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MULTI-CRITERION ANALYSIS OF FACTORS AFFECTING MAINTENANCE OF ROADWAYS

1. Introduction

Observations and experiences obtained in the underground mines indicate that there are many factors affecting the maintenance of underground workings. Ensuring the stability of such a working environment for a required period of time results from technical and operational needs. Generally, one can say that the factors justifying the selection of those methods and above other methods of securing the roadway refer to the existing mining and geological conditions present around the working environment and to the techniques and technology determining the way the work was performed [3, 5, 7]. It is, therefore, a multi-criterion issue.

The selection of key factors from the point of view of working maintenance is difficult. It often depends on the local geological and mining situation, as well as on the preferred technological solutions in the mine. For the purpose of determining the leading factors that can be considered universal, the authors analysed them using the AHP method (Analytic Hierarchy Process — [8]), which allowed for a selection of the factors and of their significance.

The analysis was performed on the basis of specially prepared surveys. The surveys were developed after initial consultation with mining engineers dealing with support of workings at hard coal mines, and considering the parameters included in the terms for steel yielding support for roadways published in the years 1999–2001 [6, 10, 11]. The authors divided the factors into three groups — natural, mining and technical, as well as two sub-groups – geo-mechanical properties and type of support.

In the group of natural factors, the following were selected:

— geomechanical properties, inclination of the strata, water inflow, exploitation along the fault line, drifting in the fold, presence of thin strata in the roof, seismic activity, presence of fault within the working.

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Sub-group (sub-criterion) of geomechanical properties included:

— compressive strength of roof rocks, tensile strength of roof rocks, compressive strength of side wall rocks, compressive strength of floor rocks, soakability, Rock Quality Designation RQD, volumetric weight.

Among many mining factors, the following were selected for the analysis:

— depth of deposit, impact of exploitation edges, neighbourhood of exploitation workings, neighbourhood of other roadways, neighbourhood of goafs, neighbourhood of left remains and pillars.

Among the group of technical factors, the following were included:

— drifting the working using a roadheader, drifting the working using explosives, progress of the face drifting, dimensions and shape of the working, type of support, load capacity of support system, type of lagging, precision of support performance, time range of working maintenance.

In the sub-group: type of support, possible applications included:

— steel yielding support, bolting, steel yielding support with bolted roof-bar, steel yielding support with a roof-bar bolted using binding joists, stand-and-roofbolting support with bolts between the arches, steel yielding support reinforced with joist on props, steel yielding support reinforced with joists.

Based on the aforementioned parameters, surveys were developed where each parameter was compared to the next in the group, according to the AHP analysis. In total, 124 comparisons were made in each of the 52 surveys obtained from experts, from this in the next criteria the following was performed:

— in the group of natural factors — 28 comparisons,
— in the sub-group of geomechanical properties of rocks — 21 comparisons,
— in the group of mining factors — 15 comparisons,
— in the group of technical factors — 36 comparisons,
— in the type of support sub-group — 21 comparisons,
— among main groups — 3 comparisons.

2. Problem identification using the AHP method

Hierarchic structure of the decision-making process involves several levels: goal, criteria, sub-criteria and possibly variants [2, 8]. AHP method is useful in the following situations [1, 4, 9]:

— there is a hierarchy of judgement criteria representing different level of detail, related to hierarchy of goals or expected benefits;
— most variant assessment criteria are not of quantitative, but of qualitative nature, and also a major part of assessments is burdened with subjectivity of the assessor;
— there is full comparativeness of variants, so e.g. when comparison and assessment refer to the set of variants belonging to the same class.

According to the AHP method, elements (factors) were compared in pairs, where the importance of a particular element has been assessed from 1 to 9, where 1 means that the

compared parameters are equivalent, and 9 that a particular parameter is extremely strongly preferred to the other. Because the assessment refers to the entire set of surveys, the result involved average values, which were subjected to further analysis.

The most interesting fact for the performance of the task was the determination of importance of particular parameters forming part of natural, mining and technical factors. This allowed for developing the final ranking that indicated how important the selected parameters are for the assessment of the maintenance of the roadways'. The final ranking was obtained by calculation for each parameter of the value summing up its utility function. The value is the sum of products of absolute weights of the parameter on the path from a particular parameter through the predefined criteria. Absolute weights for each matrix were calculated by setting its eigenvector [1, 8].

When presenting the results of assessment of the importance of particular factors in a group, apart from the average (ranking) value of the judgements, also minimum and maximum values have been presented.

3. Analysis of results

3.1. Natural factors

Pairwise a comparison of particular natural factors allowed for determining their ranking in the aspect of roadway maintenance. According to the experts' indications, the most important natural factor concerning making decisions on working maintenance is the presence of the fault within the roadway (20.6%). As the second most important factor, respondents pointed to seismic activity (17.4%). However, scores three and four — geomechanical rock properties and drifting along the fault zone — also got approx. 17% of indications (Fig. 1). Hence, it can be stated that all three factors, namely seismic activity, geomechanical rock properties and drifting

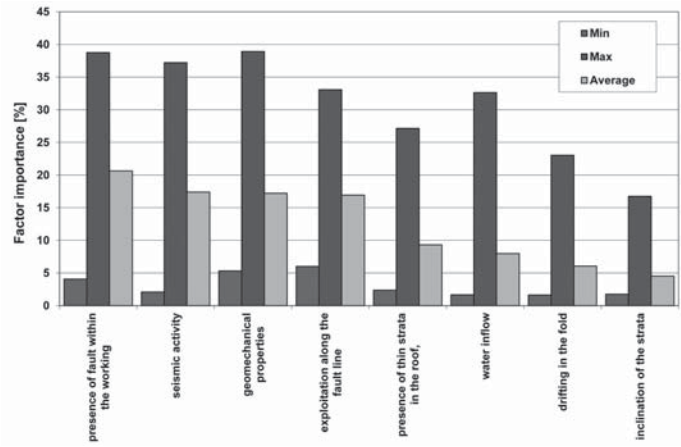

Fig. 1. Importance of natural factors for maintenance of roadways

along the fault zone are practically of the same importance to the possibility of maintaining a roadway. Further places in the importance of natural factors were taken by the presence of thin strata in the roof (9.3%), water inflow (8.0%), and drifting in a fold (6.1%). The least significant parameter was the inclination of strata, which received 4.5% indications.

Detailed data analysis indicates that the presented average values of importance of natural factors affecting maintenance of roadways stability differ significantly from maximum and minimum values specified by particular experts. This points to high differences in the importance of particular factors in the specific geological conditions. In the case of maximum values, according to one expert, the highest percentage importance goes to the geomechanical properties of the rocks, while according to another expert, slightly lower importance is assigned to the presence of the fault within the roadway and seismic activity. The maximum percentage value of indications in such cases amounted to 35÷40%. When analysing the individual judgements of the experts in the aspect of minimum value of importance of a particular factor, it must be stated that the group of respondents also included experts who pointed to a very low importance of each of the natural factors. This testifies to the fact that the importance of a factor completely varies among experts from various mines. Therefore, the big difference in the assessment of a particular factor testifies to the fact that its importance is of a local nature and therefore limited to specific geological conditions. To the contrary, where the difference in the judgement of a particular factor between maximum and minimum value is smaller, this testifies to the universal nature of certain factors, namely the high importance of any geological conditions. The result of such differences in the answers may also testify to certain subjectivity of judgements made, as these usually reflect the experts' own experiences.

3.2. Geo-mechanical properties of rocks

Pairwise comparison of particular parameters determining geomechanical properties of rocks revealed that, according to the experts' indications, the most important factors in deciding on working maintenance is the RQD index (21.7%) and compressive strength of roof rocks, as the percentage share of indications for this factor amounted to 20.8% (Fig. 2). The third major factor is the tensile strength of roof strata (15.3%). The respondents assessed the importance of compressive strength of the floor rocks as 8.3%, while as the least important — volumetric weight: 7.1%.

Individual analysis of each survey allows for determining that the priority in the assessment went to as many as four factors: RQD of roof rock, compressive strength of roof rocks, tensile strength of roof rock and soakability. They all received maximum value of approx. 40.5%. As the next important parameter, respondents pointed to compressive strength of the side walls (29.0%), then to volumetric weight (28.6%) and finally compressive strength of floor rocks (23.3%).

In the case of geomechanical properties, the expert opinions varied in the assessment of the given factors. This is testified to by significant differences among single indications

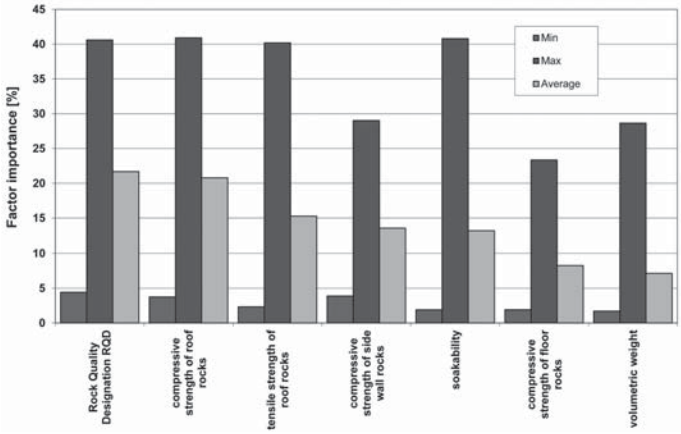

Fig. 2. Importance of geomechanical parameters for maintenance of roadways

of maximum and minimum importance of a particular factor (Fig. 2). Due to the smallest differences among maximum and minimum values from the group of geo-mechanical properties, as the most universal factors one should consider compressive strength of side wall strata and RQD of roof rock. They are similarly important in each mining area. In turn, soakability and tensile strength of roof strata are of the most local nature, namely dependent on geological conditions. This is because in this case the difference between maximum and minimum value this is the highest.

3.3. Mining factors

According to the experts, the most important mining factor affecting the working maintenance is the vicinity of the exploitation workings (24.3%). As the second most important factor, with a very similar number of responses (23.5%), the experts pointed to the impact of the exploitation edges, which is also strictly related to exploitation, and hence these two factors can be considered practically as equally important (Fig. 3). As the third most important factor, the respondents assessed the area of remains and pillars in the vicinity — 20.8%, while as the fourth — the area of goafs: 18.1%. Further scores were allocated to the depth of the deposit: 7.8%, and the area of long-wall workings: 5.4%.

The assessment of maximum degrees of importance of a particular mining factor points out that all except for those in the vicinity of long-wall workings were assessed as 44.1–46.9% (Fig. 3). This shows the importance area of vicinity of exploitation workings, the impact of exploitation edges, vicinity of remains and pillars, vicinity of goafs and depth of the deposit are equally important in local conditions. In the case of the same factors, other experts assessed their importance in the working maintenance process at the level of 4–7%. In turn, marginal importance, according to one expert, is allocated to the depth of the deposit (2%), although according to other assessments, it can be very high (44%).

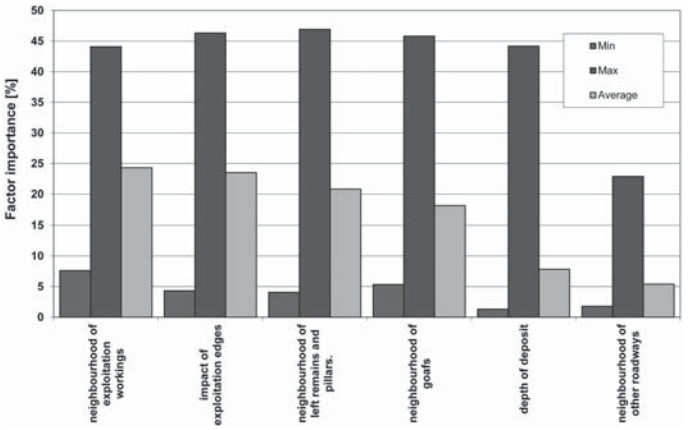

Fig. 3. Importance of mining factors for maintenance of roadways

3.4. Technical factors

The analysis of average and maximum values of technical factors indicates that the highest importance in both cases goes to the load capacity of the support system (average value 24.5%, to the maximum value 38.5%), and then the precision of support performance (average value 14.0%, to the maximum value 34.0%). The same order of importance also occurs in the case of average values (Fig. 4). The third maximum value, according to one expert, was allocated to drifting the working using blasting (33.1%) despite the fact that in the ranking of average indications all experts pointed to it as the seventh (5.1%). This is due to the fact that in mines where many development workings are performed in hard rocks, the importance of explosive applications during maintenance working is very high. The fourth most important technical parameter, according to one of the experts, is the time scale of working maintenan-

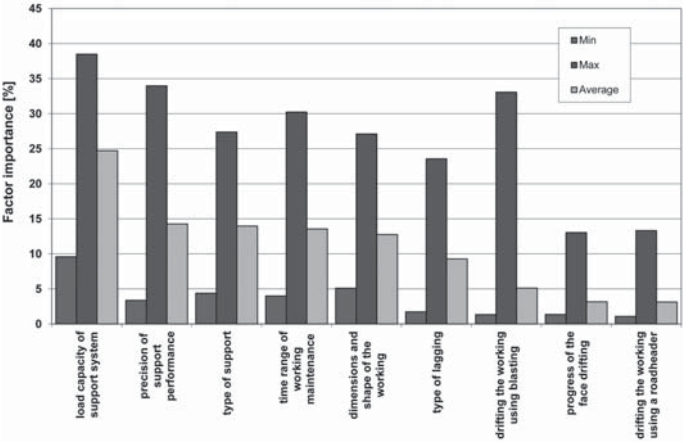

Fig. 4. Importance of technical factors for maintenance of roadways

ce (33.0%), while scores five and six, according to two other experts, are the type of support and dimensions and shape of the working assessed as 27.4% and 27.1%, respectively. The seventh factor is the type of lagging (23.6%).

Drifting of the working using roadheader and progress of the face were judged individually (minimum value) and by all (average AHP judgement) as of low significance in the aspect of roadway maintenance.

Figure 4 presents a diagram of average, maximum and minimum values for selected technical parameters. The diagram reveals that drifting using explosives, according to the assessment made, are of a localised nature, which is confirmed by the results of AHP analysis.

3.5. Type of support

Comparisons between particular parameters determining the type of support system was allowed for the creation of a ranking of preferred support structures (Fig. 5). According to the experts, the best support system for effective working maintenance is the steel yielding support with the bolted binding joists (24.4%). The second most important system, was judged by the experts to be the steel yielding support system with bolting between the arches — 20.5%. The third most important system was the steel yielding support with bolted roof--bar (14.6%). The fourth most important system listed by the experts was the steel yielding support reinforced with joist on props. Further support system achieved a similar number of responses: bolting 9.8%, steel yielding support reinforced with joists 9.3% and steel yielding support 8.5%. Therefore, it can be said that essentially they have similar significance for the maintenance of longwall working. The ranking of preferred support system created on the basis of expert judgements clearly points out that the most important and the most effective factor for maintenance of stability of the workings are the support structures which are based on steel yielding support and bolts.

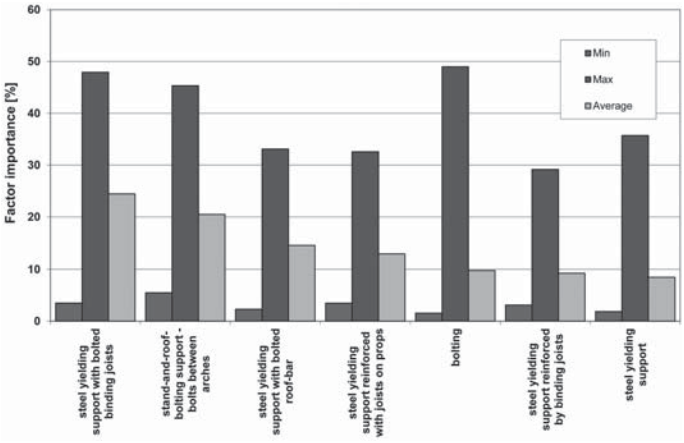

Fig. 5. Importance of type of support for maintenance of roadways

Individual assessment of the analysed support system indicate that, according to one expert, bolting (roof-bolting) carries almost 50% importance for working maintenance (Fig. 5). Maximum assessment of steel yielding support with bolted roof-bar amounted to 47.9%, steel yielding support with bolts between the arches — 45.3%, whereas the fourth scheme is the regular steel yielding support (35.7%). The next system, according to individual expert judgement, are as follows: steel yielding support with bolted roof-bars and steel yielding support reinforced with joist on props (33.1% and 32.6% respectively). The last effective support system listed by the experts pointed to steel yielding support reinforced with joists — 29.2%. Differences in judgements of maximum and average values are high in this case, which confirms differences in preference assessment. In the case of bolting, where experts have experience in applying such support type, it is assessed as significantly affecting working maintenance.

The analysis performed, therefore, indicates that experts agree that for most geological--mining conditions, most effective support types for working maintenance are:

— steel yielding support with bolts between the arches,
— steel yielding support reinforced with joist on props,
— steel yielding support reinforced with joists.

In turn, individual anchor support is of a localised nature.

4. Summary

For the correct assessment of the significance of the selected natural, mining and technical factors, it is also necessary to compare all of the three main groups. The performed AHP analysis revealed that are natural factors the most important group to be considered in the judgement of roadway maintenance (43.6%), the second group is formed by mining factors (31.7%), whereas the third — by technical factors — 24.7%. Maximum assessments of the preferences of particular experts were rather levelled 67–75%. In this case, also the highest importance was allocated to natural factors (75.1%), however, the second highest — due to technical factors (71.4%). Mining factors received the maximum of 67.5% of all assessments.

Generally, it should be noted that in the assessment of all main factors, there is no clear preference among experts.

On the basis of the hierarchy of particular factors and to be determin their rankingin order to reach a final conclusion, the following results can be formulated:

1) The most important factors in particular groups of assessments, involving the criteria and sub-criteria, which affect the maintenance of roadways according to average judgements of all experts are:
   - natural factors — presence of fault within the working — 20.6% of indications;
   - geo-mechanical properties of the rocks — RQD of roof rocks — 21.7%;
   - mining factors — neighbourhood of exploitation workings — 24.3%;
   - technical factors — load capacity of the support system — 24.7%;

- type of support — steel yielding support with a bolted binding joists — 24.4%.

2) The least important factors from the point of view of roadway maintenance according to individual expert judgements are:
   - natural factors — inclination of the strata — 4.5% indications;
   - geo-mechanical properties of rocks — volumetric weight — 7.1%;
   - mining factors — neighbourhood of longwall workings — 5.4%;
   - technical factors — drifting using the roadheader — 3.1%;
   - type of support — steel yielding support — 8.5%.
3) Among the factors analysed, attention must be drawn to the load capacity of the support system which was considered by most experts to be the most important for working maintenance in all mining-geological conditions. As for local factors, namely the importance of specific mining and geological conditions, one may consider the depth of the working and application of roofbolting. Therefore, wherever workings are made at great depths, and where bolting was applied, experts' experience showed that these may be the decisive factors for the success of roadway maintenance.

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