The use of the graphical-analytical models to determine the methods and the technologies of execution of the underground mining works when the set of natural conditions of digging are known

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Abstract: The literature in this field and the practical activity record that a method, respectively the technology used for an underground mining work have many components which, in order to be applied, demand that for each of the parameters that describe the environment of the mining work and that influence the choosing of that method and that technology of execution, must have values in an interval well determined.

There are situations when one or many parameters of the set of parameters that describe the environment of the mining work, can modify its values, and, as a result, one or more components of the methods or technology cannot be applied anymore, making necessary a replacement of their values.

The information offered by this graphical-analytical model allow the determination of optimum solutions for the process of digging of the underground mining work and thus it will result the increas of the technical-economical efficiency of the digging process and, also the increasing of the quality of the underground mining works.

Key–Words: Model, Connections matrix, Method of digging, Technology of execution, Underground mining work.

1 Overview

Underground mining constructions are of a wide range of types and dimensions and they are executed for various purposes, namely:
- development work and first mining of commercial mineral deposits with a view to capitalizing them;
- communications (underground, railway, roads or motorways);
- water feed pipes for the supplying of water to localities and to hydropower systems;
- for the storing of raw materials;
- in the military field etc.

Several methods of digging are used in executing underground mining workings and, in their turn, they can be applied in various variants of methods of digging.

Literature, as well as practical activity, point out the following groups of methods of digging used when executing underground mining workings, namely:
- the group of classical methods of digging;
- the group of modern methods of digging;
- the group of special methods of digging;

A method of digging belonging to a group can be applied in several variants of methods of digging.

Each method of digging and each variant of a method of digging, respectively, use a certain technology and a certain technological variant of digging, respectively.

A technology of digging of underground work is made up of the following components /7/:
- the component of cutting of rocks from the ground;
- the component of loading the cut rock onto means of haulage;
- the component of rock removal from the face;
- the component of face ventilation;
- the component of support of the space resulting from the cutting of the face rock, it can be either temporary or permanent;
- the component of the temporary or permanent mining workings furnishing.

The variants of the digging technologies of the underground mining workings occur when one or several components making up a technology take on different values.

The choice of a certain method or method variant of digging of underground mining workings is made depending on the data concerning the rock ground being dug.
2 Classification of data used for describing a complex system

Classification of data shown in /9/ is based on the following criteria:

a. the nature of the variables of state (or the values they can take on)
   b. variation in time;
   c. relation to decider;
   d. -result indicators.

   a. Classification of data according to the nature of state variables

   Any complex system can be characterized by a determined number of parameters which, at a certain moment, take on different values and define a certain state of the system, hence, they are also called state variables.

   State variables describe the system from two points of view: a qualitative and a quantitative one.

   Depending on the described domain, state variables, can be grouped under: category variables; continuous variables; discrete variables; category of variables X.

   Category variables represent that group of variables of state which describe the complex system from a qualitative point of view, for example: the nature of the face rocks, the type of coal, the rate of methane emanation, the type of support in a face, the type of underground transport, etc.

   Continuous variables represent that group of state variables which describe the complex system from a quantitative point of view (mass, volume, length and time). Continuous state variables take on any value within a given interval, for example: the thickness of the seam the length of the working face, the length of a borehole etc.

   Discrete variables describe the quantitative side of the system but discretely i.e. number of items elements or number of component parts. Discrete variables can take on only certain values within a given interval without going through intermediate values, for example: the number of seams, the number of face advances, the number of support units, the number of men placed in a working face etc.

   Category of variable X. In the mine practical designing activity a new concept of variable was felt necessary. It was called “the category of variable X” which corresponds to the values of the continuous variable belonging to a certain interval of pre-established values. This conditioning turns the respective continuous variable into a category variable.

   The values which this new type of variable takes on correspond to the number of subintervals into which is divided the interval where the continuous variable takes on values.

   The number of subintervals into which an interval is divided and where a continuous variable takes on values is determined by decision making factors on the basis of various reasons of practical, technical and technological nature.

   In support of the foregoing statement, by way of example, take continuous variable “seam thickness” whose values vary within an interval having its inferior limit 0 m, while its superior limit can reach hundreds of meters. Practical activities have divided the interval of values, where the seam thickness takes on values, into the following subintervals /5/:
   -0-0,5 m - representing the thickness interval corresponding to very thin seams;
   -0,5-1,3 m - representing the thickness interval corresponding to thin seams;
   1,3-3,5 m - representing the thickness interval corresponding to seams of middle thickness;
   >3,5 m - representing seams of great thickness.

   b. Classification of variables according to their variation in time

   Modifications in time of the value of one or several continuous or discrete variables lead to the modification of the state of the complex system only from a quantitative point of view.

   Any complex system is known to evolve in the course of time, to change both qualitatively and quantitatively.

   The evolutions in time of the variables describing the state of a complex system can be: dynamic, quasi-static and static.

   Dynamic variables of state are those variables which in the course of a period of time change continuously, so they are functions of time. The trajectories of these variables are not constant throughout the time interval being analysed.

   Quasi-static variables of state are those variables which in the course of a period of time undergo only changes of a discrete nature. The trajectories of these variables look like a stepped graph throughout the period of time under consideration.

   Static variables of state are those variables of state which in the course of a period of time remain constant. The trajectories of these variables are constant throughout the period of time under consideration.

   c. Classification of variables of state according to their relation to the decider

   Throughout the period of existence of a certain complex system, changes are brought about frequently or periodically with a view to modifying its state qualitatively as well as quantitatively,
depending on the aims in mind. There are variables of state that can or cannot be modified by man’s intervention. Thus, variables of state can accordingly be grouped under: stimulus variables and response variables, respectively.

*Stimulus variables* represent the multitude of the variables of state that cannot be modified by the intervention of the decider, for example: the number of seams, the nature of the face rocks, the depth of the deposit from the surface, etc.

*Response variables* represent the multitude of the variables of state that can be modified by man’s intervention, for example: the number of drills being used simultaneously for drilling holes in the face, the work force used in the active face, etc.

*d. Variables indicators of result*

The management of any system aims at turning the multitude of stimuli, S, into admissible responses R. Any operator turning objective stimuli into responses is called a determiner. The role of the determiner is played by the man or group of men that transform stimuli S into responses R according to certain established rules.

The transformation stimuli-responses written as: 

\[ S \rightarrow M \rightarrow R \]

is expected to lead to the achievement of the most effective transformation.

In order to assess the quality of the transformation certain criteria need to be established. The variables characterizing the results depend on the S and R set and are called result indicators.

3 Data underlying the choice of digging technologies

The choosing of a digging technology for underground mining workings requires that the designer should be knowledgeable about the following data:

- the technological elements that make up a digging technology;
- available technological resources;
- the qualitative values taken on by each technological element;
- the natural conditions, described by using a set of natural parameters, required by the use of a technological element;
- the intervals of values where the natural parameters take on values and which describe the natural conditions required by the use of a technological element which is a component of the digging technology which is chosen;
- the evolution of the values of the natural parameters which conditions the choosing of a technological element, within the space of the natural environment, where the mining workings are dug and for which a digging technology is chosen.

The problems concerning the technical and economic acquaintance with the elements making up a digging technology are to be found again in the technical documentations of the digging technologies and the problem concerning the evolution of the values of natural parameters which conditions the choosing of a technological element within the natural environment where the mining workings are dug, for which the digging technology is chosen, is solved by the model used in modelling the ground.

The acquaintance with the dynamics of the values of the natural parameters which describe a massif through which underground mining workings are to be executed, enables the choosing of the technologies as well as of the technological variants that can be used to dig underground mining workings. Also, a complex criterion of decision is used in order to choose the digging technology and the variant of the digging technology out of the multitude of variants generated and possible to be used for digging mining workings in a massif.

The model used for modelling the ground where underground mining workings are dug needs to systematise the data on the massif as follows:

1. *The group of information of stimuli, static and category* comprises:
   - the type of the massif stability;
   - the type of the massif rocks the mining workings go through;
   - the presence of bedding planes;
   - the tendency of the rocks in the massif towards self ignition
   - the tendency towards bed separation in the working face and from the walls of the mining workings;
   - the tendency of the rocks in the massif of rocks towards lifting;
   - the presence of ground waters in the massif of rocks penetrated by the mining workings;
   - the form of accumulation of ground waters;
   - the presence of mine gases in the massif of rocks where the mining workings are dug;
   - the form of accumulation of mine gases;
   - the form of gas emanation from the massif;
   - the presence of tectonic accidents in the massif of rocks where the mining workings are dug;
   - the presence of abrasive rocks in the massif of rocks dug through by the mining workings;
   - the type of abrasion of the rocks dug through by the development work and first mining;

2. *The group of information of static and
continuous stimuli comprises:
-the flow of underground water accumulation;
-the relative volume of mine gases in the deposit or in the surrounding ground which are dug through by the network of mining workings;
-the values of the coefficient of strength of the types of rocks dug through by the mining workings;
-the values of the abrasion coefficient of the types of rocks dug through by mining workings;
-the value of thickness of a rock seam or of a series of rocks dug through mining workings;
-the average value of the resistance to compression of the rocks belonging to a seam or to a series of rocks dug through by mining workings.

3. The group of information of static and discrete stimuli comprises:
-the number of rock seams in the ground;
-the number of tectonic accidents of the same type in the ground;
-the number of water bearing formations in the ground in which the mining workings are dug;
-the number of dirt bands in a seam of rocks dug through by mining workings, etc.

4. The group of information of dynamic and category stimuli comprises:
-the type of the variation of ground stability in the direction and dip of the ground;
-variation in the tectonic accidents in the direction and dip of the ground in which the mining workings are dug;
-vertical variation in the type of rock;
-variation in the type of rock along the dip of the deposit;
-variation in the type of rock in the direction of the deposit;
-variation in the strength of the rocks which are dug through by mining workings;
-variation in the type of gas emanations in the ground;
-variation in the type of surface relief in the direction and dip of the deposit;
-variation in the type of underground water accumulations in the direction and dip of the deposit;
-variation in the type of mine gas accumulation in the direction and dip of the deposit.

4. The group of information of dynamic and continuous stimuli comprises:
-variation in the direction of depth from the surface to the plane where the mining workings are carried out;
-variation in the dip of depth from the surface to the plane where the mining workings are carried out;
-variation in the absolute water flow of water bearing sheets;
-variation in the water pressure in a water bearing sheet belonging to the ground perimeter;
-variation in the absolute volume of mine gases emanation in the deposit;
-variation in the pressure of mine gases in the ground;
-variation in the circulation speed of waters in water bearing formations;
-variation in the geothermal level;
-variation in the mine pressure;
-variation in the strength of a rock in a seam along direction and dip.

6. The group of information of dynamic and discrete stimuli comprises:
-variation in the number of dirt bands in a coal seam along direction or dip;
-variation in the number of rock seams in a massif along direction and dip.

4. Graphical-analytical model for generating methods and variants of methods of digging as well as technologies and technological variants of executing underground mining workings /9,10/

4.1 Presentation of the graphical-analytical model for generating the conditions under which mining workings are executed

The ground where underground mining workings are to be executed can be represented by a descriptive model presenting: the series of rock formations, the tectonic of the ground, the ground gas dynamics, the ground hydrogeology.

Description of rock formation includes the description of the following data: the nature of the rocks, the type of rocks, the physical-mechanical and chemical characteristics of each type of rock, the geometrical parameters of the rock formation, the mineralogical and petro-graphical description of the rock formation, etc..

Once we have the descriptive model of the ground where the underground mining workings are to be dug, we can attempt to transpose it into a graphical-analytical model.

In order to transpose the data presented in the descriptive model into a graph structure model, these data have to be systematised according to the foregoing presentation (3).

Once the systematisation of the data shown in the descriptive model has been achieved, the next step is the plotting of the graph of conditions. This graph
enables the generation of a very great number of conditions under which the underground mining workings can be carried out.

A graph represents a graphical construction made up of columns of nodes linked with arcs from left to right (fig 1).

![Graph Example](image)

**Fig. 1. Example of graph**

A column of nodes represents the values taken on by a parameter used for describing the natural conditions under which the mining working is dug.

The number of columns of nodes in the graph is equal to the number of parameters used for describing the natural environment in which the mining working is being dug.

The order of the columns of nodes is based on the degree of relationship of the data, while the order of nodes in the column depends on the values taken on by the parameter attached to that column.

The graph begins with a single node column which represents the starting node of the graph called "START" and it also ends in a single node column called "STOP".

The arcs of a graph link the nodes belonging to two adjoining columns, the order of linking being from left to right. These arcs can take on the following values:

- "1" when there is a relationship between the two nodes i.e. the nodes are compatible;
- "0" when there is no relationship between the two nodes i.e. the nodes are incompatible

**Observations**

- All the arcs having their origin in the "START" node and their destination the "STOP" node have the value "1".
- The "START" and "STOP" nodes are compatible with nodes in the graph, from construction.

The graph representation of the parameters describing a massif through which a mining working is dug solves only the compatibility between adjacent nodes. Under the circumstances, the number of conditions that would be generated by this graphical construction is:

\[ N_d = \prod_{i=1}^{n} n_i \]

where: \(i = 1, 2, 3, \ldots, n\) –represents the number of columns in the graph;
\(n_i\) –represents the number of nodes in the column "i".

For the graph in fig. 1 it is to generate \(N_d = 1 \cdot 5 \cdot 3 \cdot 3 \cdot 2 \cdot 1 = 90\) paths.

Obviously, not all the paths generated by the graph in fig. 1 are admitted.

In order to determine the number of paths admitted, one will have to solve the compatibility of the nodes in a column with all the nodes belonging to the non-adjacent column. This is not possible using the model with a graph structure. However, the problem can be solved by means of the connection or contingency matrix which represents the transposition of the graph structure model to analytical form.

The connection matrix representing the analytical transposition of the graph structure model in fig. 1 is presented in fig. 2.
Observation. The data necessary to draw the graph (fig. 1) and the connection matrix (fig. 2) are taken at random.

The connection matrix is composed of two modules:
-the first module of the matrix represents the connection module resulting from the analytical transposition of the graph structure model and it is the dark part in the matrix;
-the second module of the matrix is called "the module of the added matrix" and it solves the compatibility of the nodes in non-adjacent columns.

4.2 The algorithm for generating the variants of conditions

The start is from the C₀ module, the box c₀₁ moves to the right up to the first modul C₁, where the first box of value 1 is sought for and it is c₁₁. Next, we move downwards up to the C₁ module and search for the line of box c₁₁, then we move to the right up to module C₂ seeking along the line of box c₁₁ for the first box of value 1 which is the one at the intersection of column c₂₁ with the line c₁₁. Next, we move downwards up to module C₂ and indentify line c₂₁ and we move to the right along this line up to module C₃ seeking for the first box of value 1 this being at the intersection of column c₃₁ with line c₂₁.

Then we go downwards to module C₃ indentifying the line of box c₃₁ and moving to the right along this line up to module C₄. We seek for the first box of value „1” and find it to be at the intersection of column c₄₁ with line c₃₁. Next, we move downwards up to module C₄ identifying the line c₄₁ and then move to the right up to module C₅. Then, along the line c₄₁ we seek for the first box of value 1, and find it to be c₅₁ belonging to the final column “STOP”. The first identified path has the direction $D₁ = \{c₀₁, c₁₁, c₂₁, c₃₁, c₄₁, c₅₁\}$.

In order to verify whether the path is admitted, it is necessary to verify the compatibility of each element of the path with all the elements of the path, thus:

- we verify if c₁₁ is compatible with c₃₁ and c₄₁. From construction, the starting node and the final one are compatible with each node in the graph. We identify in the matrix the line of c₁₁, then we move to the right along this line up to the box of column c₃₁ and check if it is of value 1. If this is the case, we continue to verify the compatibilities but if the value is “0”, the result is a path which is not admitted (impossible to be found in nature) and the compatibility verifications for this path are stopped. In the case under examination, the value is “1”, so the movement is continued up to column c₄₁ where the value is “1”;

- next, the compatibility of c₂₁ with c₄₁ is verified; at the intersection of column c₄₁ with line c₂₁, the value is “1”. Hence, path $D₁$ is an admitted path.

The next path is determined in the following way: we maintain the direction of path $D₁$ up to c₃₁, i.e. $D₂ = \{c₀₁, c₁₁, c₂₁, c₃₁\}$ and we move along the line c₃₁ to the right of column c₄₁. Since the value found in the box resulting from the intersection of the column c₄₂ with line c₃₁ is “1”, it follows that the resulting path is $D₂ = \{c₀₁, c₁₁, c₂₁, c₃₁, c₄₂, c₅₁\}$.

The compatibility of c₁₁ and c₂₁ with c₄₂ is verified. It follows from the matrix that in the two boxes resulting from the intersection of lines c₁₁ and c₂� with column c₄₂ the value found is “0”, consequently the resulting path is not admitted.

The algorithm continues with the root of the path $D₃ = \{c₀₁, c₁₁, c₂₁, c₃₁\}$. Then we move on to the right of column c₄₂ along the line c₃₁ searching for another value “1” in the area of module C₄. In our case, there are no more columns left. We go back to the root of the path eliminating from it value c₃₁, thus resulting the root $D₄ = \{c₀₁, c₁₁, c₂₁\}$. We move on along the line of c₂₁, to the right of column c₃₁ and verify if in column c₃₂ the value is “1” and, in the given case, it is. Further on, we identify line c₃₂, moving on to the right up to module C₄ and identifying the first box of value “1” found at the intersection of line c₃₂ with
The direction of the path is $D_3 = \{c_{01}, c_{11}, c_{21}, c_{32}, c_{41}, c_{51}\}$. The compatibility of the elements is verified:
- $c_{11}$ with $c_{32}$ and $c_{41}$, compatibility results from the matrix;
- $c_{21}$ with element $c_{41}$, compatibility results from the matrix, since in the box resulting from the intersection of line $c_{21}$ with column $c_{41}$ the value “1” is found it follows that the path is admitted.

The algorithm continues until all the boxes in the matrix have been verified.

The last path to be possibly generated by the connection matrix has the direction $D_f = \{c_{01}, c_{15}, c_{23}, c_{33}, c_{42}, c_{51}\}$. As a result of the analysis of the compatibility of the non-adjacent elements, obviously the path is not admitted since $c_{15}$ is not compatible with $c_{42}$.

4.3 The graphical-analytical model for generating technological solutions to digging an underground mining work under given conditions

The work process necessary for the execution of an underground mining working comprises the following set of operations:
- the cutting of rocks in the face;
- the loading and evacuation of rocks in the face;
- temporary support of the space resulting from rock ramming;
- permanent support of the space resulting from rock ramming;
- mining workings furnishing depending on destination;
- ventilation of the mining working;
- supplying the working face with the necessary materials;
- mine working furnishing.

4.3.1 The group of technologies used by classical methods of digging

The classical methods of digging consisted in executing the underground mining workings using the methods of rock ramming through drilling and blasting operations or manually.

The difference between the manual execution technology and the one by means of drilling and blasting operations lies in the way rock ramming is achieved as the rest of the stages is the same.

The process of drilling boreholes can be carried out with the help of drills which, depending on their weight, can be operated manually, mounted on telescopic columns or mounted on drilling installations.

The classical technology for digging by means of drilling and blasting operations consists in the following set of main operations:
- hole drilling;
- charging bore holes and blasting them;
- ventilation of working face;
- loading and evacuation of rammed rock;
- support of the space resulting from face ramming;
- ventilation of the mining work;
- supplying the working face with the necessary materials;
- mine working furnishing.

4.3.2 The group of technologies used by the modern methods of digging (mechanized)

As seen with the group of digging technologies through drilling and blasting, the complex of operations related to the cutting of rock out of the ground and the loading of rocks onto the means of transport take up most of the time of a cycle of production involving a great consumption of work effort. In order to eliminate these disadvantages, complex machines have been designed and produced which can carry out the two sets of operations. They can carry out the cutting and loading of rocks onto the means of transport (drifting machines, drill carriages and loading machines).

Also, the rest of the technological stages (the support of the space resulting from rock ramming in the face; ventilation of the mining workings, supplying the working face with the materials necessary in the face; mining workings furnishing) in the case of this group of methods, are carried out in a mechanized way using, for this purpose, a wide range of mining equipment.

4.3.3 The model with a graph structure for generating technological solutions to digging an underground mining working

Given the group of methods for digging an underground mining work and the sets of operations of a process of digging we identify for each set of operations all the types of mining equipment (simple as well as complex), installations, devices, tools and
we make a list with all this information.

For each group of mining equipment existing on the list, we identify all the type of equipment belonging to each group. Also, for each type of equipment we identify the existing typo-dimensions.

Having the list of equipment which comprises data about a group of equipment together with the types of equipment and the typo-dimensions of each equipment, we go on to draw the “solution graph”.

A “solution graph” is identical to the one in fig. 1.

In order to solve the problem of the compatibility of the nodes belonging to the non-adjacent columns, we resort to the connection matrix. Under the circumstances, a compatibility between two nodes belonging to adjacent and non-adjacent columns achieves a technological coupling which can work in practical activity.

The information necessary to establish the compatibilities between the nodes of the adjacent and non-adjacent columns comes from technical books where there are descriptions of the technical-economic characteristics and of the natural conditions in which this equipment can work. It is the specialists in this field who are called upon to determine these compatibilities.

The graph of solutions, the way it has been plotted, generates solutions to technologies and technological variants when we know the natural conditions under which they are executed.

4.4 The model with the graph structure for generating a technology or technological variants for digging underground mining workings when the natural conditions under which they are executed are known

Given the two models with a graph structure for generating the conditions of execution of an underground mining workings and technologies as well as of the technological variants for the digging of a mining work; the following question arises: how does one use the two types of models with a graph structure for determining the technology and the technological variant for digging an underground mining workings, respectively, when one knows the natural conditions under which the digging take place?

The answer to this question is as follows: the two graphs are united into one, thus resulting a new graph called “the graph conditions-solutions”. However, this new graph cannot be used for solving the foregoing problem.

To be able to use it for determining technologies or technological variants when we know the natural conditions under which the underground mining workings are carried out, we also need the connection matrix resulting from the analytical transposition of the graph “conditions-solutions”.

The resulting new matrix solves the connection between the graphs “conditions” and “solutions”, it is a connection made by completing the matrix with the module “added matrix”.

This connection is achieved with the help of the module “added matrix”, called “connecting module” i.e. it connects “condition matrix” to “solution matrix” and it is situated on the right of the modules of the condition matrix, fig. 3.

![Fig 3. Matrix of connections conditions-solutions](image)

Observations.

1. The data used for drawing the graph solutions and the matrix of the connections of the graph solutions are of the type “Responses” according to the
criterion of data classification “the nature of variables (or the values they can take on)”.  
2. The type of data according to the criteria “variation in time” and “relation to decider” are the same as in the case of the construction of the graph conditions.

5 Conclusion
The model with graph structure is a complex instrument and its implementation requires a thorough documentation in the approached field.

Regarding its use for generating solutions, prior knowledge of the set of conditions under which these solutions are to be put into practice, is required. The number of possible paths generated by the graph is relatively high.

For each path generated by the graph, the compatibilities of the non-adjacents nodes are verified.

After verifying the compatibility between the non-adjacents nodes of the generated paths of the graph, the number of admitted paths will be reduced to a reasonable number.

With a relatively small number of admitted paths, based on an imposed optimization criterion, one can determine the optimum variant of the solution to be applied to the set of the given conditions.

The model with graph structure can be applied in decision-making processes belonging to areas of activity, which make decisions based on some sets of specified conditions. Updating the model is done easily in a short time.

The construction and utilization algorithm of the model with graph structure may be transposed into an IT application, which can make its practical application quite accessible and effective.

References: