Process Model and Digitalization of the Coal Gas Outburst Prevention

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Abstract

Regional coal gas outburst prevention has become the prerequisite of coal mining in the most China underground collieries. It touched on miners' lives so closely, but especially lacked of digitalization due to the hostile working environment, sightless strata reserves, complicated and long-time workflow. By synthesizing the vital rules issued by China governments and various techniques of coal gas outburst prevention, we proposed a novel process model for them embodied as a logical workflow. The model consisted of two operation links and two judging nodes, and dealt with three types of data. Then an easy-use and practical process data management software system was developed. By testing in Qinan colliery, the system was proved to be fully considering user experience and helpful to promote digitalization of coal gas outburst prevention. Compared with the traditional management, the digitalization might help engineers identify anomalies more quickly and avoid gas accidents in time.

Keywords: digital mine, coal gas outburst prevention, process model, data management

1. Introduction

With the underground coal exploitation extending to depth rapidly in China, high geo-stress, high gas, high inhomogeneous, low permeability and low coal mass strength, namely phenomenon of three high and two low, makes the problem of coal and gas outburst hazard become more and more outstanding. To avoid touch outburst coal seam closely and eliminate gas content, over the last decades, a series of regional gas pre-drainage techniques have been presented from a variety of aspects [1, 2], such as ground boreholes, along-seam boreholes, cross-seam boreholes, gob pipes, inclination roadway, etc. Further on, based on numerous fundamental research and widely practical experiences, several vital rules are issued by China governments: "Coal and Gas Outburst Prevention Regulations" [3], "Gas Extraction Provisional Regulations for Coal Mine" [4], "Coal Mine Safety Regulations" [5], etc. Through numerous practice and summary over ten years in China collieries, it has been well recognized that regional coal gas outburst prevention is one special industrial process [1, 6], and is obviously different from the processes in other fields, embodied at least in four points as the following:

1) Regional coal gas outburst prevention process must run for an especially long time, often more than 1 year, even 2-3 years, and during the period, the coal mining has to be forbidden. So the rational process management directly facilitates coal production efficiency;

2) Although there exist diversified gas control measures which has been mainly standardized respectively, but it's hard to synthesize them and develop its support software system because of the low digital degree. Now all operations in the process such as designing, construction, management, etc, have to be implemented manually. Then man-made mistakes happen inevitably, even lost some important data;

3) There are several pivotal validation links in the process to connect adjacent process units. If the validation result is fail, then the coal gas outburst hazard hasn't been eliminated,

and the process must return to the front unit and supply additional measures. So the front unit and validation link form a loop which terminates until validating succeeds;

4) It must be pointed out that the process management has closely related to miner lives, and any mistake may lead to gas accidents.

With information technology integrated into coal industry [7-14], many software systems have sprung up in the last years [15], such as Micromine [16], Minesight32D [17], Surpac, DataMine, AMSKAN, PENDM [18], etc. By them, coal reserves calculating, production planning, material and financial management are well supported [19, 20]. However, all they have devoted themselves to coal production system rather than coal gas outburst prevention practice.

Therefore, it is necessary and urgent to establish the normative and good-adaptive process model for coal gas outburst prevention and control. Further on, in order to manage the process effectively, a support software system based on the novel model was developed, in which a comprehensive data structure was proposed and the key management function was implemented by several man-machine interfaces.

2. Process Modeling for Regional Coal Gas Outburst Prevention

According to "Coal and Gas Outburst Prevention Regulations" [3], the industrial process of regional coal gas outburst prevention mainly consists of four sequential steps: 1) predicting coal gas outburst danger regionally; 2) implementing regional gas pre-drainage measures; 3) examining coal gas outburst danger regionally; 4) validating the residual gas pressure and content during coal mining, as shown in Figure 1.
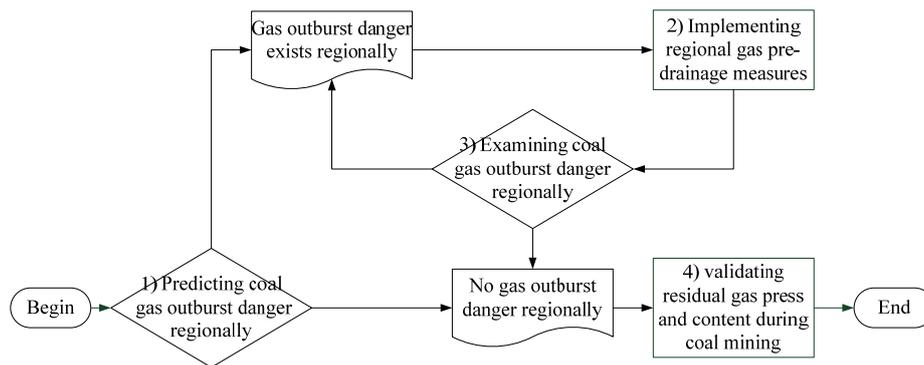

Figure 1. Schematic Diagram of Regional Coal Gas Outburst Prevention Process

In Figure 1, the first step is a decision node used to predict whether coal mass in the given region has gas outburst danger. When danger exists, go to the second step, otherwise directly turns to the fourth step. In the second step, the suitable regional gas pre-drainage measures will be implemented for a planned long time. After that, regional coal gas outburst danger is examined in the third step. Liking the first step, only pass the third steps successfully with conclusion "no gas outburst danger regionally", the fourth step can start, otherwise returns to the second steps and supply additional regional measures until pass the third step. In the fourth step, accompanying coal mining, the validation of the residual coal gas pressure and residual coal gas content must perform at intervals of a given distance in the coal mass. When dangerous, must control gas partially until not dangerous. For the fourth step is a particularly node that expresses another industrial process of underground coal mining that is also comprehensive and complex, and beyond the scope of regional coal gas outburst prevention, it won't be discussed in this paper.

3. Data Structure Analysis

As same as the industrial process in various fields such as electronics, petrochemical engineering and mechanical manufacturing, etc, the process management of regional coal gas

outburst prevention must deeply rely on the description data produced in the process. Although multifarious gas pre-drainage measures are different in detail, but they mainly include the three kinds of data, defined as follows:

Type 1: Basic parameters. They describe coal reserves, gas occurrences, gas permeation and geologic structure, which are relatively invariable in the range of a coal mining working face and used as the basis of relevant computation;

Type 2: Construction parameters. They contain the designing and construction parameters of coal and rock roadway, working face, drill field, various boreholes and their spatial relation, all which make up the infrastructure of gas pre-drainage;

Type 3: Gas extraction parameters. They record the quantity of gas elimination and are composed of two aspects that are extraction gas in sealed pipes and windblown gas in roadway. By the gas monitoring system installed in most China collieries, they can be gained abundantly.

Because coal gas outburst prevention process is continuous in view of time, amount of Type 2 and Type 3 parameters will form a number of dynamical time series. In addition, the construction process is also spatially sequential, and the Type 2 parameters will well reflect related construction activities. In various coal gas pre-drainage techniques, cross-seam boreholes constructed in drill fields on side of floor rock roadway, along-seam boreholes constructed in coal roadway are wildly used in China. Limits to these two kinds of boreholes, we establish data structure of coal gas outburst prevention process as shown in following Figure 2.
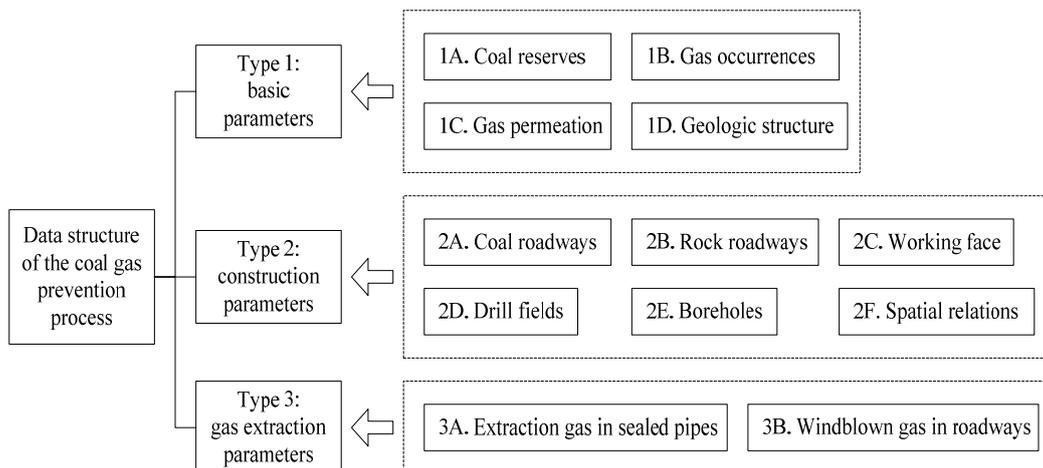
Figure 2. Data Structure of Regional Coal Gas Outburst Prevention Process

As a complex industrial process, each data item in Figure 2 is composed of several sub-items. For example, to elaborate coal reserves, according strata modeling technology [11], the data item 1A need contain a series of scatter point that form the triangle network of 3D model. Each point records a point identifier that will refer its spatial coordinate, and its type is defined as 0 or 1, in which 0 indicates locating on coal seam floor and 1 means lying on coal seam roof. The detail of other data item will be discussed in 4.1.

4. Development of the Data Management Software System
4.1. Data Modeling

Corresponding to data structure shown in Figure 2, each data item is defined as one entity; each sub-item is defined as a property belongs to its father entity. Further on, we define the dependence of entities as relations. In this way, all items are transformed into entities and relations, namely E-R diagram shown in Figure 3.
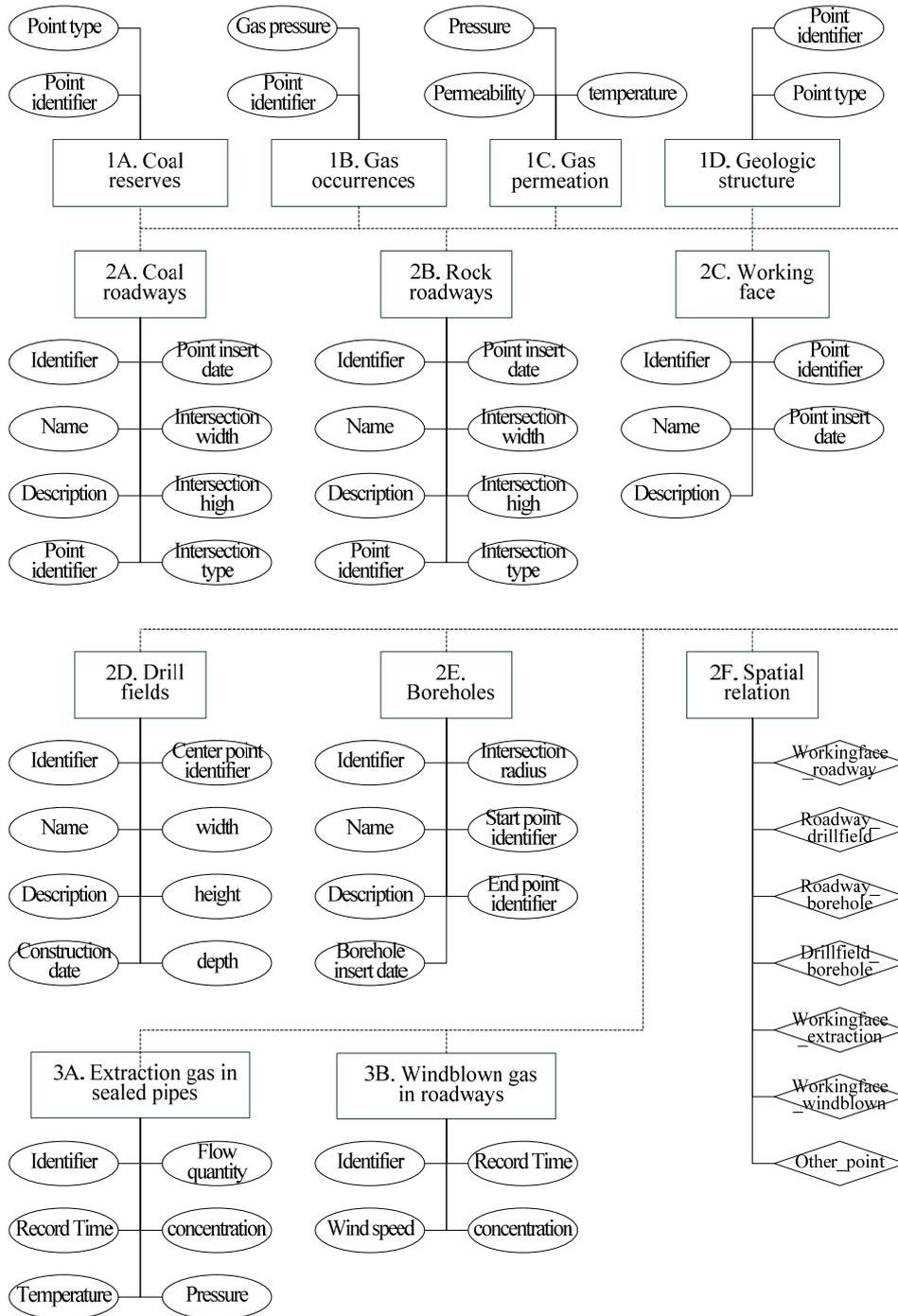
Figure 3. E-R Model of Regional Coal Gas Outburst Prevention Process

In Figure 3, item 1A has been elaborated above, and others are described as following:

1) Item 1B records the determined value by scientific research institution at selected positions of the given coal mass. The value consists of position coordinate and gas pressure;

2) Item 1C is used to store the data of gas permeability and embodied as a set of records, and each record contains temperature, pressure and corresponding permeability value;

3) Item 1D describes geologic structures that emerge in the given coal mass. Based on 3D geographic model, they are saved as a series of point coordinates and their types;

4) Items 2A, 2B, 2C, 2D and 2E are used to describe spatial structure of roadways, working faces, drill fields and boreholes, whose data consist of identifier, name, description, key points and their intersection characteristics;

5) Item 1F is a particular entity used to state the dependent relations between entities, including the relation between working face with roadways, roadway with drill fields, drill field with boreholes, working face with gas extraction, working face with gas windblown, and all entities with points;

6) According to coal gas monitoring system, item 3A contains identifier, flow quantity, record time, gas concentration, temperature and negative pressure, and item 3B contains identifier, record time, wind speed and concentration.

4.2. Software System and its Application

To satisfy the digital requirement of coal gas outburst prevention process, specific to the established database, a comprehensive management software system was developed in the integrated environment of Visual Studio .Net 2010. In this system data input, maintenance and query functions are implemented through several interfaces, including:

1) Basic data;
2) Roadway construction;
3) Working face mining;
4) Drill field construction;
5) Borehole construction;
6) Extraction and windblown gas data.

When user logged in the software system, a main container window with six topmost menu items displayed as shown in Figure 4. By clicking the menu items, corresponding sub interface could activate and embed in the container window. In particular, the complex relations of entities would be handled by computer automatically.

To test the software system, an application case was given in Qinan colliery, Anhui province, China. Selected area is located in the No.716 working face with size of $983*180m^2$, mining the No.7 coal seam and lying at the third segment on right flank of No.81 mining area. In there, the No.7 coal seam is the riskiest outburst seam, with an average thickness of 2.64m, average inclination of 10 degrees. It has been measured that the gas pressure is 3.5MPa at the -550m level, and the gas content is $12.29-15.38m^3/t$. Since 1997 there are six times of gas power phenomenon in all has been recorded, along with the outburst of 171 tons of coal rocks and $32,160m^3$ of gas.

Before coal mining, the gas has been regionally pre-extracted by amount of upward cross-seam boreholes combined with along-seam boreholes. For this, one floor rock roadway, 39 drill fields, 2134 upward cross-seam boreholes and 983 along-seam boreholes have been constructed. In addition, the whole procedure lasted for over 2.6 years that was from October, 2009 to June, 2012. During the long period, about four engineers who directly served the project altered, and there were more than 10G digital data and over 3000 tables recorded. Whenever need query or analyze some parameters, data manager feels intractable, let alone conclude its regularity and diagnose anomalies.

By adopting the studied process model and its data management software system, all the engineers felt convenient to manage and maintain the huge number of parameters. With its help, man-made mistakes significantly reduced and abnormal data identification got easier. Here the following Figure 4 and Figure 5 show two representative operation interfaces.
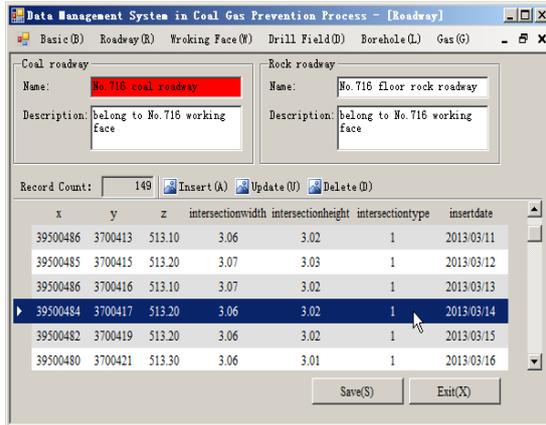
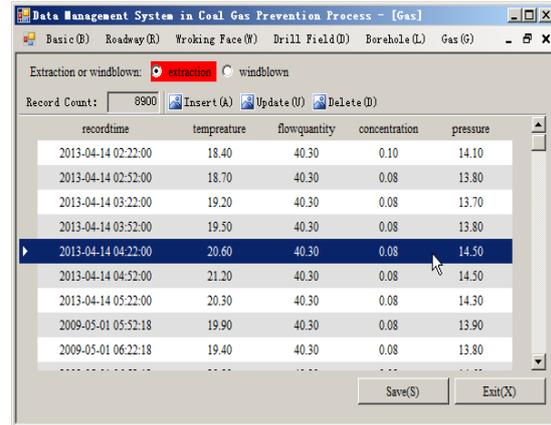Figure 4. Roadway Parameters Management

Figure 5. Gas Extraction Parameters Management

5. Conclusion

With the underground coal exploitation extending to deep rapidly, coal gas outburst prevention has become the prerequisite of coal mining. It touched on miners' lives so closely, but especially lacked of digital support. According to several strategic rules issued by China governments and relevant achievements gained in last decades, we proposed a systematic and integrated process model expressed in a logical work flow. The model consisted of two operation links and two judging nodes. The former described necessary operations to eliminate coal gas, and the later determined whether residual gas reserves reached the expected targets.

Using entity-relation model, the data structure was built which contains three kinds of parameters defined as basic parameters (Type 1), construction parameters (Type 2) and gas extraction parameters (Type 3). Type 1 is relatively invariable and the other two forms a number of time series. Then the corresponding data management software system was developed, in which a comprehensive E-R data model was built and transformed into its background database. Specific to the database, a set of man-machine interfaces consisted of one topmost container window and six sub-windows was implemented.

At last, in Qinan colliery that well represent regional coal gas outburst prevention measures in China, we tested the software system. Result shown it was fully considering user experience and can visually, effectively manage numerous data. Maybe the achievements can help to promote the digital management ability of coal exploitation, coal gas outburst prevention and anomalies identification.

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