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Research paper

Model proposal for representing a deep coal mine spatial and functional structure

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A R T I C L E I N F O

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A B S T R A C T

Underground coal mining usually requires the development of a set of underground corridors (workings). The workings fulfill many different functions. They are used for transportation, ventilation, dewatering and even escape pathways. The proposition of a formal representation of a working's structure for deep coal mining has been presented. The model was developed as a basis for the software system, support management and operational activities for longwall deep mine. The proposed solution is based on graph formalism along with its matrix representation. However, the idea of matrix representation is enhanced. Not only are the topological properties of workings structure considered, but also information about their functions and spatial characteristic. The object model was designed and implemented based upon the matrix idea.

1. Introduction

The underground excavation of natural resources is a challenging and difficult process. Despite continuous advances in deposit recognition and underground mining technology development, there is still space for improvements and the application of new solutions. Coal is one example of underground resources where extraction in deep mines is technologically demanding and exposed to natural hazards. The term 'deep mine' is used here for underground mines using a system of shafts and drifts for its operation.

A typical deep coal mine uses the longwall extraction method. A system of shafts and headings is built to gain access to the deposit and form pathways for people, material, and raw material transportation. The workings are built both in coal deposits and the surrounding strata, forming a complicated web of correlated connections. Every working is designated to fulfill a certain role in the mine's functioning and is equipped with the appropriate infrastructure. Typical roles of this working include: transport, ventilation, research, etc. During the time of mine functioning, its role can change. As workings are built in rugged conditions, they are often exposed to natural geophysical processes. Because of this, the working can lose its parameters and functionality, and in the most severe case, can be completely destroyed.

The knowledge of workings' spatial, functional and topological properties is of crucial importance for mine operations. It becomes even more important when accidents occur, as it is helpful for rescue planning and management. Nowadays, mines are obligated to track the working's parameters and history. However, it is rare that the complete formal representation of workings structure is used for this purpose. There are known IT applications in the coal mine industry that support working structure management. Unfortunately, most of them are focused on visual representations and, in fact, are of little more use than just visualization. Moreover, there is a lack of a common information representation model for a mine working's structure.

In this paper, the formal representation of a coal mine working's structure is presented. The matrix representation of a graph was used as the basic idea. It was assumed that the matrix structure will hold references to the objects, which contain a set of working properties. The presented model is capable of storing both spatial and common data (eg. working function, ventilation parameters or transport capabilities) and can be used as a basis for software solution development. A simple implementation of the proposed model was developed and tested as a 'proof of concept'.

The application of computer science tools and methods to model underground networks of workings, shafts, and geological structures seems highly promising. However, it has to be noted that there are relatively few scientific publications in this field. Most

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computer systems and solutions used in the mining industry are safety and production control oriented (Cheng, Cheng, & Chen, 2015). The systems dedicated to structure visualizations usually focus on graphic and graphic representation. One can observe a lack of appropriate information layer support. Moreover, the safety, production planning, control system, as well as visualizations, are hardly integrated (Kabiesz, Iwaszenko, & Trenczek, 2012). Though their usefulness is beyond question, they could be utilized in a much more efficient way. There is also very little information about information systems that use contextual information and are dedicated to coal mines, although there is some research in this field (Xue, Chang, & Liu, 2014). The problems associated with the development of underground coal mine structure models are also poorly represented in the literature. This seems to correlate with the lack of available software. Because of this, it is reasonable to look for solutions in different areas, which have structure similar to deep coal mine.

A deep coal mine is formed by a set of underground mine workings. They have different sizes and spatial orientation, play different roles in mine functioning and are equipped with a wide range of infrastructure. Therefore, the following levels of its structural analysis can be considered:

— The spatial placement and orientation of workings, along with their dimensions and shapes,
— The functional structure of deep mine workings – the role each working plays in the mine's operation, how they connect considering their function, and the potential function exchange between workings (e.g. which workings can be possibly used for ventilation)
— The infrastructure in workings, such as power lines, monitoring equipment, machinery, and working protection.
— Current characteristics of the workings' state, the measurements results, equipment operation, etc.

Despite the level of analysis, it is suggested that the working structure is viewed as a set of corridors or just connections forming a special kind of network. Similar structures have been modeled in the past. As a discipline, which is particularly similar to underground workings, road networks and corridors can be considered when carrying out this analysis (Febbraro & Sacco, 2004; Lupton & Bolsdon, 1999). Other fields where network structures are modeled are information technology (Ermolin, 1999; Kim & O'Grady, 1996) and electronics/telecommunications (Rhee & Park, 1997).

No matter which area, the representations used can be essentially reduced to a graph. Sometimes this graph takes the form of a tree or can be easily reduced to a form of a tree (Ermolin, 1999). In more complicated structures graphs with more complex topologies are used (e.g. Petri networks (Febbraro & Sacco, 2004)). A matrix (e.g. admittance matrix in circuit theory (Sánchez-López, Fernández, & Tlelo-Cuautle, 2010)) is also occasionally used for graph representation.

Object-oriented analysis and design play an important role in contemporary software development. Object-oriented methods are also applicable in modeling networks and graph structures. They can be found in many different fields of application, for example, object-oriented methods were successfully used in the modeling of computer networks with high bandwidths. Objects were used to represent both the devices on the network nodes and the connections between them (transmission lines) (Rhee & Park, 1997). In addition, this technique was used to describe the transfer taking place between the points (nodes) of the network. The individual objects implement finite automata functionality. Object-oriented techniques have also been used in road network and road transport modeling (Lupton & Bolsdon, 1999), where object methods were used along with Geographic Information System (GIS) technology. They represented both the hierarchy of the roads and their connections' structure. One of the most important aspects of the representation is the relationship between domain model objects and objects used for visualization. Another important aspect is the way the links between the nodes of the graph and the graph's edges are represented. In literature, two main methods of graph structure representation are used. The first uses objects only for representing graphs nodes. The edges are represented by references held by each object representing the node. This solution is similar to the representation of data structures as lists or trees. The second solution represents both nodes and edges as objects. The nodes hold the references to edge objects. Matrix graph representation is usually used when the nodes are not represented as objects and the only information associated with the edges is their weight (Kim & O'Grady, 1996).

2. Materials and methods

2.1. Model assumptions

Every deep mine consists of a complicated network of underground workings. They are crucial for mine operation. Each working plays an important role in the structure of the mine. There are workings dedicated to ventilation, transportation of ROM (Run-of-Mine) and equipment, transportation of people, research, longwall formation, etc. Moreover, the workings each have unique placement, dimensions, and shape. They are also connected with each other. It was assumed, that a developed model domain will include following entities:

– Set of all workings in the mine
– Set of the workings' properties
– Relationships between the workings along with their type
– Geometry (working placement, dimensions, and shape)

The relations between workings can take many different forms. They include, but are not limited to, a physical connection. It is assumed that a 'relationship' describes any kind of direct relationship that can exist between two given workings, e.g. the possibility to make a connection during a rescue operation. The workings do not need to be connected to make such an operation feasible. The relationship can also be characterized by a set of properties, for example, the time necessary to make a physical connection between two workings.

It was assumed that the developed model is stationary; it is a snapshot of mine structure at a given time. This assumption is not very limiting. The time domain can be divided into periods within the changes to the mine structure are so small, that can be neglected. Then, a set of models, representative for selected periods of time, can be used to describe the evolution of the mine's structure. It is also possible to connect the property's sets with time. However, in this paper time dependent changes are not considered. The mine structure model is based on the following paradigms:

– Object methods are suitable for representing mine structure
– The graphs are an appropriate general idea of representing deep mine workings' structure. The nodes, as well as the edges, should store information dependent on the function they provide.

Because of the possibly large amount of relationships that are necessary for mine representation, it is preferable to use other than referential graph representation.

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