PIOTR MAZIK
GRZEGORZ GALOWY
ŁUKASZ WRÓBEL

Monitoring and prediction of seismic hazards in a mining geophysics station

The article features new functions of a dispatching system designed for mining geophysics stations. A number of functions were presented: those enabling to determine and interpret so-called passive tomography maps and those of a new innovative solution which is based on computational intelligence methods for predicting the EPZ energy in each excavation.

Keywords: *seismic hazards prediction, passive tomography, classification, computational intelligence*

1. INTRODUCTION

One of the major tasks of geophysics stations in hard coal mines is monitoring and determining the rock-burst hazard degree in working excavations. In order to determine this degree, there are different assessment methods applied, depending on the mine. The following methods are usually employed [1]:
- seismic-acoustic methods,
- seismic methods,
- small-diameter drilling.

In order to automate the operations performed by the geophysics stations personnel, an IT system Hestia was developed in the Institute of Innovative Technologies EMAG [11]. The system is now extended and improved by the SEVITEL company.

The Hestia system, designed for the storage of collected and processed measurement data, uses a relational database (in the current version of the system – Microsoft SQL Server 2012) [12]. On this basis the mine structure is featured on four tables:
- department,
- bed,
- district,
- excavation (understood as longwall or face).

For each excavation there is information entered about the following: state of emergency assessed with the use of the mining method, excavation height, excavation type, roof development method, etc.

In addition, the database of the Hestia system receives information from the following programs: ARES_E for the analysis of seismic-acoustic phenomena, OcenaWin for the assessment of rock-burst hazards by means of the seismic-acoustic method, ARAMIS ME for the analysis and location of seismic phenomena, and Multilok manufactured by the Central Mining Institute GIG. This information includes: the values of shift deviations of energy and seismic-acoustic activity, hazard assessment resulting from the seismic-acoustic method (performed for each excavation after each shift), epicentre co-ordinates and registration time of a seismic and seismic-acoustic phenomenon, energy of a seismic phenomenon. Additionally, the database stores information entered by the user, such as the values of the faces and longwalls development and information about performed drills [12].

2. HAZARD ASSESSMENT AND REPORTING

The basic task of Hestia is to assess rock-burst hazards with the use of the complex method according to GIG's instruction [1]. Thus it is possible to conduct detailed and complex assessments for each excavation. The system enables to perform assessments after each completed shift and to generate the so called Aggregated Report (Fig. 1) which has to be made by each geophysics station at least once a day.

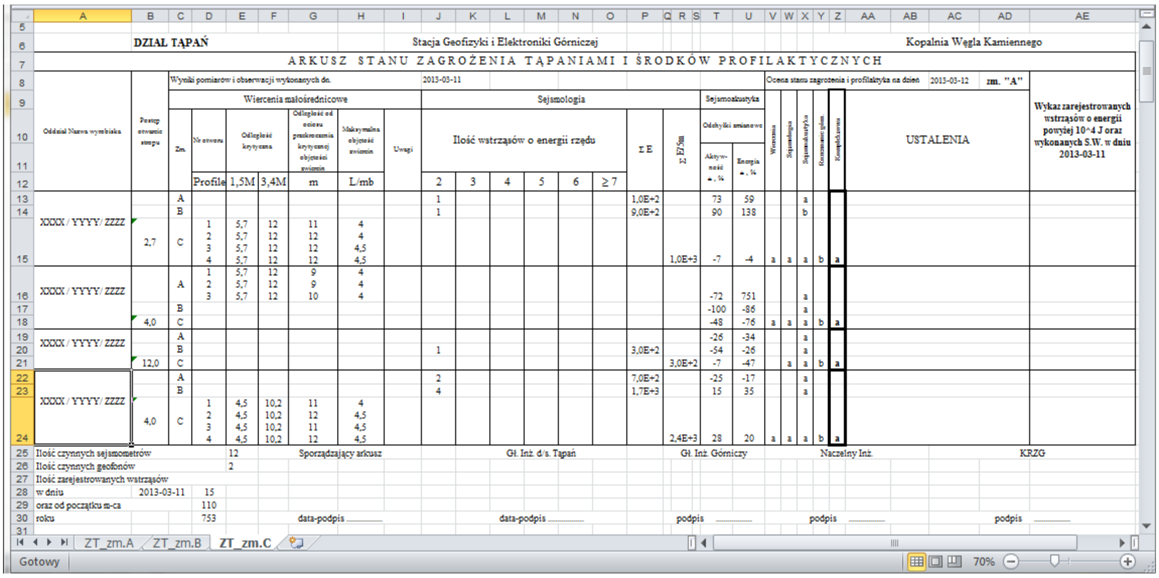
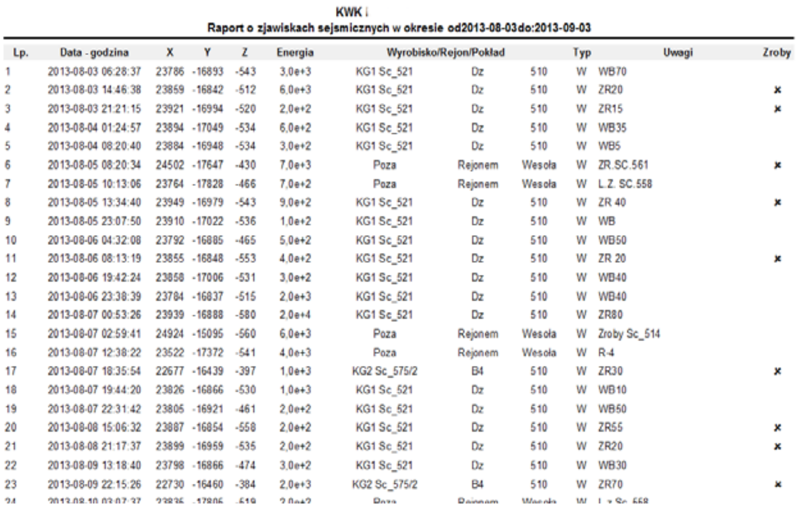


Fig. 1. View of aggregated daily report about rock-burst hazards

In the current version Hestia enables to assess hazards on the basis of: seismic centre parameters (seismic moment and energy index), changes in the time window of the b coefficient value of the Gutenberg-Richter relationship, and maximum amplitudes of peak particle velocity (PPV) in the rock mass around the excavations where mining works are underway.

Apart from the aggregated report, Hestia is able to generate reports, specifications and charts, for example about the registered seismic phenomena (Fig. 2), number of bursts in particular energy ranges (from 10^2 J to 10^7 J), rock-bursts histogram (Fig. 2), total energy of bursts, etc.


KWK
Raport o zjawiskach sejsmicznych w okresie od2013-08-03do:2013-09-03

Lp.	Data - godzina	X	Y	Z	Energia	Wyrobisko/Rejon/Pokład			Typ	Uwagi	Zroby
1	2013-08-03 06:28:37	23786	-16893	-543	3,0e+3	KG1 Sc_521	Dz	510	W	WB70	
2	2013-08-03 14:46:38	23859	-16842	-512	6,0e+3	KG1 Sc_521	Dz	510	W	ZR20	×
3	2013-08-03 21:21:15	23921	-16994	-520	2,0e+2	KG1 Sc_521	Dz	510	W	ZR15	×
4	2013-08-04 01:24:57	23894	-17049	-534	6,0e+2	KG1 Sc_521	Dz	510	W	WB35	
5	2013-08-04 08:20:40	23884	-16948	-534	3,0e+2	KG1 Sc_521	Dz	510	W	WB5	
6	2013-08-05 08:20:34	24502	-17647	-430	7,0e+3	Poza	Rejonem	Wesoła	W	ZR.SC.561	×
7	2013-08-05 10:13:06	23764	-17828	-466	7,0e+2	Poza	Rejonem	Wesoła	W	L.Z. SC.558	
8	2013-08-05 13:34:40	23949	-16979	-543	9,0e+2	KG1 Sc_521	Dz	510	W	ZR 40	×
9	2013-08-05 23:07:50	23910	-17022	-536	1,0e+2	KG1 Sc_521	Dz	510	W	WB	
10	2013-08-06 04:32:08	23792	-16885	-465	5,0e+2	KG1 Sc_521	Dz	510	W	WB50	
11	2013-08-06 08:13:19	23855	-16848	-553	4,0e+2	KG1 Sc_521	Dz	510	W	ZR 20	×
12	2013-08-06 19:42:24	23858	-17006	-531	3,0e+2	KG1 Sc_521	Dz	510	W	WB40	
13	2013-08-06 23:38:39	23784	-16837	-515	2,0e+3	KG1 Sc_521	Dz	510	W	WB40	
14	2013-08-07 00:53:26	23939	-16888	-580	2,0e+4	KG1 Sc_521	Dz	510	W	ZR80	
15	2013-08-07 02:59:41	24924	-15095	-560	6,0e+3	Poza	Rejonem	Wesoła	W	Zroby Sc_514	
16	2013-08-07 12:38:22	23522	-17372	-541	4,0e+3	Poza	Rejonem	Wesoła	W	R-4	
17	2013-08-07 18:35:54	22677	-16439	-397	1,0e+3	KG2 Sc_575/2	B4	510	W	ZR30	×
18	2013-08-07 19:44:20	23826	-16866	-530	1,0e+3	KG1 Sc_521	Dz	510	W	WB10	
19	2013-08-07 22:31:42	23805	-16921	-461	2,0e+2	KG1 Sc_521	Dz	510	W	WB50	
20	2013-08-08 15:06:32	23887	-16854	-558	2,0e+2	KG1 Sc_521	Dz	510	W	ZR55	×
21	2013-08-08 21:17:37	23899	-16959	-535	2,0e+2	KG1 Sc_521	Dz	510	W	ZR20	×
22	2013-08-09 13:18:40	23798	-16866	-474	3,0e+2	KG1 Sc_521	Dz	510	W	WB30	
23	2013-08-09 22:15:26	22730	-16460	-384	2,0e+3	KG2 Sc_575/2	B4	510	W	ZR70	×

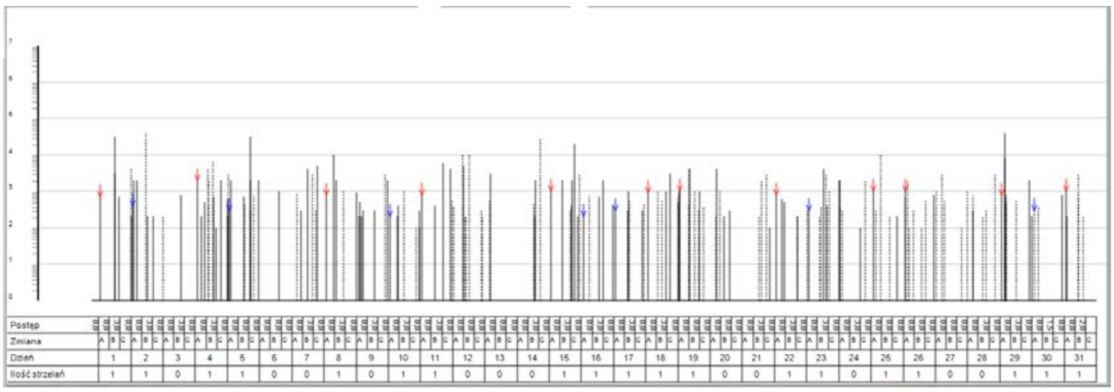


Fig. 2. View of seismic phenomena report and histogram

3. VISUALIZATION

An important part of geophysics stations operations (especially for excavations with rock-burst hazards) is the visualization of registered phenomena on coal bed maps. The Hestia system has very extensive visualization possibilities in the form of two- and three-dimensional visualization.

The visualization model is equipped with an editor of coal bed maps which enables to draw and edit the maps and to import digital maps (e.g. AutoCad) and raster maps (jpg, bmp, png, tiff). The maps edition program contains a large number of predefined graphic objects (fault, goafs, face, inclines, seismometer, geophone, building, road, etc.) which significantly facilitate the map preparation.

The maps are drawn and printed in a user-defined scale. The layer structure enables to configure freely the mine structure display.

Here are some functions of the visualization module:

- drawing and editing coal bed maps, particularly: drawing maps in a certain scale, drawing on particular layers;
- defining graphic reports (10-day, monthly and quarterly maps); map with charted phenomena of particular type, energy and user-defined duration; dynamic map on which the user can observe the sequence of the phenomena occurrence and the longwall development (time flow modelling);
- grouping seismic-acoustic phenomena according to the similarities in their location and time of occurrence; depending on the defined number of groups, the user can observe where the phenomena groups are the biggest; visualization of created groups facilitates to analyze in which parts of the excavation there are areas with increased seismic-acoustic activity (the areas are made by the created phenomena groups);
- drawing a map which visualizes the average value of seismic energy emitted in the given section of the excavation;
- supervision mode (Fig. 3) which allows on-line assessment of emergency states: many visualization windows, which present the mine structure, display the current state of seismic and seismic-acoustic phenomena and the seismic-acoustic emergency state defined on the basis of geophones registrations (energy and activity deviation, on-line assessment of seismic-acoustic hazard for an hour and a shift);
- three dimensional visualization when the spatial structure of the mine is displayed, along with its geological structure and seismic phenomena; in 3D visualization faults and shafts have different heights and inclinations; it is possible to magnify and turn the whole 3D view of the mine;
- generating cross sections which enable to visualize the cross section of the geological structure on a plane in any place in space; on the plane of the cross section it is possible to chart seismic phenomena as points or circles with diameters depending on the phenomenon energy.

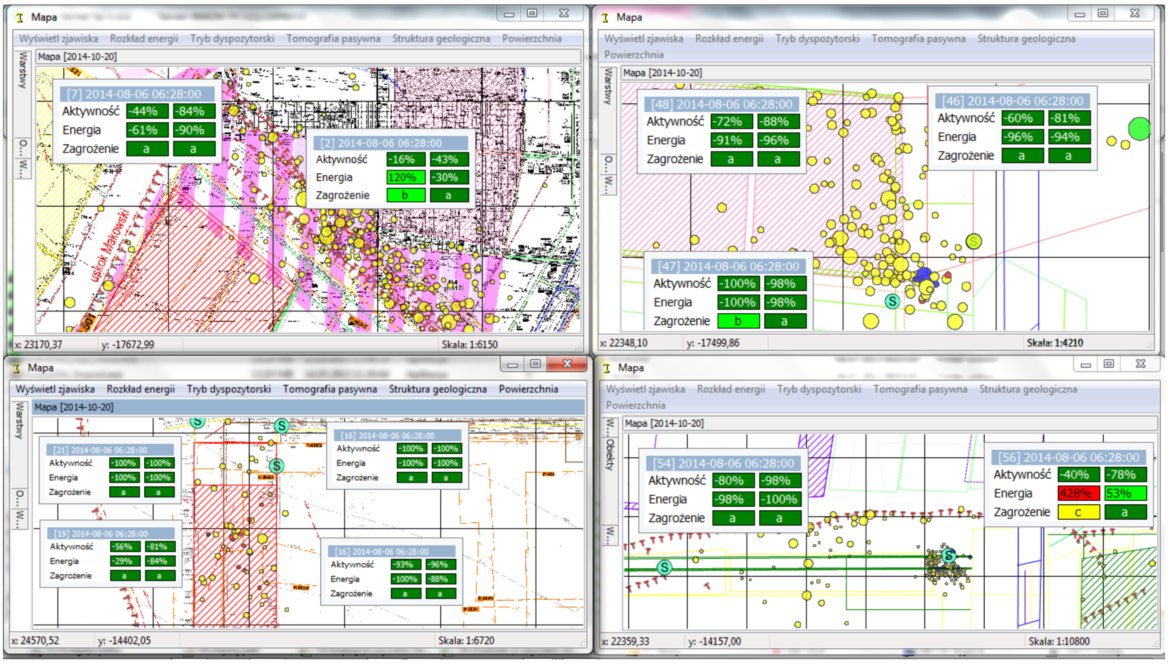


Fig. 3. View of supervision mode with many visualization windows based on raster maps along with geophones states and seismic phenomena

4. TOMOGRAPHIC MAPS

Tomographic methods are used more and more frequently to assess seismic hazards in mines [3, 4, 5, 6, 7]. In the case of passive tomography the records of seismic phenomena are used. When bursts were registered (and after they were located), the bursts centres become sources which triggered seismic wave coming through the rock mass. Then the wave was registered by seismometers located in excavations. Tomographic maps of the given area are used for comparing the views of velocity fields in changing time windows. Such a solution enables to track the relocation process of potentially hazardous areas [4].

A module for generating a model of passive velocity tomography was developed in co-operation with the Geophysics Institute of the Polish Academy of Sciences in Warsaw. This kind of tomography is a non-invasive technology for visualizing the inner structure of the rock mass. The software makes use of the analysis of a seismic wave (P) propagation velocity. The obtained velocity tomography models reproduce the spatial distribution of anomalies in the seismic waves velocity [4]. In order to make a tomographic picture, the times of the P wave entries are used, which are set in the Aramis ME software for locating seismic phenomena, while the examined parameter is the wave velocity. The methodology of this approach is based on analyzing the relation between the P wave propagation time and the velocity distribution. On this basis it is possible to generate the times of the seismic wave passage from the source to the sensor.

A module for drawing tomographic maps was implemented in the Geophysics Institute of the Polish Academy of Sciences [2], however, it is fully integrated with the Hestia system. Communication with the map drawing module, particularly the selection of map generating algorithms and setting their parameter values, is performed by means of a user graphic interface provided by the Hestia system.

The process of the model generation consists of three phases:

- making a model of a passive tomography map in the form of velocity values in particular nodes,
- map smoothing, i.e. generating medians of velocity between the nodes of the net,
- creating velocity isolines on the passive tomography map.

Due to the operations of the tomographic maps generation module, the user obtains two passive tomography models: the most likely model (MLL) and the averaged model (AVR). The exploitation experience shows that the averaged model is the closest to reality. The generated map can be visualized in the visualization module. After a selected map is downloaded into the visualization module, the following layers are added:

- map of the most likely model (MLL),
- map of the averaged model (AVR),
- map of covering with rays (RAY),
- isolines of the averaged model map (ISO_AVR),
- isolines of the most likely model map (ISO_MLL).

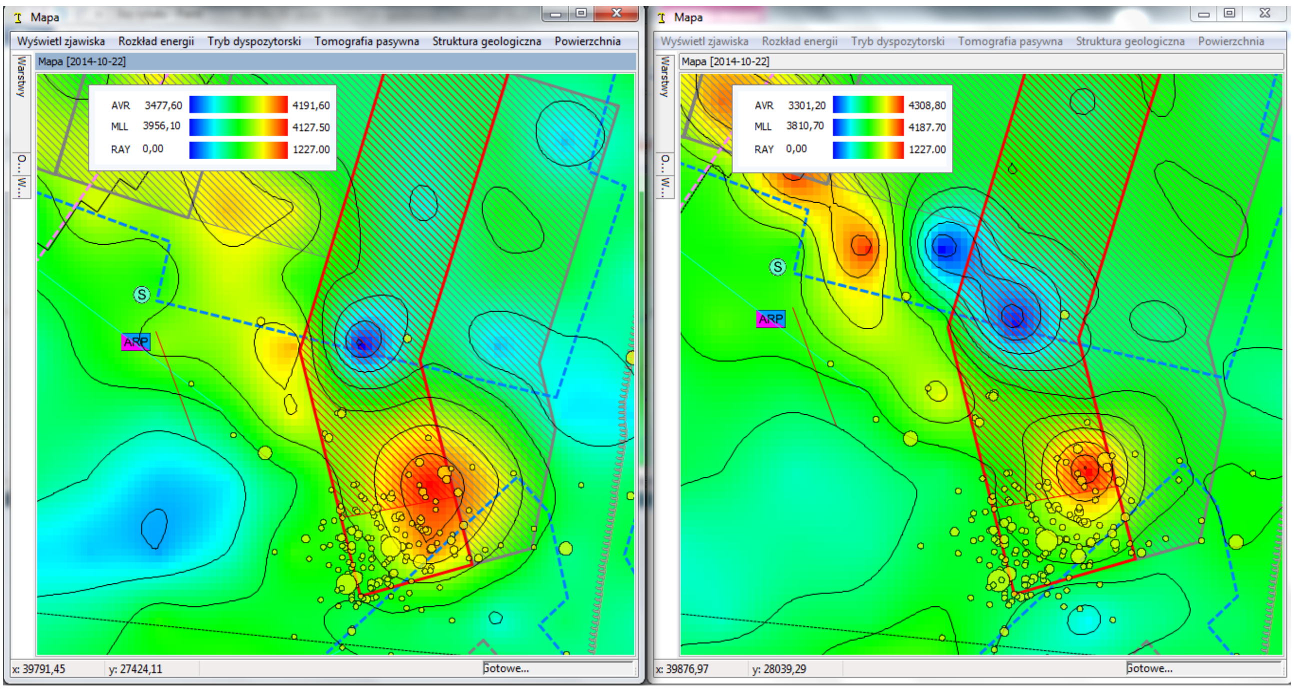


Fig. 4. Generated different variants of a tomographic map with seismic phenomena from the next month

Each layer is a separate text file. The red colour on the maps stands for the maximal velocity of the longitudinal wave in the rock mass, while blue – for the minimal one. In addition, isolines with a wave velocity values are drawn on the maps. All layers related to passive tomography are subject to the same rules as the map layers (hiding, reordering, etc.)

The assumption of the software developers was not to perform automatic modelling but to provide the operator with access to most parameters. This way the operator controls the process of the map generation. The applied techniques give different, though approximate results. Thus it is the geophysicist who decides about the technique to be employed and about the modelling parameters in a given mine. After implementation and trials with different models and settings, he/she is able to assess which method is suitable for the given mine.

5. PREDICTION OF ZERO POINT ENERGY (ZPE) AS A FORM OF HAZARD PREDICTION

A module enabling to predict aggregated zero point energy (ZPE) which is emitted in the given excavation within the nearest time and shift was developed in the course of the project conducted by the EMAG Institute, Sevitel, Silesian University of Technology, and Warsaw University of Technology. The proposed method to predict seismic hazards is based on the zero point energy in the given excavation. The method was described in the latest instruction how to assess seismic hazards in hard coal mines [1]. The document contains only the description how to calculate ZPE as aggregated energy of registered rock bursts and properly recalculated seismic emission registered by geophones installed in the given excavation. Additionally, the document includes a proposal concerning the time horizon of the prognosis.

There have been works conducted to develop analytical algorithms that would be good enough to solve the prediction task with user-accepted accuracy. The accuracy is understood as sensitivity (i.e. detecting situations when the predicted energy value exceeds the set security threshold, e.g. 5.10^5J) and specific character of the method (i.e. minimizing the so called false alarms). So far, two analytical approaches have been used: one based on the analysis of time series [8, 9] and the other on induction methods of classification rules [7, 10, 13].

Within the project, the data coming from several longwalls and faces were analyzed. This analysis allowed to work out an approach covering acquisition, measurement data conversion and data analysis [10, 13]. In addition, the approach can be used in online prediction.

The results of conducted experiments allow to propose the following scheme of developing and implementing a rule classifier for the prediction of seismic hazards (Fig. 5). The classifier is the basic element of the prediction system. The system carries out the acquisition and aggregation of measurement data which then become the basis for the classifier learning. Apart from the implementation issues, it is possible to say that the classifier learning process is activated periodically on an increasing set of examples and is repeated as long as the received classifier results are better than the set minimal values. In particular, the classifier prognoses have to be better than the prognoses generated by routinely applied methods. The classifier which fulfils minimal quality requirements is then used for the incoming measurement data, while the quality of the generated prognoses is monitored all the time.

The process of the classifier development consists of many stages and is based on learning different classifiers, checking their efficiency by means of cross validation and selecting a classifier which achieves the highest values of the set quality criterion. Thus it is necessary to perform the following: collect a suitable set of learning data, work out the procedure for learning and selecting optimal values of the prediction algorithm parameters, determine the minimal accepted quality of prognoses, define the procedure for prognoses quality supervision, and, finally, define the procedure for selecting learning examples in case the system has to be learned again.

The authors became familiar with the necessity of re-learning the system while performing the prediction of methane concentration. In order to select a new set of learning examples, a simple procedure was used based on expanding the learning set with the latest measurement data. If the size of the examples set was too big, the oldest records were removed. Though there were no tests conducted in this area, it seems that in the case of seismic hazards and possible necessity to re-learn the classifier, it would be sensible to remove only the oldest examples representing the majority decision class no hazard. The rules defined by a domain expert can be added to automatically created rules. The expert-defined rules can represent common-sense dependencies or reflect one's knowledge on mining.

In order to compare the results of the classifier with those of the routine method (complex method preformed in compliance with the instruction [1]), it was assumed that the routine assessment a corresponds to the classifier assessment no hazard, while other results of the routine method (b, c, d) correspond to the classifier assessment which indicates a hazard (hazard occurred). The results of the comparison made for two longwalls are presented in Table 1. In addition, the table has information about the basic accuracy resulting from the number of actually registered emergency states.

Table 1.
Comparison of the prediction accuracy of a rule classifier and routine methods

Prediction task/ excavation	Method	Status "hazard occurred" [%]	Status "no hazard" [%]
Task 1 SC503	Classifier method	75.2	93.6
	Routine method	56.8	57.0
	Basic method	17.2	82.8
Task 1 SC508	Classifier method	81.5	73.1
	Routine method	77.0	43.0
	Basic method	11.3	88.7
Task 3 SC503	Classifier method	63.2	73.2
	Routine method	52.5	82.4
	Basic method	10.8	89.2
Task 3 SC508	Classifier method	51.4	72.9
	Routine method	48.3	47.8
	Basic method	6.1	93.9

The results in Table 1 show unequivocally that for the purposes of seismic hazards prediction, the assessments generated by the classifier are definitely more accurate than those generated by the routine method. However, accepting the classifier as a supplementary method for seismic hazards prediction requires many formal actions to be undertaken.

Rule induction algorithms are not too stable. In some cases small changes in the learning examples set may cause big changes of the prognostic model. Therefore, for each new excavation there should be a separate classifier dedicated to generating prognoses for this very excavation. Therefore the method should have a start-up period. The research presented in [13] showed that it is not possible to make one universal model for all excavations.

Currently the Hestia system is expanded by an analytical and prognostic module which enables to fulfil the concept presented in Fig. 5.

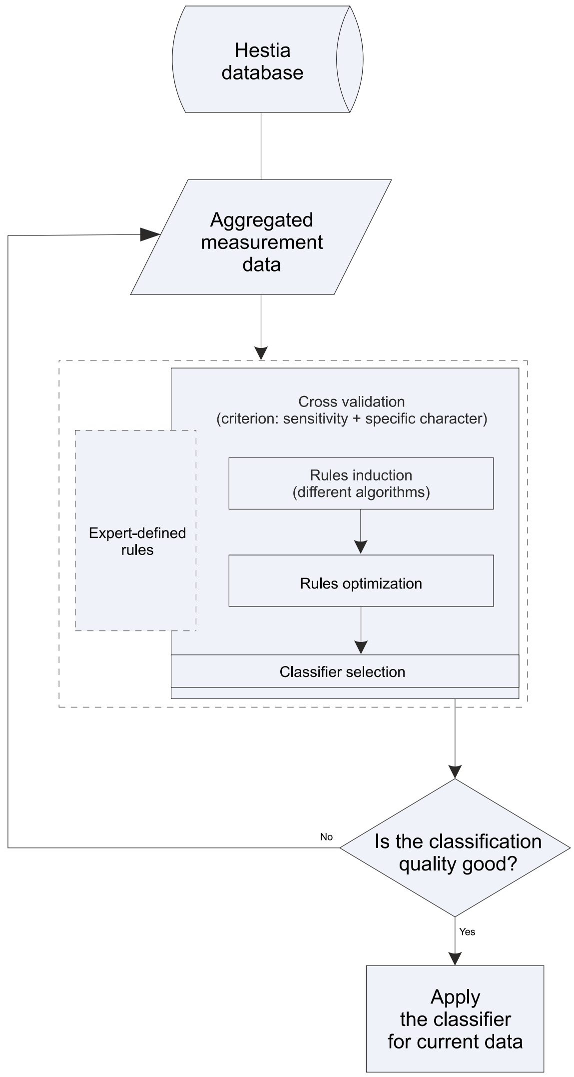


Fig. 5. Methodology of making a system for the prediction of ZPE energy values

6. CONCLUSIONS

For several years the Hestia system for supporting the operations of geophysics mining stations has been working in the majority of Polish hard coal mines as well as in a number of overseas mines too (China, Russia). Thanks to valuable comments by the users, it was possible to automate significantly the process of hazards assessment and to provide many new useful options to the system itself. An extensive set of functions and configuration possibilities allows easy management of data stored in the database.

Currently, the system is developed further. The conducted operations concern mainly the development of passive tomography and incorporating the ZPE prediction module into the standard functionality of the system.

The results of works described in this publication were performed and financed in part from the PBS2/B9/20/2013 project fund obtained from the National Research and Development Centre within the Applied Research Programme.

References

1. Barański A. i inni: Zasady stosowania metody kompleksowej i metod szczegółowych oceny stanu zagrożenia tąpaniami w kopalniach węgla kamiennego (*Regulations for using complex and detailed methods of rock-burst hazard assessment in hard coal mines*). Główny Instytut Górnictwa, Seria Instrukcje Nr 22, Katowice 2012.
2. Dębski W.: Seismic tomography software package. Publs. Inst. Geophys. Pol. Acad. Sc. B-30(353), 1-105, 2002.
3. Dębski W.: The probabilistic formulation of the inverse theory with application to the selected seismological problems. Publs. Inst. Geophys. Pol. Acad.Sc. B19(293), 1-173, 1997.
4. Dębski W.: Tomografia sejsmiczna w zastosowaniach górniczych (*Seismic tomography in mining*). Przegląd Górniczy 68(7), 67-71, 2012.
5. Dokumentacja oprogramowania mctom7 (Documentation of mctom7 software). IGF PAN, Warszawa 2013.
6. Dubiński J., Lurka A., Mutke G.: Zastosowanie metody tomografii pasywnej do oceny zagrożenia sejsmicznego w kopalniach (*Application of passive tomography in the assessment of seismic hazards in mines*). Przegląd Górniczy Nr. 3, 1998.
7. Kabiesz J., Sikora B., Sikora M., Wróbel Ł.: Application of rule-based models for seismic hazard prediction in coal mines. Acta Montanistica Slovaca 18(4), pp. 262-277, 2013.
8. Kornowski, J., 2003. Linear prediction of aggregated seismic and seismoacoustic energy emitted from a mining longwall. Acta Montana, Ser. A 22, 4–14.
9. Kornowski, J., Kurzeja, J., 2012. Prediction of rockburst probability given seismic energy and factors defined by the expert method of hazard evaluation. Acta Geophysica 60, 472–486 2012.
10. Sikora M.: Induction and pruning of classification rules for prediction of microseismic hazard in coal mines. Expert Systems with Applications 38(6), s. 6748-6758, 2011.
11. Sikora M.: System wspomagania pracy stacji geofizycznej – Hestia (*Hestia – the computer system supporting workers in mine geophysical stations*) . Mechanizacja i Automatyzacja Górnictwa, nr 12, 15-19, Katowice 2003.
12. Sikora M., Mazik P.: W kierunku większych możliwości oceny zagrożenia sejsmicznego – systemy Hestia i Hestia Mapa (*Towards better possibilities of seismic hazard assessment – Hestia and Hestia Mapa systems*). Mechanizacja i Automatyzacja Górnictwa, nr 3, 5-12, Katowice 2009.
13. Sikora M., Wróbel Ł.: Application of rule induction algorithms for analysis of data collected by seismic hazard monitoring systems in coal mines. Archives of Mining Sciences, 55(1), s. 91-114, 2010.

PIOTR MAZIK, GRZEGORZ GALOWY
Sevitel Sp. z o.o.,
Katowice, Poland
p.mazik@sevitel.pl; g.galowy@sevitel.pl

ŁUKASZ WRÓBEL
Institute of Innovative Technologies EMAG
Katowice, Poland
l.wrobel@ibemag.pl