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Emergency decision model of coalmine sudden gas events based on bayes theory

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ABSTRACT

Issues, such as improving the capacity to timely collect information and correctly analyze the emergency scene after coalmine gas disasters, adjusting response options of emergency plans to make scientific decisions according to analysis and predictions of dynamic changes in uncertainty consequence of specific disasters, have been necessary for research in coalmine sudden gas events. Considering this, this paper analyzed uncertainties of coalmine sudden gas events. Based on Bayes risk decision theory, a mathematical emergency decision model of coalmine sudden gas events was built. Specific cases have been put into practice. Thus, the key point of the optimized emergency decision for coalmine sudden gas events was proposed, as well as practical application values of emergency decision model of coalmine sudden gas events. The application result of the emergency decision model showed, for the accident emergency decision maker, correct judgment in risk of high concentration gas intrusion area is very important to correct selection of emergency decision plans. However, gas concentration dynamically varies within mine workings. Therefore, it is required to correctly select the emergency plan promptly according to gas distribution. During decision making, decision bias and traps shall be avoided as much as possible.

Key words: Gas, Sudden events, Emergency decision, Bayes Theory

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INTRODUCTION

During 2004 to 2009, among the extraordinarily serious coalmine accidents causing deaths over 100 in China, most attribute to the occurrence of sudden gas events. 42 minutes and 31 minutes time intervals respectively between outburst and the explosion of Xinxing Coal Mine accident and Daping Coal Mine “10·21” accident, as well as the 12 minutes time intervals between rock burst and explosion of Sunjiawan Coal Mine “2·14” accident, demonstrated the golden time to prevent sudden gas events from inducing explosions is only less than several tens of minutes. After sudden gas events, quick and efficient development of emergency rescue as well as maximally reduction in loss due to the accident is objectives to be achieved by personnel participating in emergency rescue. To realize such objectives, cautions must be taken in advance and a reasonable and optimized emergency plan must be prepared. An emergency plan is prepared prior to the accidents. Relevant authority assumes and predicts the general consequences potentially caused by sudden events according to their own experience. Thus, the emergency plan is formulated based on such staring point. Application effect of the emergency plan is subject to most uncertainties of the accident scene. This requires decision makers to predict uncertainty consequence of specific disasters according to experience, thus adjusting the emergency plan accordingly. When sudden events occur in mines, handling time left for decision makers is pressing. In addition to this point, strong crisis awareness and mental stress, as well as insufficient information available for analysis result in decision makers’ difficulty in selecting an optimized decision plan from available ones.

How to improve the capacity to timely collect information and correctly analyze the emergency scene after coalmine gas disasters, adjust response options of emergency plans to make scientific decisions according to analysis and predictions of dynamic changes in uncertainty consequence of specific disasters have been key issues of coalmine sudden gas events to be researched. Such a key process is faced with the dynamic variation events with gradual increase in gas backflow scope. In view of this point, the decision plan must be real-time adjusted according to accident scenes. In coal mine emergency field, such as emergency plan, emergency information management system, emergency communication and command dispatching system, empirical emergency decision model still was remaining. Guo [1] proposed an emergency response plan of the coal and gas outburst and a hazard assessment emergency response model based on general regulations. Robot [5] provides a concise methodology for developing a comprehensive industrial program to handle major emergencies such as fires, gas leaks, and explosions, based on the expert guidance on techniques. An emergency rescue wireless communication system underground mine to implement the rescue action based was proposed [7]. It can acquire the key information data and status information on disaster site quickly and accurately, but it did not describe how to rationally use these data and information in the rescue. Launa [3] studied warning messages during an emergency evacuation, which concluded that the implementation of a few relatively simple human factors principles could have improved the efficacy of warning communication systems. A management information system for managing of mine emergency resources, practicing of mine emergency program and commanding of emergency rescuer is developed on the base of mine accident emergency scheme [8]. The system can automatically monitor the situation of rescuer personnel, rescue materials and rescuer equipments in daily, but doesn’t include the emergency rescue decision method and technology.

Currently, such a real-time adjustment purely depends on personal experience of decision makers. However, judgment precision of decision makers is subject to their selection preference, experience intensity and information collected. Therefore, paragraphs below will initially explore solutions to the dilemma where risk decision theory can be applied to solve emergency rescue of coalmine sudden gas events and makeup in drawbacks in decision making according to experience analysis of decision makers, thus reducing unfavorable consequence due to personnel decision bias.

UNCERTAINTY ANALYSIS OF EMERGENCY DECISIONS OF COALMINE GAS EVENTS

Gas source uncertainty in occurrence time, location and scale: In a gas emergency event, hazard degree mainly depends on abundance of advance preparations and accurate predictions of gas scale and distribution within short time. However, when emergency decisions are made, high uncertainties exist in determination of the strength and time of gas emergency source. We can reduce uncertainty of gas source by getting gas data information through underground monitoring system and manual probed data, and can constantly correct the gas source through improved and changed information we have collected.

Reliability in ventilation system of gas emergency: When gas emergency event happens, gas, releasing to the mine workings, moves with the mine atmosphere even forms reserving flow, which may cause disorder in mine ventilation system. Direction of motion and speed of underground air and distance of high pressure gas backflow depend distribution of gas density and route of gas with high density. However, when gas emergency event happens, uncertainty of outburst intension causes distance of backflow unknown; stability and reliability in the original ventilation system causes uncertainty to have a right analysis and judge on scope of dangerous gas. We can reduce this uncertainty through monitoring of gas density change and correction of manual information.

Decision bias in experts’ prediction on gas source, spreading scope and spreading direction: In emergency decision, the decision makers need to evaluate and have a judgment on various parameters of gas releasing, such as time, quantity, duration and spreading degree mainly based on contemporary documents. Because of uncertainty of judgment of gas emergency event in gas source and ventilation system, it’s hard for experts to have a right judgment on various gas parameters in a short time, which may cause corresponding uncertainty to decision.

Uncertainty caused by decision makers’ values and decision preference: Decision makers’ values and decision preference of various plans in emergency decision are decisive elements and they directly determine the option of emergency plan. Since they are uncertain, emergency decision is accordingly uncertain.

Because of uncertainty in the above emergency decision of sudden gas events, it is important to reduce the uncertainty in emergency decision of sudden gas events by analyzing information when the event happens with basic discipline and theory of technology to improve correctness of decision. Based on Bayes risk decision theory, an emergency decision model of sudden gas events was built in this paper to reduce uncertainties of sudden gas events and improve correctness of decision.

EMERGENCY DECISION MODEL OF COALMINE SUDDEN GAS EVENTS

Bayes risk decision theory [2]: Decision and judgment have the following characteristics: subjectivity, environmental uncertainty, reliability of information, timeliness of condition and selectivity of plan [10]. Bayes decision theory has advantages that general decision methods don't have. For example, without full information, Bayes decision theory can conduct subjective probability estimation on some unknown parts; then correct the probability of unknown parts through relationship between the known parts and the unknown parts; finally, have a best decision with expectation value and corrected probability [4]. Bayes decision is a kind of risky decision where though decision makers cannot control the change of objective elements, they can have a good knowledge of their possible states and probability distribution of various states and make expectation value (possible average state in the future) a principle.

Assume that there is decision matter composed of state space Θ, decision space A and loss function $L(\theta,a)$. State Θ has a prior probability $\pi(\theta)$, $\Sigma\pi(\theta)=1$, assuming that x is the observation sample; X is the sample space; posterior probability of state θ is $\pi(\theta|x)$ and the probability of information X under state θ is $f(x|\theta)$

$$\pi(\theta \mid x) = f(x \mid \theta)\pi(\theta) / \sum_{\Theta} f(x \mid \theta)\pi(\theta) \tag{1}$$

When x and θ are both discrete random variables, definition of Bayes risk on decision a is as follows

$$R(\pi,a) = E^{\pi}[R(\theta,a)] = \sum_{\Theta}\sum_{x\in X} L(\theta,a) f(x \mid \theta)\pi(\theta) \tag{2}$$

If decision a_1 and a_2 have the following relationship with Bayes risk

$$R(\pi,a_1) < R(\pi,a_2) \tag{3}$$

Then decision a_1 is better than decision a_2. So analyze with Bayes decision is to choose a decision behavior a^* which makes (2) reach the minimum value, namely

$$R(\pi,a) = \min_{a\in A} E^{\pi}[R(\theta,a)] \tag{4}$$

For Bayes decision, in case there is no measurement, a prior distribution of Bayes decision corresponding to parameter θ.

Emergency decision model of coalmine sudden gas events: Among the uncertain elements of sudden gas events, uncertainty of distribution of gas with high concentration is the direct influential element of emergency decision when emergency happens. If decision has bias with the actual distribution of gas with high density, there will come human's death and injury and material loss. Besides, with time going by and new data increasingly being gotten, uncertainty of distribution of gas with high concentration will be lower, which accords with Bayes theory. Build an emergency decision model of sudden gas events according to Bayes risk decision theory to improve emergency decision level.

(1) Basic definition

State space $\Theta=\{\theta\}$: Θ is a type collection of gas field in some area. This paper divides gas field type into gas field with low concentration θ_1 (<5%) and gas field with high concentration θ_2 (>5%). Prior probability $\pi(\theta)$ of each gas field type can be gotten through analysis of historical documents on times which each gas field has happened.

Sample space (information collection) $X=\{x\}$: X is data or information about gas field in some certain time or time period, including concentration of gas in every monitoring point, wind direction in mine workings and likelihood probability $f(x|\theta)$ of sample information x under some gas field state based on historical documents (mainly on monitoring coefficient).

Posterior probability $\pi(\theta|x)$: In sample space X, posterior probability of gas field θ appearing is $\pi(\theta|x)$. Calculate $f(x|\theta_j)$ after getting predicted gas data x (sample data) at one time, then calculate posterior probability $\pi(\theta_j|x)$ as per Bayes theory and prior probability $\pi(\theta_j)$ of each gas field type. It's necessary to note that for original decision from the beginning moment, prior probability $\pi(\theta_j)$ of each type is gotten according to historical data, while for other moments, prior probability $\pi(\theta_j)$ of each type is gotten according to the posterior probability $\pi(\theta_j|x)$ of corresponding type. Applying new predicted gas data to correct happening probability of various wind fields reduces uncertainty of gas moving with ventilation system and makes decision more complied with actual situation.

(2) Decision plan A
Decision plan set $A=\{a\}$, where A stands for a set of plan that decision makers may take and a stands an element of a. In actual safety management of coalmine gas, the enterprises must establish reasonable responsibility system according to relevant regulations and stipulations to ensure reasonable and valid ventilation and promptly monitor change of gas concentration. In case the gas concentration is higher than 2%, staff and operators must evacuate [6]. Only by strictly abiding by relevant regulations and stipulations, we can reduce the happening of emergency and accident in as much as possible. There are two kinds of dangers of gas emergency, namely oxygen suffocation caused by abundant gas flooding into mine working, and harmful effects caused by gas explosion when gas concentration reaches the explosion limit. Relevant documents show that when gas concentration is higher than 25% to 30%, people will have suffocation symptom; when it is higher than 80%, people will soon die [9]. High temperature and pressure, poisonous and hazard air after explosion will put underground staff and emergency rescue workers in danger. Therefore, according to characteristic of gas emergency event and decision plan suggestion of gas emergency event, we may apply two kinds of integrated actions which mean evacuation & fire source controlled and evacuation & fire source not controlled.

(3) Loss function $L(\theta,a)$
Loss function $L(\theta,a)$ is the outcome (or benefit or loss) of taking emergency action a at gas field θ and is a comprehensive reflection of good and bad decision. In actual mine situation, it is a reflection of the threat to staff. Loss function determines the quantification of whether decision is good or not. Being a judgment of decision plan, it has direct influence on decision. When gas emergency event happens, we should reduce its harm to people as much as possible considering the actual condition, that is to say, considering the feasibility of plan, reduce the threat of gas to people's health and lives as much as possible. Gas with high concentration may has the following dangers to people's health and lives: suffocation caused by gas with high density, explosion hurt caused by explosive gas and duration time of people in gas with high concentration. Therefore, when making decision, we should take suffocation probability, explosion probability, time of people in gas and people's quantity into full account.

(4)Assessing standard for decision risk
The target of emergency decision model of coalmine sudden gas events is to choose one of Bayes decision plans which is the least risky to be the final decision plan in some stage. Generally speaking, it's not easy to get Bayes risk $R(\pi,a)$ in different optional plans. According to relevant document [8], when formula (5) is minimum, formula (4) is also minimum, namely

$$R''(\pi,a)=\sum_{\theta\in\Theta}L(\theta,a)\pi(\theta\mid x) \tag{5}$$

This paper will seek the minimum value of R instead of its minimum value through formula (5) to judge risk of decision plan.

(5) Emergency decision action in different stages
In actual decision making, the situation is often complex, especially where natural state changes with time. Here, we may divide the whole decision process into several stages and each stage includes prior analysis, pre examination analysis, posterior analysis and other procedures. With many stages mutually connecting and decision result of last stage being condition of the latter stage, a whole decision analyzing process is formed, referred to as multistage decision.

When gas emergency event happens in coalmine, because ventilation system, gas will spread in gas source downwind and upwind area of the same level and different levels, so emergency decision action may be different from area to area. Therefore, we should divide the ventilation system into several subsystems to improve level and accuracy of emergency decision. The lower the subsystem is, the better the decision is, however, the decision process is more complicated and it is harder to solve. To clearly explain process where Bayes risk decision theory is applied to coalmine emergency decision and to ensure analysis simplicity of typical cases at the same time, we often have a rough division only in the subarea, namely, dividing according to level and gas source downwind and upwind area between levels as the emergency scope. For the specific mines, division quantity may be different. Number the divided decision subareas in order to calculate and analyze.

Take the same emergency decision in the same subarea, but each subarea is not dependent with each other. Based on people's acceptable degree, each subarea has relevance with each other, namely, to meet some relevant restriction. It's acceptable to take the same managing method with main considering the gas source and area far away from it.

Make the minimum Bayes risk $R(\pi,a)$ of gas emergency decision a target and each emergency action a, taken in each emergency decision subarea, a decision variable; abide by suggested value of relevant stipulations and experiments and acceptable degree.

From the analysis above, emergency decision model of sudden gas events was built as follows:

$$\min R''(\pi,a)$$

$$R''(\pi,a)=\sum_{\theta\in\Theta}L(\theta,a)\pi(\theta\mid x)$$

$$A=\{a_1,a_2,...,a_n\}$$

$$a_i=\begin{cases}-1 & \text{Adopt (evacuation + fire source controlled)}\\ 1 & \text{Adopt (evacuation + fire source not controlled)}\end{cases} \tag{6}$$

$$L(\theta,a_i)=L_{ij}$$

Where, i is element quantity of decision plan set A; j is element quantity of gas field type set Θ; L_{ij} is the possible loss when decision plan a_i was taken under some gas field state θ and it can be persons and things with equal quantity or value with equal price or expert's assessing value for the above variables.

PRACTICAL APPLICATION OF EMERGENCY DECISION MODEL OF COALMINE SUDDEN GAS EVENTS

"11.21" particularly significant gas explosion accident of Xinxing coalmine: November 21, 2009, 1:37 am, the Xinxing coalmine of Hegang Branch Company of Heilongjiang Longmei Co., Ltd. had a particularly significant gas and coal (rock) outburst accident. The backflow gas in the 2nd level unloading roadway area reach the explosion limit. At 2:19 am, it encountered the ignition source and then exploded, which caused 108 deaths.

Xinxing coalmine uses inclined shaft multilevel development, which is arranged in the development method of floor pick heading and zoning crossheading in each level. At present, the mine is exploiting the 2nd level and the 3rd level. The mine has two production levels, eight mining areas, 30 mining and digging faces (which include 6 faces for coal mining, 16 faces for coal digging and 8 faces for rock digging).

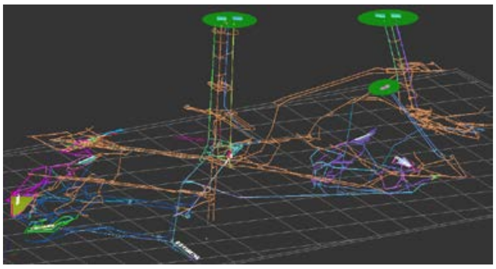

Fig. 1: Plan of Mine Mining Engineering

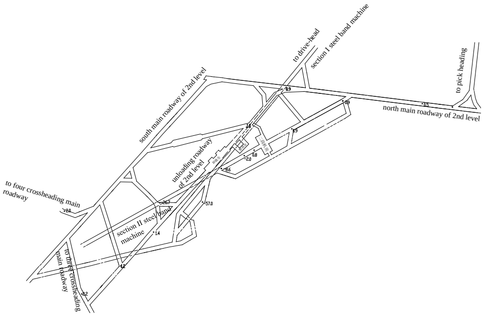

Fig. 2: Neighboring Area of Unloading roadway of 2nd level

November 21, 2009, 1:37 am, a particularly significant gas and coal (rock) outburst accident occurred in the digging face of coal prospecting way of the south two crossheading in the 3rd level. The gas backflow flew through the south main roadway and the two-section steel band machine of 3rd level, and reached the south main roadway of 2nd level. The gas flew downwind, which caused the gathering of explosive gas in the south main roadway of 2nd level, unloading roadway and the neighboring area. November 21, 2009, 2:19 am, the south main roadway of 2nd level, unloading roadway and the neighboring area had a gas explosion, which spread to the south main roadway of 2nd level, section I steel band machine and section II steel band machine in the region. After the accident, the fireboss found over-limit gas and then organized 162 workers evacuation. While receiving the evacuation notice and after discovering the accident signs, there were 258 survivors who had evacuated autonomously.

The direct reasons for the gas and coal (rock) outburst are: in the digging face of 15th coalbed coal prospecting way in the south two crossheading of 3rd level, which has extremely complicated geological structures and is 394m deep from the earth's surface, the 15th bed coal has a particularly massive gas and coal (rock) outburst; the outburst gas flows into the south main roadway of 2nd level against airflow direction of the 3rd level and then flows downwind in the 2nd level, which causes explosive gas gathering in the unloading roadway of 2nd level and its neighboring area; an electric spark, which is produced by line clamp joint of aerial wire of electric locomotive serving in the unloading roadway, ignites the gathering gas.

Basic parameters: The case of Xinxing coalmine can be divided into 2nd level and 3rd level subareas according to the occurrence of accidents, which should be recorded as subarea 1 and subarea 2. The gas fields of sudden gas events can be divided into $\theta_{1,}$ low concentration gas field (<5%), and θ_2, high concentration gas field (> 5%), according to the lower gas explosion limit.

Setting the case emergency plan as a_1 （power failure & excavation on foot） and a_2 (non power failure & rapid excavation by belt).

According to the historical situation of the coalmine before the outburst, have a preliminary evaluation of the distribution probability in gas field, then we can have a prior probability of the distribution of gas field θ_1, ($\pi(\theta_1)$ and $\pi(\theta_2)$ refer to the probabilities of θ_1 and θ_2 gas fields), which are set in the following Table 1.

Table 1 Prior Probabilities

Subarea number	$\pi(\theta_1)$	$\pi(\theta_2)$
Subarea 1(2nd level)	π_1	$1-\pi_1$
Subarea 2(3rd level)	π_2	$1-\pi_2$

According to the gas monitoring data at an initial moment, calculate the likelihood probabilities of sample x= ｛gas exceeding the standard and so on｝, which are the probabilities of occurring x (such as 3%) in θ_1 and θ_2 gas fields respectively

$f(x|\theta_1)=p_1$， $f(x|\theta_2)=p_2$

Calculate the posterior probabilities of θ_1 and θ_2 gas fields on the condition that x appears (such as 3%)

$\pi(\theta_1|x)= \pi p_1/(\pi_1 p_1+(1-\pi)p_2)$

$\pi(\theta_2|x)= \pi p_2/ (\pi_1 p_1+(1-\pi)p_2)$

In the accident, it is difficult to describe the confirmation of loss function L through using pure quantity (such as quantity of workers or matters) according to the investigation. Therefore, the loss function, while adopting action a, selects the gas threat degree in the subarea (shown in table 2). a_1 is the first plan as on foot excavation when there is power failure and a_2 is the second plan as rapid excavation by belt when there is no power failure. As for the coal mine sudden gas events, apart from the risks of gas stifle and personnel pressing and burying, there is also the risk of gas explosion. However, in the region of high gas concentration, the key to control the risk of gas explosion is to control the ignition source. Therefore, loss function L is the number of workers with the stifle threat of high concentration gas and the threat of gas explosion.

Table 2 Loss Function

Subarea number	L/a_1		L/a_2	
	θ_1	θ_2	θ_1	θ_2
Subarea 1 (2nd level)	$L1_{11}$	$L1_{12}$	$L1_{21}$	$L1_{22}$
Subarea 2 (3rd level)	$L2_{11}$	$L2_{12}$	$L2_{21}$	$L2_{22}$

Bayes decision analysis of the 3rd level: After the gas outburst, as for the 3rd level, apart from the low concentration in the gas field beside the original small region of accident, then the existence of ignition source will not cause gas explosion and does not have the danger of gas explosion. However, the personnel in the part of original region of the accident will face threatens of gas stifle, and people in other areas are safe, therefore, $L2_{11}< L2_{21.}$ On the contrary, apart from the original place, when high gas concentration appears in many places, gas will not only influence the personnel in the accident region, but also have influence on the personnel in neighboring regions. And at this time, the existence probability of ignition source will have significant influence on gas explosion. Since the 3rd level electromechanical equipments are coalmine permissible type, the ignition source of electromechanical equipment can be neglected, and the remaining largest ignition source is the ignitions source which are caused by static electricity and collision in the gas environment. This kind of ignition source has no relevance to the power failure of electromechanical equipment. The explosion risks at the two decision plans are the same (ignoring the difference of personnel number which is caused by the personnel in the 2nd level moving speed). Therefore, we can assume that $L2_{12}= L2_{22}$. Based on Equ.(6), then

$$\frac{R_2''(\pi,a_1)}{R_2''(\pi,a_2)}=\frac{L2_{11}\pi_2+L2_{12}(1-\pi_2)}{L2_{21}\pi_2+L2_{22}(1-\pi_2)}<1$$

According to the Bayes Decision Theory, plan a_1 is better than plan a_2. Therefore, the superior decision scheme of 3rd level is to choose the decision plan a_1, that is, immediately power cut and evacuate, which is corresponding to the emergency plan and regulation requirements of coal mines.

Bayes decision analysis of the 2nd level: The 2nd level decision is rather complicated. The 2nd level risk decision process is closely related to the 3rd level gas condition and the personnel motion state and the decision is closely related to time. Make a flow chart of gas transport path after the gas outburst, refer to Fig.3. The key to decide the 2nd level decision plan is the probability of outburst stifle and the probability of gas explosion. The probability of gas explosion is not only influenced by the influence of ignition source, but also influenced by the gas concentration level. Therefore, the key of gas stifle and gas explosion is in-time mastery of the backflow of high concentration gas. Bayes risks of the 2nd level decision plan are as follows

$$R_1''(\pi,a_1)=L(\theta_1,a_1)\pi(\theta_1\mid x)+L(\theta_2,a_1)\pi(\theta_2\mid x)$$

$$R_1''(\pi,a_2)=L(\theta_1,a_2)\pi(\theta_1\mid x)+L(\theta_2,a_2)\pi(\theta_2\mid x)$$

According to the description of accidents at about 1:40 am, November, 21st, 2009, there are gas exceeding the limit and gas backflow occurred in the 2nd level. According to the accident investigation, the backflow route after gas outburst can be made into simple flow chart, shown in Fig. 3. According to the process of accident explosion, the gas backflow is an important factor which causes the expansion of accident. Many types of electromechanical equipment in the 2nd level air intake area are not mine permissible type. Therefore, the power failure will change the existence probability of ignition source. Once high concentration gas enters into the 2nd level, then the gas risk will increase from stifle to huge risk of explosion and the risk will improve greatly. As for the emergency rescue plan, Fig. 3 shows that the important significance of discovering the high concentration gas backflow, which moves from the section II steel band machine of 3rd level to the south main roadway of 2nd level, to correct emergency decision. Before the explosion accident, sensors in many regions of the 3rd level alarm, which shows the massive scale of gas outburst. At the same time, it is found that the 3rd level has the backflow of gas, therefore it is necessary to pay close attention to the probability of backflow to the 2nd level. In the condition of θ_1, in the table 2, $L1_{11}=L1_{21}$, and $L1_{12}$ and $L1_{22}$ should be evaluated specifically according to the actual situation. In the following, we will analyze Bayes risk decision process at three key times: 1:36:28, 1:40:53 and 1:42:42. In the initial analysis, $\pi(\theta)$ and $f(x|\theta)$ are obtained from the analysis of historical data.

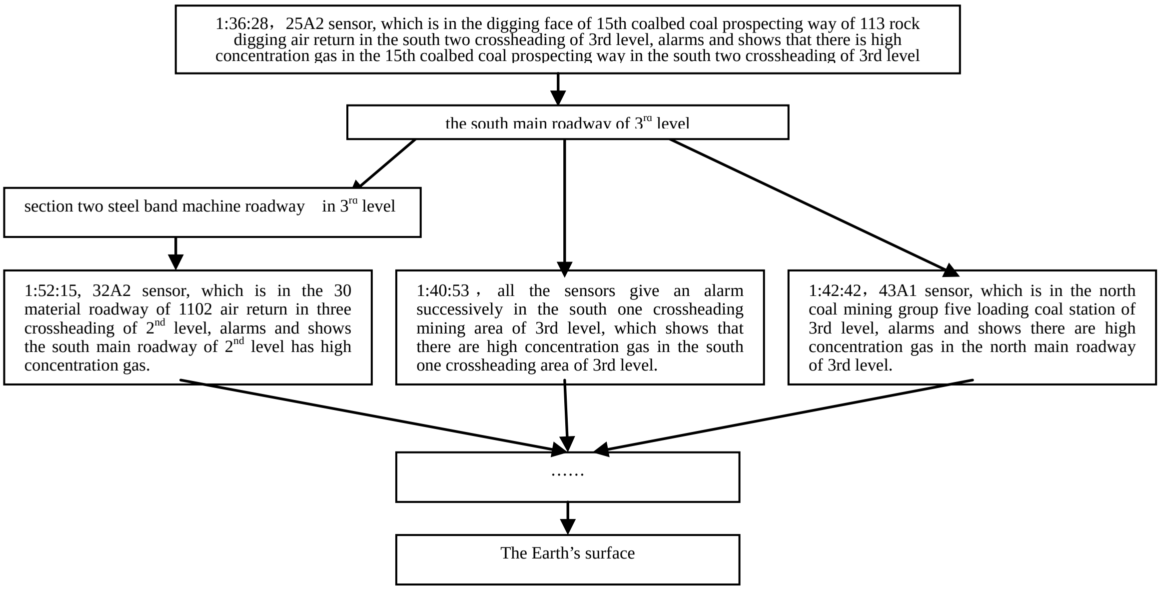

Fig. 3 Gas backflow transport path and sensor reaction

Table 3 Related parameters in different times of the 2nd level

Time	$\pi(\theta_1)$	$\pi(\theta_2)$	$f(x\|\theta_1)$	$f(x\|\theta_2)$	$\pi(\theta_1\|x)$	$\pi(\theta_2\|x)$
1:36:28	0.60	0.40	0.30	0.70	0.39	0.61
1:40:53	0.39	0.61	0.35	0.65	0.26	0.74

(1) 1:36:28

$$R_1''(\pi,a_1)|_{1:36:28}=0.39\times L1_{11}+0.61\times L1_{12}$$

$$R_1''(\pi,a_2)|_{1:36:28}=0.39\times L1_{21}+0.61\times L1_{22}$$

At this time, the 2nd level has no gas exceeding alarm, the 3rd level has only 25A2 sensor alarm, the 3rd level gas concentration has not exceed the standard in general. As for the 3rd level, except for the alarm points, the gas concentration in other flow directions of the 2nd level is low. Therefore, the probability of having high gas field in the 2nd level is almost zero. Now, it can be considered as free from the risk of gas stifle. In the situation of lacking explosive high concentration gas, power failure or not will not change gas explosive risk, and has no explosive threats. Therefore, now it can be considered as $L1_{11}= L1_{21}=0$， then

$$\frac{R_1''(\pi,a_1)}{R_1''(\pi,a_2)}\leq 1$$

Therefore, $R_1''(\pi,a_1)|_{1:36:28} \leqslant R_1''(\pi,a_2)|_{1:36:28}$, that is power failure or not have no influence. The Bayes risk of decision plan a_1 is better than that of decision plan a_2, at least that Bayes risks of these two plans are the same. It shows that at present it is not suitable to carry out the decision of power failure. Carrying out the more conservative decision of power failure will not lower Bayes risk, that is, power failure has no important influence.

(2) 1:40:53
Here, according to the development condition of the accident, adjust $f(x|\theta)$， increase $f(x|\theta_1)$ ratio (since the mine has no outburst before the accident). Then,

$$R_1''(\pi,a_1)|_{1:40:53}=0.26\times L1_{11}+0.74\times L1_{12}$$

$$R_1''(\pi,a_2)|_{1:40:53}= 0.26\times L1_{21}+0.74\times L1_{22}$$

All the sensors in mining area of the south two crossheading of 3rd level start to give an alarm at 1:36:51. At around 1:40, firebosses in the south one crossheading and south two crossheading of 3rd level found out abnormal signs, including gas over limit and airflow reversal. At this moment, the probability that high concentration gas reversely flows from the 3rd level to the 2nd level significantly increases, as well as the probability of the 2nd level high concentration gas, which contributes to a notable increase in $L1_{12}$ and $L1_{22.}$ Make a further assumption that $L1_{11}$ equals to $L1_{21,}$ if plan a_1 is carried out here, the explosion probability will be lowered where there is high concentration gas. Major threat of the explosion is the one induced by ignition source in walking process. In spite of the fact that plan a_2 lowers the personnel existence probability in high concentration gas area and the asphyxiation probability, the threat is much smaller than that of explosion induced by ignition source generated by electromechanical equipment running with electricity. Therefore, $L1_{12}<L1_{22}$ is workable,

$$\frac{R_1''(\pi,a_1)}{R_1''(\pi,a_2)}<1$$

Here, Bayes risk of decision plan a_1 is lower than that of decision plan $a_{2.}$ That is to say, from the perspective of preventing secondary disaster, the plan of excavation on foot with power failure is superior to scheme of excavation by belt without power failure.

(3) 1:42:42 and afterwards
Similar to Bayes decision at 1:40:53, Bayes risk of decision plan a_1 will be continuously lower than that of decision plan a_2, namely $\frac{R_1''(\pi,a_1)}{R_1''(\pi,a_2)}<1$, and the plan of excavation on foot with power failure is superior to scheme of excavation by belt without power failure.

Eq.(6) restores the analysis above, which demonstrates the changes in decision plan in different time points after the gas accident, shown in Fig.4.

Fig. 4: Regression of time-varying decision plan

Fig.4 above indicates that knowing the condition of the gas backflow in 2nd level is the key for emergency decision making. However, while making decisions, individuals and groups are not in an entirely rational state, which will cause decision bias and decision traps. Bayes Risk Decision Theory is a rational decision theory. When the backflow gas in 3rd level fails to be found in time, the decision results will be in a state with or without power failure. In fact, before the accident, there exists a phenomenon of collective blindness in the decision group, namely that no one notices the backflow state of gas after finding out the outburst, and no one continue to moniter the sensor state, which displays the flow state of gas. Hence, the best time for correct decision is missed, which leads to the occurrence of explosion accident and a further expansion in range of influence.

KEY ANALYSIS AND PRACTICAL SIGNIFICANCE OF OPTIMAL DECISION MADE BY REFINING PROBABILITY AND LOSS VALUE

Key analysis: The above-mentioned calculation indicates that Bayes decision process of gas emergency event is on the basis of fundamental probability, continuously correcting the original concept on emergency, reducing Bayes risks, lowering the uncertainty on gas emergency event and getting close gradually to optimal decision by using newly-gained information related. It is important to note that gaining new information in time is of great significance to improving decision-making level. With respect to gas emergency event, obtaining dynamic information of gas is the key to improve the accuracy of decision. As for the "11.21" accident, key information influencing the gradual improvement of Bayes risk is exactly gaining the range of gas backflow timely, while the key to handle the matter is to install gas sensor with air intake area.

In the process of Bayes decision process, loss function plays an important role, while the adjustment to $f(x|\theta)$ and expert evaluation of loss function are critical in the development process of the event. With the development of the event, certain part of gas emergency event shall be increased, while uncertain part shall be reduced. Expert evaluation of loss function reflects the experts' risk preference. Changes in posterior probability and preference adjustment to loss function make a big difference in final calculation of Bayes risk. Bias in expert evaluation of loss function shall come into being where backflow fails to be found. These biases shall have an effect on the calculation of Bayes risk, which causes the decision bias. Therefore, as for decision makers, accurate judgment in risks of gas area is of great importance to select correct emergency decision plan, while finding the gas backflow is the key to reducing evaluation bias.

In the gas explosion accident in Xinxing coalmine, if the first decision is carried out without noticing the gas backflow, sensors exist in the air intake area from the 3rd level into the 2nd level. Re-supplement of decision can also avoid explosion accident where backflow gas reaches the connecting location and release the warning information. Hence, in the premise of obtaining and judging correct flow state of gas in the air intake area, setting effective sensor in different key locations (e.g. the connecting location between the 3rd level and the 2nd level in Xinxing coalmine) is necessary and valid to monitor the dynamic changes of gas in roadways and shafts, to select correct emergency plan in accordance with dynamic situations of gas distribution.

From the view of behavior and psychology, decision makers and groups should fully understand the influence of behavior and psychology on individual and group emergency plan, to avoid the occurrence of decision bias and decision traps in the decision process. The above-mentioned Emergency Decision Model of Coalmine Sudden gas events can base on sensor location, carrying out regional division in line with actual mine area, as well as a further subdivision. Based on the flow condition of gas from sensor reaction, a network deducing system combining sensor data system with Bayes model shall be set up to carry out real-time analysis and judgment of emergency decision plan.

It is important to note that the advantage of making risk decision of gas emergency event by Bayes Theory as compared with that by experience is that: Bayes Decision Theory integrates prior distribution and sampling distribution into a posterior distribution (empirical distribution of revised gas) and then selects the decision plan, in which posterior distribution is the starting point, with the judgment of loss state by making full use of prior information (statistical information of previous gas emergency event, namely original empirical documentation), data information (sampling information, namely the newly-gained information related to gas) and modeling information (mathematical model). The decision plan shall be in continuous recursion and closer to correct decision plan with certain information where the sampling information of gas keeps being updated. Where, the judgment of loss can be conducted by creating reasonable loss function or relying on the empirical analysis of experts or decision makers. Since Bayes Decision Theory of gas emergency event is an inference method based on the uncertainty of probability, existing information networks (e.g. monitoring system) can be used, combining with judgment methods adopted by experts, to set up an intelligentized decision system, which shall make optimal decision in the early stage of gas emergency event and reduce the drawback of making decision purely by experience.

Significance of practical application: Empirical decision dealing with gas emergency event is on the basis of collection and analysis of relevant information. After gas outburst is found in the 3rd level air intake area, outburst location and the current range of outburst backflow at one point can be judged by monitoring system display and gas concentration reported by fireboss in the mine. While the ranges of outburst gas backflow and the dynamic change of backflow distance can not be accurately analyzed. Therefore, a rough decision is the only choice, which is more likely to contribute to inadequate response or over response. Since the factors of decision include: 1) analyzing the possibility of gas reaching the 2nd level area by backflow based on historical data and experts' experience when the 3rd level outburst event happened; 2) analyzing existing blast or asphyxiation loss in the 2nd level and thye 3rd level area; 3) making optimal decision by an analysis of various decision plans on the basis of the previous two points. Obviously, experience-based judgment is not equal to a correct analysis and overall consideration of the three factors, which is the actual significance of Bayes risk decision dealing with on-site sudden events.

The advantage of making risk decision of gas emergency event by Bayes Theory as compared with that by experience is that: Bayes Decision Theory integrates prior distribution and sampling distribution into a posterior distribution (empirical distribution of revised gas) and then selects the decision plan, in which posterior distribution is the starting point, with the judgment of loss state by making full use of prior information (statistical information of previous gas emergency event, namely original empirical documentation), data information (sampling information, namely the newly-gained information related to gas) and modeling information (mathematical model). The decision plan shall be in continuous recursion and closer to correct decision plan with certain information where the distance of gas backflow keeps expanding and sampling information of gas keeps being updated. Where, the judgment of loss can be conducted by creating reasonable loss function or relying on the empirical analysis of experts or decision makers. Since Bayes Decision Theory of gas emergency event is an inference method based on the uncertainty of probability, existing information networks (e.g. monitoring system) can be used, combining with judgment methods adopted by experts, to set up an intelligentized decision system, which shall help make optimal decision in the early stage of gas emergency event and reduce the drawback of making decision purely by field experience.

CONCLUSION

Since the coalmine gas emergency event is a process with dynamic changes and abundant uncertainty, the emergency decision plan differs with continuous changes in new situations. In order to reflect the changing process of emergency decision and solve the dilemma caused by the uncertainty of gas emergency event, the author has put forward an emergency decision model in accordance with Bayes Risk Decision Theory and put it into practice with the Xinxing particularly significant gas explosion accident “11.21” accident. And then the practical significance that the key decision-making technology and modified probability and loss value plays in the emergency decision model are proposed.

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