knowledge through computer, deposit them to knowledge base in standardization form, and construct fault tree.

D. Dynamic database.

This database can store the known facts and intermediate results, and the real-time data and historical data of safety monitoring, ventilation, safety information management.

Table 1: The unsafe incidents

symbol	types of incidents	symbol	types of incidents
T	Gas explosion accidents on working surface	X_7	Gas accumulation after blasting
M_1	Overrun gas aggregation	X_8	Low wind speed at upper corner
M_2	Gas gathered at the upper corner	X_9	Blow fire
M_3	Gas missed out examination	X_{10}	Welding and gas welding
M_4	Fire source	X_{11}	Spontaneous combustion
M_5	Open flame	X_{12}	Friction fire through hit
M_6	Electrical fires	X_{13}	Fire source on fire zone
M_7	Electric short-circuit	X_{14}	Equipment detonation
X_1	The gathering gas without timely processing	X_{15}	Electrical Interface Technology adverse
X_2	Deficiency in draught	X_{16}	Bad cable connection method
X_3	Monitor no timely	X_{17}	Cable mechanical damage
X_4	Alarm power instrument is malfunctioning	X_{18}	Transformer motor and switch internal short-circuited
X_5	Alarm power instrument improperly located	X_{19}	Gas achieving the explosion concentration
X_6	Gob gas accumulation gush	X_{20}	The fire source and the concentration of gas explosions up to meet

E. Knowledge base (fault tree).

It deposits safety rules, accident classification, characteristics, accident algorithm and reasoning rules, reflects cause-and-effect relationship of the system; we can be used for accident reasoning. Knowledge of knowledge base includes experience knowledge, logic knowledge and metaknowledge. Metaknowledge is knowledge about building, managing and operating the fault tree. Knowledge in knowledge base is organized in tree structure according to the representation, the nature, the level and the content of the knowledge.

F. Inference engine.

It is the knowledge reasoning components of the whole system. The inference is completed by computer reasoning algorithm, including two aspects as reasoning and control. A mixed mechanism combined with forward reasoning and backward reasoning is used in the system.

G. *Evaluation optimizing institution.*

In the continuous operation of the system, correctness of the reasoning and problem solving ability can be improved by making continuously periodic evaluation to the reasoning process and the knowledge source. According to the user and state of system, the knowledge with bad predicting ability will be marked and stopped using. The lacking knowledge will be warned and prompted.

H. Self learning module.

According to the summary of system evaluation and action effects of control commands, it carries on correctness to the knowledge and instruction of the system. Simultaneously, it can continually perfect and innovate the system, and enrich the knowledge in knowledge base real-timely, automatically revise and delete the knowledge which the system performance is weak and control deviation is strong. So the system can adapt to the coal mine's complex safety condition and forecast exactly.

I. Coal mine safety management monitoring institution and information management system.

This organization mainly depends on the existing safety monitoring system and safety production management information system, takes the workflow engine as the platform. The information can be shared among each application system. Simultaneously hidden dangers and questions will be found through the prompting of inference organization and then automatic reduction ability can be achieved [11].

III. Basic Theory of Fault Tree Analysis

Fault tree is the core of the whole knowledge base; it is made up of qualitative analysis and quantitative analysis. Qualitative analysis is to find the reasons and the reason combination of the top event. It can help us to redue the potential failure and modify the safety operation management plan. Quantitative analysis mainly calculates and estimates the probability of top event and the importance degree of bottom event. Through the qualitative analysis and quantitative analysis, effect of the factors of safety management is revealed, which have important meaning to improve the accuracy in safety management and the accident prevention [12].

A. Qualitative analysis

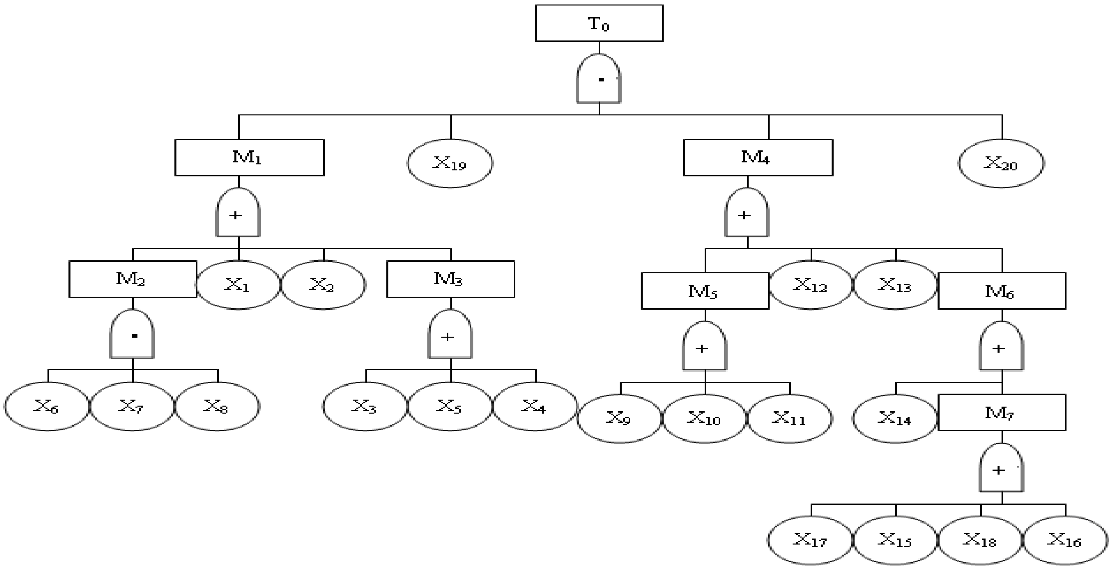

Figure 2: The gas explosion fault tree

The minimum cut sets and the minimum path sets play an important role in the qualitative analysis; the fault tree analysis will achieve maximum results with little effort if we apply the two methods flexibly. It will provide important basis to control accident effectively [11]. Because of the minimum path sets can be obtained by the minimum cut set, only minimum cut set is introduced here. The application of qualitative analytic method sees the following example.

B. Calculation of the top event's probability

There are several methods to calculate the occurrence probability of top event, including two algorithms common used; the minimum cut set algorithm and the path minimum set algorithm. It is much simpler to use quantitative analysis method and the minimum cut set algorithm because there are many or-gate in the system. The minimum cut set includes logic "add" and "multiply", the probability function of fault tree can be written in the form of logic "multiply" of the minimum cut set [14].

$$g(q) = p_i(T) = \prod_{j=1}^{p}[1 - \prod_{i \in p_j}(1 - q_i)] \qquad (1)$$

Where,

$$p_i = x_1 + x_2 + ... + x_m (i = 1, 2, 3, ..., k) \qquad (2)$$

M is the number which the basic event p_j contains. Calculate the probability of the top event of accident tree top according to including-excluding formula:

$$g(q) = 1 - \sum_{r=1}^{p}\prod_{i \in p_j}(1 - q_i) + \sum_{1 \le h < j \le p}\prod_{i \in p_h \cup p_j}(1 - q_i) + ... + (-1)^{p-1}\prod_{i=1}^{n}(1 - q_i) \qquad (3)$$

Where, I is the ordinal number of the basic event; p is the number of the minimum path set; r, h, j is the ordinal number of the minimum path set.

C. Calculation of importance degrees

The contribution of an element components or minimum cut set made to the occurrence of the top event is called importance degree. Due to the different design object, the calculation methods of importance degree are different, currently, the main means are the structure importance, the probability importance, the critical importance, the cut importance and the fuzzy importance developed in recent years [15]. The structure importance will be mainly introduced in this paper.

The structure importance is the important degree of the basic event analyzed from the structure of fault tree [16]. When the state of xi changes from 0 to 1 and the other basic state remains unchanged, the state of top event changes from $\phi(0_i, x) = 0$ to $\phi(1_i, x) = 1$, in other words, the basic event has played an important role to the top event, multiplies the accumulation of all these events by 1/2n-1 ("n" is the number of the basic event for the accident tree), we get the structure importance:

$$I(i) = \frac{\sum [\phi(1, x) - \phi(0, x)]}{2^{n-1}} \qquad (4)$$

IV. REALIZATION OF THE KEY TECHNOLOGIES OF THE SYSTEM

A. Establishment of Gas explosion Fault Tree and computation example

We rest on the New Coal Industry Group all previous years accident record file to carry on the analysis and statistics, choose the major accident as top event according to the principles for defining the top event, then seek all the direct factors which lead to the top event, and push down by the time until not constituting significant affecting factors. Figure 2 is the gas explosion fault tree. Table 1 is the unsafe incidents.

a. Minimal cut set solution of the Fault tree

The minimal cut sets are congregation of elementary events of top event, is the hazards resource and way of accident occurrence, which has reflected system's risk. The goal of qualitative fault tree analysis is to find all minimal cut sets, discover the system hidden dangers or all possible causes of the appointed top event occurrence, and systematically find out possible problems to cause the top event from the hidden danger inspection. In this paper, we use the method of Boolean algebra simplification to calculate all fault tree's minimal cut sets, the fault tree's function structural equation is:

$$T=X_{19} X_{20} \cdot (X_6 X_7 X_8 + X_1 + X_2 + X_3 + X_4 + X_5) \cdot (X_9 + X_{10} + ... + X_{17} + X_{18}) \quad (5)$$

By simplifying we can see that the fault tree's minimal cut sets has 60, in sequence is:

$$\begin{aligned} &K_1 = \{X_{19}, X_{20}, X_6, X_7, X_8, X_9\} \\ &K_2 = \{X_{19}, X_{20}, X_6, X_7, X_8, X_{10}\} \\ &K_3 = \{X_{19}, X_{20}, X_6, X_7, X_8, X_{11}\} \\ &\dots \\ &K_{10} = \{X_{19}, X_{20}, X_6, X_7, X_8, X_{18}\} \\ &K_{11} = \{X_{19}, X_{20}, X_1, X_9\} \\ &\dots \\ &K_{20} = \{X_{19}, X_{20}, X_1, X_{18}\} \\ &\dots \\ &K_{51} = \{X_{19}, X_{20}, X_5, X_{18}\} \\ &\dots \\ &K_{60} = \{X_{19}, X_{20}, X_5, X_{18}\} \end{aligned} \quad (6)$$

b. Structure importance analysis

The contribution to top event occurrence which a bottom event or the minimal cut set has is called the importance degree. The important degree analysis is playing a guidance role in reliability prediction and inspection in coal mine safety system, the systems operation and consummation, the formation of expert reserves. The structure importance refers to the impact of the degree which each basic event occurs to top event occurrence only from the structural analysis and without regard to the basic events' occurrence probability. After qualitative fault tree analysis, we may determine the safety system's weak point, compute the fault tree structure importance coefficients and sort them, may know that the bottom event have the size of impact on top event , whose order is the order of system reliable effect. Analysis algorithms of importance are more, just like the structure importance, the probability importance, the critical importance and cut-sets importance as well as fuzzy importance which recently appears. We select the structure importance's quadratic formulas to solve the importance coefficient, the formula is as follows:

$$I_{\phi(i)} = 1 - \prod_{x_i \in k_j} \left(1 - \frac{1}{2^{n_j - 1}}\right) \quad (7)$$

In the formula, I $^{\phi(i)}$ is the i-th bottom event's structure importance coefficient; k_j is the total number of minimal cut sets; n_j is total number of bottom event in minimal cut sets k_j which the i-th bottom event belong to; $x_i \in k_j$ says that the i-th bottom event belongs to the j-th minimal cut set.

$$I_{\phi(1)} = \dots = I_{\phi(5)} = 1 - \left(1 - \frac{1}{2^{4-1}}\right)^{10} = 0.737$$

$$I_{\phi(6)} = I_{\phi(7)} = I_{\phi(8)} = 1 - \left(1 - \frac{1}{2^{6-1}}\right)^{10} = 0.272$$

$$I_{\phi(9)} = I_{\phi(10)} = \dots = I_{\phi(17)} = I_{\phi(18)} = 1 - \left(1 - \frac{1}{2^{4-1}}\right)^{5} \cdot \left(1 - \frac{1}{2^{6-1}}\right) = 0.503$$

$$I_{\phi(19)} = I_{\phi(20)} = 1 - \left(1 - \frac{1}{2^{4-1}}\right)^{50} \cdot \left(1 - \frac{1}{2^{6-1}}\right)^{10} = 0.99908268$$

The sorting of structure importance coefficient of each bottom event is as follows:

$$I_{\phi(19)} = I_{\phi(20)} \succ I_{\phi(1)} = \dots = I_{\phi(5)} \succ I_{\phi(9)} = I_{\phi(10)} = \dots = I_{\phi(17)} = I_{\phi(18)} \succ I_{\phi(6)} = I_{\phi(7)} = I_{\phi(8)}$$

B. The instance of the establishment of the workflow engine

The workflow engine is the critical part in entire system. The relevant personnel may track the workflow information by the level distribution in accordance with the order of management flow, and all levels of personnel sign and feedback the information to the senior leader after receiving the program information of the project. Through it the leadership can fully monitor the project flow[16].

We use the flow of issues notice to illustrate the setup procedure of workflow. As shown in Figure 2, process is as follows: First fill in the issues notice according to the problem which the inspectors check, sent to the work captain to carry on the inspection, and make the rectify notice by the safety inspectors senior, the process result is sent to safety supervision department to examines and approves, if reexamination is eligible, this flow end, otherwise, carrying on the penalties of individual integral, then fill in reexamination notice and orders rectification again, then enters the flow, until the entire department flow finishes [17]. Issues notice workflow is shown in Figure 3.

Process flow of issues notice W=（A，T，F，S，ID）, where,

A={a1,a2,a3,a4,a5}

T={ i,c1,c2,c3,c4,o}

c1=(I1,N1,F1,L1,D1,R1,S1)

Vicissitude= (rule number, name, rule type, trigger identification, executive conditions, executive actions, priority)

I1= No.1

N1: issues notice

F1:Accept_Order(issues notice)

L1:Null

D1:({order} ， {orderName ， Re_OrderID ， CreditID})

R1:{R11,R12}

R11:(ON(EndOf(Assign)) IF(TRUE)DO(Accept_Order))

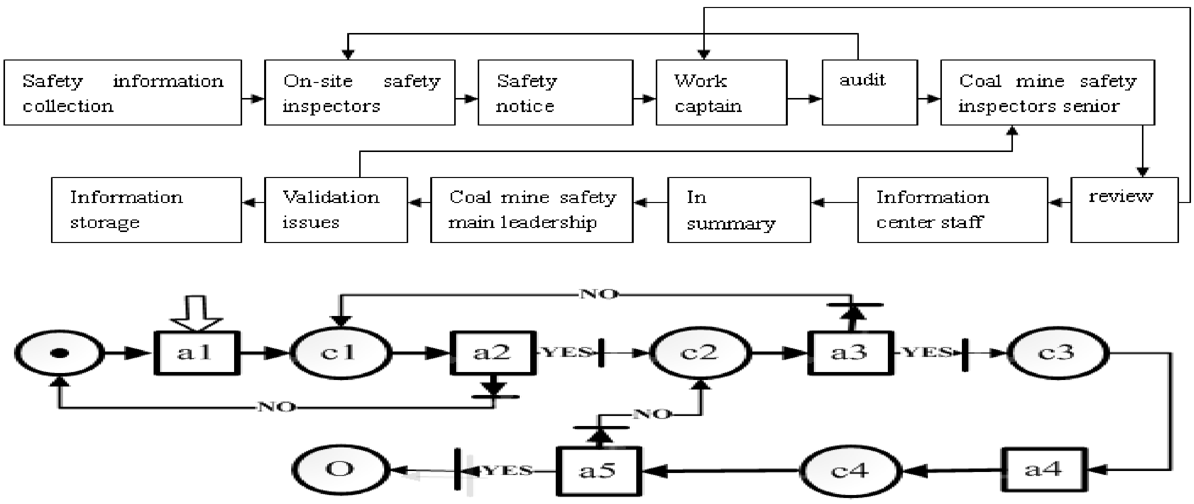

Figure 3: The flowchart of issue notice processing workflow

R12:(ON(EndOf(Accept_Order))IF(TRUE) DO(Send_To({OrderName,CreditID},"corrective instruction")) (Send_To({Re_OrderID};" coal mine safety inspectors senior")) (Send_To({Order};" Rectification By Safety Inspectors Senior"))

S1:Null

Where, Send_To(A,B) indicates the body A sends an object B.

C. Storage structure of Fault Tree inference mechanism

The inference mechanism bases mainly on the fault tree, data is stored and managed in terms of tree structure from the computer algorithm aspect. The top event, the bottom event, the intermediate state gate or the logical gate are managed as the node, using the form of linear linked list, each node in the form of class to manage. The node class Node's attribute includes the node name, node type and failure probability, the number of occurrences, the prediction scheme number, the role, the sequence of father node's indicator and child node's indicator. The father node's indicator points to upper stage logical unit, if root node, is spatial. Each node possibly has many sub-nodes, uses an indicator sequence to record each sub-node's position in sequence. And this node is the top event, the bottom event, the AND gate or the OR gate and so on, is used the type of node to record. This is the computer storage structure of an abstract fault tree model.

D. Realization method and procedure of fault tree computation in storing process:

The fault tree computation is mainly the binary tree class operation. The binary tree traversal refers to visit each node in binary tree by certain order, visit each node once, and carry on various operations to the node. Computational method of binary tree's storing process in sql-server is given as follows.

Parameter explanation: id denotes automatic serial number, pid denotes father ID, id-path denote node way, flg denotes position, 0 denotes left, 1 denotes right

```
ALTER  PROCEDURE [dbo].[get_class]
@class int,
@return int output
AS
SELECT  @return=isnull(( select top 1 id  from class wh
ere pid=@class and flg=0 ),-2)
if @return>-1  -- There are child nodes, recursive calls
   begin
   exec get_class @return,@return output
   end
else
   begin
   SELECT @return=@class --No child nodes is the
accident     source
   end
GO
```

IV. SYSTEM IMPLEMENTATION

The implementation of the system includes the following steps.

Step 1. Investigate historical information to define boundaries scope. Through the statistics and analysis of historical information and investigate on-site safety supervision personnel, investigation and analysis of the incident situation of past the mine and other units, system contained content and boundary scope can be determined.

Step 2.Identify top event of the fault tree. According to investigation, the accident which is prone to occur and has serious consequences in various systems is determined as the top event.

Step 3. Investigate all reason events related to the top event.

Step 4. Fault tree mapping. In accordance with the principle of establishing the fault tree , analyzes the respective immediate cause event the step by step, from the top event, uses the logical gate to connect upper and lower event, until the bottom, form a fault tree according to the mutual relations.

Step 5. Fault tree qualitative analysis. The qualitative analysis is the core content of the fault tree analysis. Its goal is to analyze the types of accident's occurrence rule and characteristic, find out a feasible plan to control the accident by striking a minimal cut set (or minimal path set), and analyze each basic event's important procedure from the accident structure and occurred probabilistic, in order to respectively take countermeasure in order of priority.

Step 6. Fault tree quantitative analysis. The task of quantitative analysis is to calculate and estimate the probability of the top event occurrence and bottom event's importance degree and so on.

Step 7. Learning system design. Form the perfect and applied security information specialist management system through the learning system to improve measures unceasingly.

V. Conclusions

A coal mine security information management expert system based on the fault tree is proposed, taken a variety of factors into consideration, The system improves through self-learning institutions with the fault tree's procedure. which is helpful to the safety managers to understand a variety of complex factors to control mine safety, discover the accident phenomenon as early as possible, definite the various causes of the accident, prevent the occurrence of accident and reduce serious damage of accident promptly[19]. It has strong science rigorous and versatility and high practical application value. At present this system is put into use in Zibo mining industry group and Xu Chang coal plants in China. The system is running well and realized automated analysis and automatic transmission of the security information. It innovatively changes the past form of coal mine safety management, enhances effectiveness and accuracy of safety in production, and improves coal mine's management level and economic efficiency greatly.

References

[1] FAN Weitang, LU Jianzhang, SHEN Baohong. *Technology and measures of mine hazards control[M]*. Xuzhou: China University Mining and Technology Press, 2007.

[2] LIN Boquan, ZHOU Yan, LIU Zhen tang. Safety system engineering[M]. Xuzhou: *China University Mining and Technology Press, 2005.*

[3] Fitzgeerald R W.Building . Fire safety evaluation method[R].*Worcester Polytechnic Institute, 1993*

[4] Watts JR, M John. *Fire Safety Science[C]*.5th International Symposium, USA, 1997: 101-109

[5] Blaschke Wieslaw; Gawlik, Lidia. Coal mining industry restructuring in Poland: implications for the domestic and international coal markets. *Applied Energy Volume*: 64, Issue: 1-4, September 1, 1999, pp. 453-456

[6] Greb, Stephen F.; Popp, John T. Mining geology of the Pond Creek seam, Pikeville Formation, Middle Pennsylvanian, in part of the Eastern Kentucky Coal Field, USA. *International Journal of Coal Geology Volume:* 41, Issue: 1-2, August, 1999, pp. 25～50

[7] WFMC.Workflow Management Coalition Specification: Terminology & Glossary. *Document Number WFMC-TC-1011, Brussels*, 1996

[8] Petra H, Stefan J, Jens N, Katrin S, Michael T.A comprehensive approach to flexibility in workflow management systems[J].In: *Software Engineering Notes, 1999*

[9] Workflow Handbook [Z].*Lighthouse Point, FL, USA: Future Strategies Inc*., 2004

[10] LING Biaocan. Discussion on content of safety assessment for colliery flood [J].*China Safety Science Journal*, 2004, 14(7): 64-66.

[11] CAO Shugang, ZHANG Liqiang, LIU Yanbao, et al.Causing model of accidents and preventing system of small mines[j] .*Journal of China Coal Society,* 2008, 33(6): 629-634.

[12] LOU Chunhong, XIE Xianping.Comparison study of accident-causing theories [J] .*Journal of Safety Science and Technology*, 2007, 3(5): 111-115.

[13] JI Changwei, RONG Jili, HUANG Wenhu.Research on intelligent diagnosis for spacecraft based on fault tree and neural network [J] .*Chinese Journal of Space Science*, 1999, 19(2): 160-166.

[14] QIAN Xinming, CHEN Baozhi.Catastrophe model for accident cause [J] .*China Safety Science Journal*, 1995, 5(2): 1-4.

[15] YUAN Changming.On funding versatile solution of the least cut set and least path set in fault tree analysis by computer [J] .*Journal of China Institute of Metrology*, 2002, 13(4): 308-310.

[16] DING Caihong, HUANG Wenhu, JIANG Xingwei.A method of fault isolation for spacecraft based on minimum cut sets' rank[J] .*Chinese Journal of Space Science*, 2000, 20(1): 89-94.

[17] MU Zhansheng, ZHOU Yun. The design and implementation of - distributed workflow system based on web service [J], *Computer Application and Software*, 2008 25(12): 99-101

[18] WANG Xianghui, WANG Kangjin. Embedded workflow system integration research [J], *Computer Application and Software*, 2008 25(11) 95-122

[19] Greb, Stephen F.; Popp, John T..Mining geology of the Pond Creek seam, Pikeville Formation, Middle Pennsylvanian, in part of the Eastern Kentucky Coal Field, USA. *International Journal of Coal Geology Volume*: 41, Issue: 1-2, August, 1999, pp. 25-50