ZESZYTY NAUKOWE POLITECHNIKI ŚLĄSKIEJ 2015
Seria: ORGANIZACJA I ZARZĄDZANIE z. 81 Nr kol. 1934

Tomasz NAWROCKI
The Silesian University of Technology
Faculty of Organization and Management, Zabrze
tomasz.nawrocki@polsl.pl

Izabela JONEK-KOWALSKA
The Silesian University of Technology
Faculty of Organization and Management, Zabrze
izabela.jonek-kowalska@polsl.pl

FUZZY LOGIC IN RISK ASSESMENT OF A MINING ENTERPRISE IN THE CONTEXT OF POLISH ECONOMIC CONDITIONS

Summary. Mining enterprises function in the conditions of enhanced internal and sector risk, which cause their financial results to be exposed to considerable and frequent deviations from the values planned. The circumstances indicated require special protection from risk, implying a necessity for deep and multi-aspect risk assessment. Therefore, the main objective of this article is to present the authors' method of operational risk assessment in a mining enterprise that utilizes fuzzy logic.

Keywords: risk in hard coal mining, operational risk assessment, utilization of fuzzy logic in hard coal mining.

LOGIKA ROZMYTA W OCENIE RYZYKA W PRZEDSIĘBIORSTWIE GÓRNICZYM W KONTEKŚCIE POLSKICH UWARUNKOWAŃ GOSPODARCZYCH

Streszczenie. Przedsiębiorstwa górnicze funkcjonują w warunkach podwyższonego ryzyka wewnętrznego i sektorowego, co sprawia, że ich wyniki finansowe są narażone na znaczne i częste odchylenia od planowanych wartości. Wskazane okoliczności wymagają szczególnej ochrony przed ryzykiem, co implikuje potrzebę dokładnej i wieloaspektowej oceny ryzyka. Dlatego też głównym celem niniejszego artykułu jest przedstawienie autorskiej metody oceny ryzyka operacyjnego w przedsiębiorstwie górniczym, uwzględniającej wykorzystanie logiki rozmytej.

Słowa kluczowe: ryzyko w górnictwie węgla kamiennego, ocena ryzyka operacyjnego, wykorzystanie logiki rozmytej w górnictwie węgla kamiennego.

1. Introduction

The hard coal mining industry is a traditional branch of industry functioning in many places in the world. It is also an industry that represents one of the world's most important energy carriers. In Poland this industry is of key significance to the economy of the Upper Silesian Coal Basin and for the energy security of the entire country. A number of typical hazards not encountered in other traditional industries are tied to the hard coal mining industry[1]. These hazards' occurrence strongly corresponds not only to financial results but also to negative influences on human health and life[2]. Therefore this industry requires an individualized approach to risk management. This approach, apart from the sources of risk accompanying the industrial activity, should take into consideration the full spectrum of specific sources of risk tied to conducting mining extraction.

Due to the aforementioned circumstances, this article considers the problem of operational risk identification and assessment in a mining enterprise, treating the aforementioned beginning stages of risk management as key stages for the security and risk control in the enterprise that follows them. The method of risk identification and assessment suggested by the authors fits into the concept of *Enterprise Risk Management* (*ERM*), in which a holistic treatment of all risk sources in the enterprise is suggested[3] and therefore their joint assessment is also a result of various mutually interpenetrating hazards and realization of the goals and strategy of the enterprise. During the process of assessment and aggregation of the particular risk sources, the methodology of fuzzy sets was used[4].

In light of this explanation, the main objective of this article is to present an author's method of operational risk assessment in a mining enterprise, taking into consideration the use of fuzzy logic. In order to meet the objective stated in such a way, in the first part of the article a holistic identification and description of risk sources in the activity of the mining enterprises is conducted. Then the particular sources of risk are assigned individual assessment indicators, and the rules of aggregation of constituent assessment in the suggested model are presented. This content filled the second substantive methodological part of the

[1] See: Gu X., Wang J., Liu Y.: Water resistant features of high-risk outburst coal seams and standard discriminant model of mining under water-pressure, „Mining Science and Technology" 2010, Vol. 20, Iss. 6, pp. 797-802; Khanzode V.V., Maiti J., Ray P.K.: A methodology for evaluation and monitoring of recurring hazards in underground coal mining, „Safety Science" 2011, Vol. 49, Iss. 8-9, pp. 1172-1179.

[2] Compare: Poplin G., Miller H.B., Ranger-Moore J., Bofinger C.M., Kurzius-Spencer M., Harris R.B., Burgess J.L.: International evaluation of injury rates in coal mining: A comparison of risk and compliance-based regulatory approaches, „Safety Science" 2008, Vol. 46, Iss. 8, pp. 1196-1204.

[3] More: Bromiley Ph., McShane M., Nair A., Rustambekov E.: Enterprise Risk Management: Review, Critique, and Research Directions, „Long Range Planning" 2014, pp. 1-12; Gordon L.A., Loeb M.P., Tseng C.-Y.: Enterprise risk management and firm performance: a contingency perspective, „Journal of Accounting and Public Policy" 2009, Vol. 28, pp. 301-327.

[4] Compare: Yan Z., Wang X., Fu Y.: Study on Early Warning Model of Coal Mining Engineering with Fuzzy AHP, „Systems Engineering Procedia" 2012, Vol. 5, pp. 113-118.

article. In the summary, directions for further research are presented along with the advantages and limitations of the suggested approach.

2. Risk sources identification in a mining enterprise

The literature concerning risk identification and assessment in mining enterprises mostly emphasizes issues regarding natural hazards connected with conducting underground exploitation. Occurrence of such hazards triggers particularly heavy losses of human resources and in the natural environment, therefore risk management in hard coal mining is concentrated on prevention of natural and technical hazards[5].

Nevertheless, in the contemporary economy, in the conditions of advancing globalization and increasing co-dependence of the resource markets, mining enterprises are more often faced with increasing industrial and systematic risk. The effects of ignoring or establishing insufficient protection from this risk may be observed in Polish mining enterprises that, due to cyclic economic fluctuations on the energy resources market, are exposed to significant fluctuations of financial results (fig. 1)[6]. At the same time the advancing recession in the segment of hard coal in the last two years has led Polish enterprises to financial collapse, and they may be threatened with bankruptcy[7].

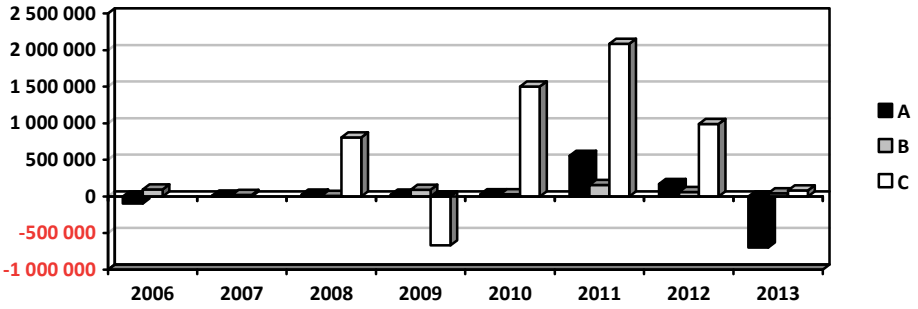

Fig. 1. Net financial result of three largest mining enterprises in the years 2006-2013 [in PLN thousand]
Rys. 1. Wynik finansowy netto trzech największych przedsiębiorstw górniczych w latach 2006-2013 [w tys. zł]
Source: own work.

[5] Kuzior A.: Etyczna aktywność firm w dziedzinie ochrony środowiska, [in:] Aplikovana etika a profesionalna prax. Univerzita Mateja Bela v Banskej Bystrici. Fakulta humanitnych vied. Katedra etiky a aplikovanej etiki. Banska Bystrica: Fakulta Humanitnych Vied. Univerzita Mateja Bela, 2011, pp. 90-97.

[6] See. Jonek-Kowalska I.: Data envelopment analysis w ocenie efektywności technicznej wielozakładowego przedsiębiorstwa górniczego, „Przegląd Organizacji" 2014, nr 3, pp. 4-10.

[7] See: Michalak A.: Strategie finansowania przedsiębiorstw w branżach kapitałochłonnych na przykładzie polskich i światowych przedsiębiorstw górniczych, „Zarządzanie i Finanse – Journal of Management and Finance" 2013, Vol. 11, No. 1, pp. 331-346; Jonek-Kowalska I.: Bankruptcy risk in a Polish mining enterprise - reasons, symptoms and consequences, [in:] Aktualne problemy podnikovej sfery 2013. Zbornik vedeckych prac. Aut.: S. Majtan a kolektiv. Ekonomicka Univerzita v Bratislave. Fakulta Podnikoveho Manazmentu. Katedra Podnikovohospodarska. Bratislava: Vydavatel'stvo Ekonom, 2013, pp. 211-217.

Efficient risk management requires a comprehensive and multi-aspect risk identification and assessment that fits a conception of holistic approach to risk defined in literature and practice as *Enterprise Risk Management*[8]. Mining enterprises should therefore place other risk sources in resources different than the geological-mining ones and embedded in the micro- and macroenvironment in addition to internal-specific risk mainly related to natural hazards. The scheme of risk sources placement understood in this way is presented in figure 2.

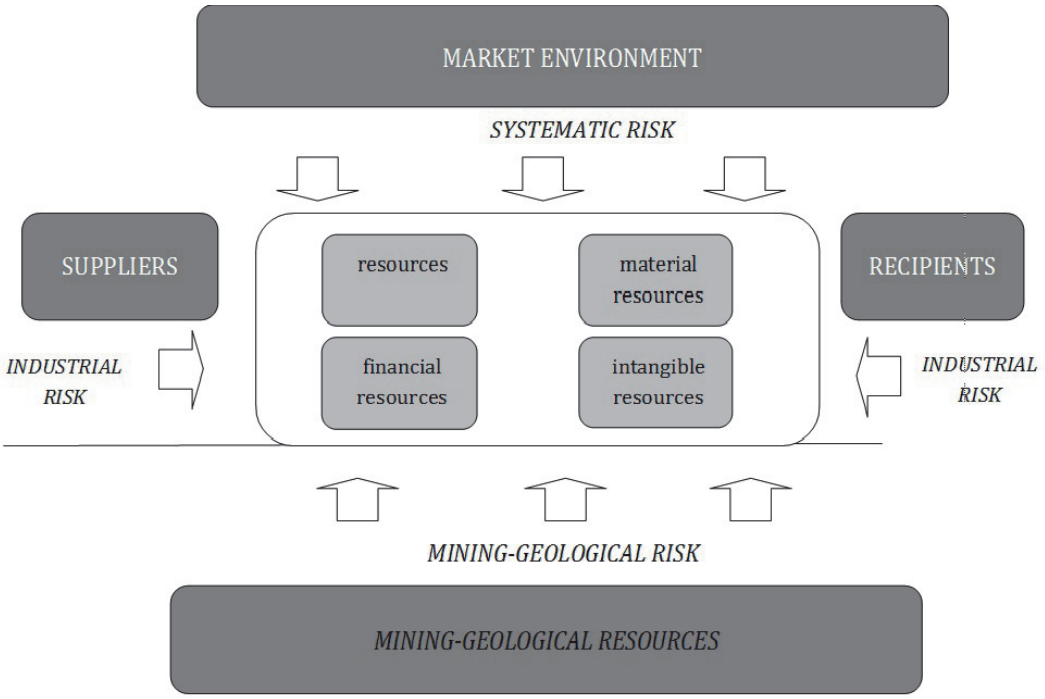

Fig. 2. Sources of specific and systematic risk in a mining enterprise
Rys. 2. Źródła ryzyka specyficznego i systematycznego w przedsiębiorstwie górniczym
Source: own work.

As was already mentioned, in the Polish mining enterprises, risk is perceived mainly in the context of mining-geological resources. Exposure to risk sources connected with these resources is increasing due to deeper excavation and mining concentration, which is causing an increase of the intensity of natural hazards and increasing the cost of countermeasures. However, in Polish hard coal mining there are also intensified industrial and systematic risk sources, which mining enterprises pay much less attention to. One of the most serious problems is high variability of hard coal prices on global markets, mainly periodic price decreases that are hard to predict (figure 3)[9]. Under the conditions of systematically rising

[8] Compare: Hoyt R.E., Liebenberg A.P.: The value of enterprise risk management, „Journal of Risk and Insurance" 2011, Vol. 78, No. 4, pp. 795-822; Kaplan R.S., Mikes A.: Managing risks: a new framework, „Harvard Business Review" 2012, Vol. 90, No. 6, pp. 48-60; Marchetti A.M.: Enterprise Risk Management Best Practices: From Assessment to Ongoing Compliance. John Wiley & Sons, Inc., Hoboken, New Jersey 2011.
[9] More: Jang Ch-J., Xuan X., Jacson R.B.: China's coal price disturbances: Observations, explanations and implications for global energy economies, „Energy Policy" 2012, No. 51, pp. 720-727; Liu M-H., Margaritis D., Zhang Y.: Market-driven coal prices and state-administered electricity prices in China, „Energy Economics" 2013, No. 40, pp. 167-175; Papież M., Śmiech S.: Causality-in-mean and causality-in-variance within the

production costs (figure 4) the Polish mining enterprises are not able to adapt to changing price conditions in a flexible way and stop being competitive in comparison with cheaper hard coal imported from Russia, the Czech Republic, the United States and Australia (figure 5). This is reflected in problems with selling the Polish resource and in the rapidly growing level of inventory[10] (figure 6 and 7).

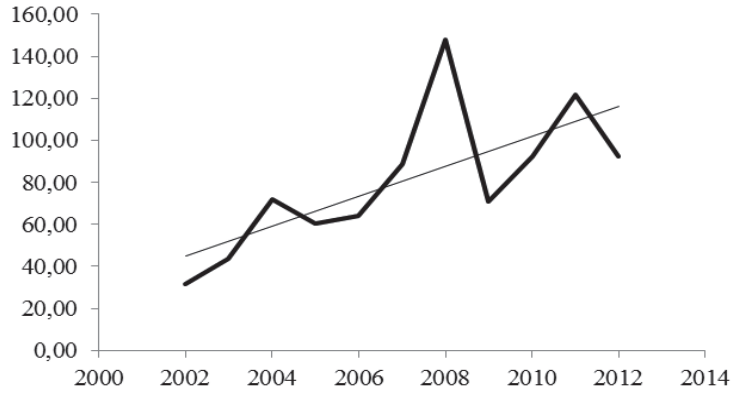

Fig. 3. Northwest Europe market price in the years 2000-2014 [in $/t]
Rys. 3. Ceny rynkowe w Północnowschodniej Europie w latach 2000-2014 [w $/t]
Source: Jonek-Kowalska I., Wolny M., Sojda A.: Analiza trendów i korelacji cen węgla kamiennego na rynkach międzynarodowych w erze dekarbonizacji, Zeszyty Naukowe Politechniki Śląskiej, s. Organizacja i Zarządzanie, Gliwice 2015, paper in press.

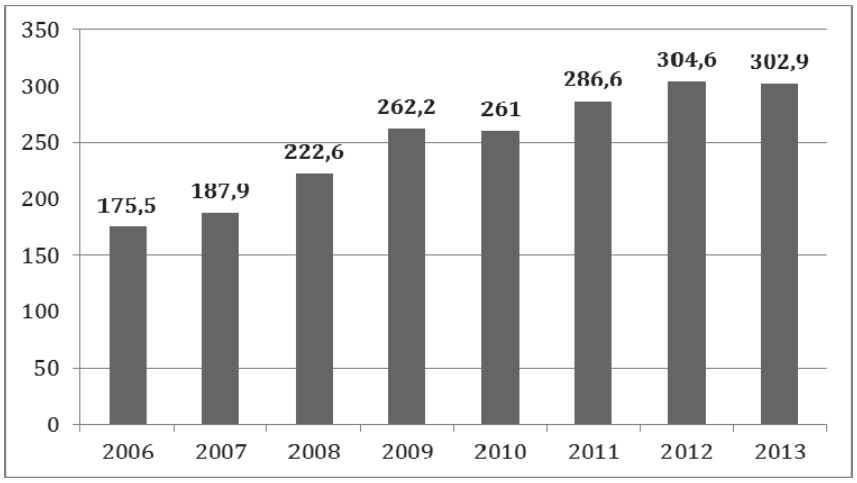

Fig. 4. Unit excavation cost in the Polish hard coal mining in the years 2006-2013 [in PLN/t].
Rys. 4. Koszt jednostkowy wydobycia w polskim górnictwie węgla kamiennego w latach 2006-2013 [w zł/tonę]
Source: own work based on data of the Ministry of Economy.

international steam market, „Energy Economics" 2013, No. 36, pp. 594-604; Lorenz U., Grudziński Z.: Sytuacja na międzynarodowych rynkach węgla energetycznego. „Gospodarka Surowcami Mineralnymi" 2005, Vol. 21, No. 2, pp. 5-16.

[10] Compare: Olkuski T.: Zależność Polski w zakresie importu węgla kamiennego, „Gospodarka Surowcami Mineralnymi" 2013, Vol. 23, No. 3, pp. 115-129.

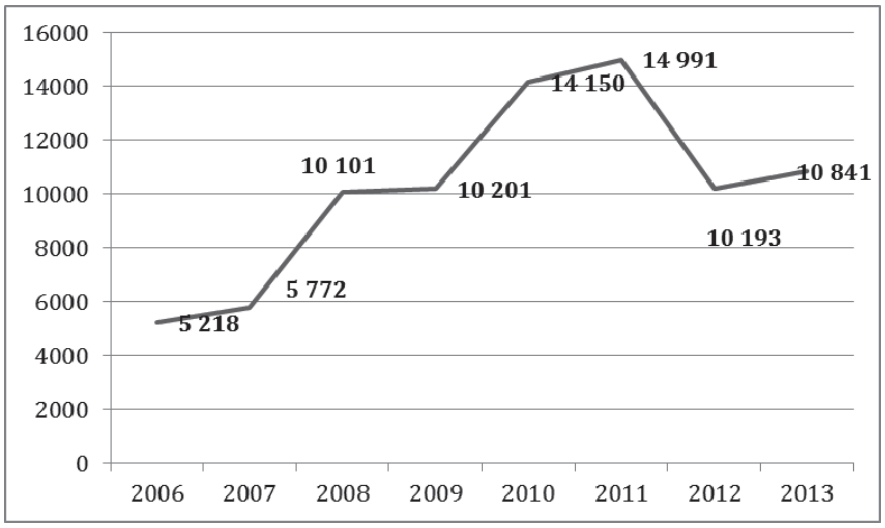

Fig. 5. Hard coal imports to Poland in the years 2006-2013 [in thousands of tons]
Rys. 5. Import węgla kamiennego do Polski w latach 2006-2013 [w tys. ton]
Source: own work based on data of the Ministry of Economy.

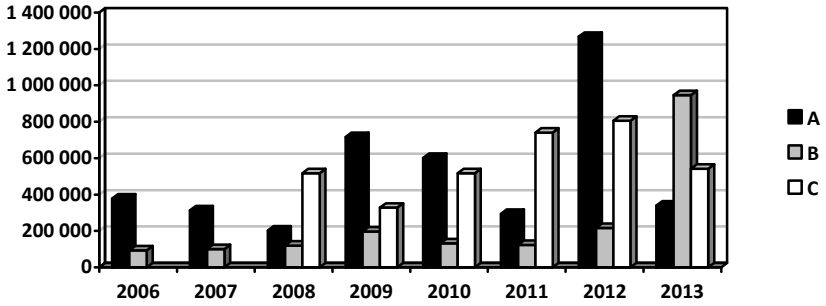

Fig. 6. Net financial result of three largest mining enterprises in the years 2006-2013 [in PLN thousand]
Rys. 6. Wynik finansowy netto trzech największych przedsiębiorstw górniczych w latach 2006-2013
Source: own work.

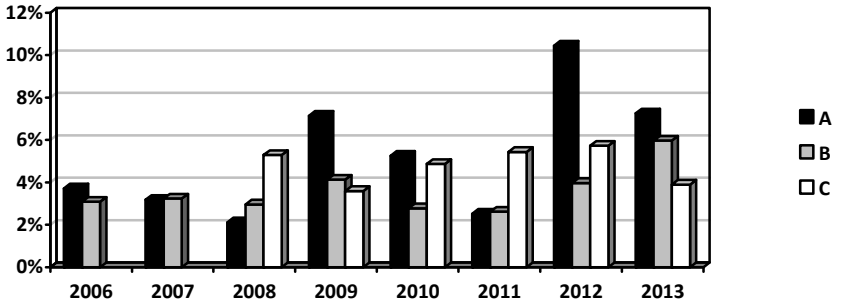

Fig. 7. Share of inventory in total assets in the three largest Polish mining enterprises in the years 2006-2013 [%]
Rys. 7. Udział zapasów w aktywach ogółem w trzech największych przedsiębiorstwach górniczych w latach 2006-2013 [w %]
Source: own work.

Another significant threat to the Polish mining enterprises is the advancing decarbonization in the European Union, which manifests itself in aggravated emission restrictions and in the promotion of renewable energy sources[11]. Without investment and innovative technologies, the Polish hard coal mining industry will not be able to comply with the requirements of ecologically cleaner production. Meanwhile, the quality of the Polish resource is systematically deteriorating, which is reflected in a rising level of sulfur and ash, reducing the circle of potential coal buyers in the commercial energy industry.

Not without significance for the Polish mining enterprises is the additional restriction of EU regulations concerning the range of state aid for the hard coal mining industry[12]. The decisions in force these days do not allow subsidizing of unprofitable mines without a time limit and make financing of initial investments by the State Treasury impossible. State aid may be granted to the hard coal mining industry mostly for liquidation of unprofitable mining enterprises and reduction of the social and ecological effects of their liquidation.

The economic conditions mentioned above confirm the necessity of a holistic look at risk in mining enterprises, primarily including Polish hard coal mining. They also justify a need to conduct research in the area of risk assessment and induce further actions aimed at risk reduction.

3. Risk assessment model in a mining enterprise

In the model suggested by the authors for risk assessment in a mining enterprise, the identification of the particular sources of risk is of holistic character and includes all risk sources presented in figure 1. Essentially, it is conducted in two basic areas. The first refers to risk assessment within the frames of resources gathered in the company, and the second is related to the specificity of operating activity undertaken by the enterprise, including the influence of internal and external conditions on the results of this activity at the same time. A graphic depiction of the suggested solution is presented in figure 8.

[11] Compare: Malko J., Wojciechowski H.: Polityka Unii Europejskiej w zakresie rozwoju energetyki zero-emisyjnej, [in:] M. Ściążko (ed.): Uwarunkowania wdrożenia zero-emisyjnych technologii węglowych w energetyce. Instytut Chemicznej Przeróbki Węgla, Zabrze 2007, pp. 13-17; Olkuski T.: Zasoby węgla kamiennego – najpewniejsze źródło energii. „Przegląd Górniczy" 2011, No. 7-8, pp. 42-45.

[12] See: Paszcza H., Białas M.: Pomoc publiczna dla górnictwa węgla kamiennego – przegląd oraz zagrożenia i perspektywy po 2010 r. Materiały XXIII konferencji z cyklu Zagadnienia surowców energetycznych i energii w gospodarce krajowej, Zakopane 2009, pp. 135-156; Białas M.: Pomoc publiczna dla górnictwa węgla kamiennego w świetle nowej decyzji Rady Unii Europejskiej, Materiały XXIII konferencji z cyklu Zagadnienia surowców energetycznych i energii w gospodarce krajowej, Zakopane 2011, pp. 17-28.

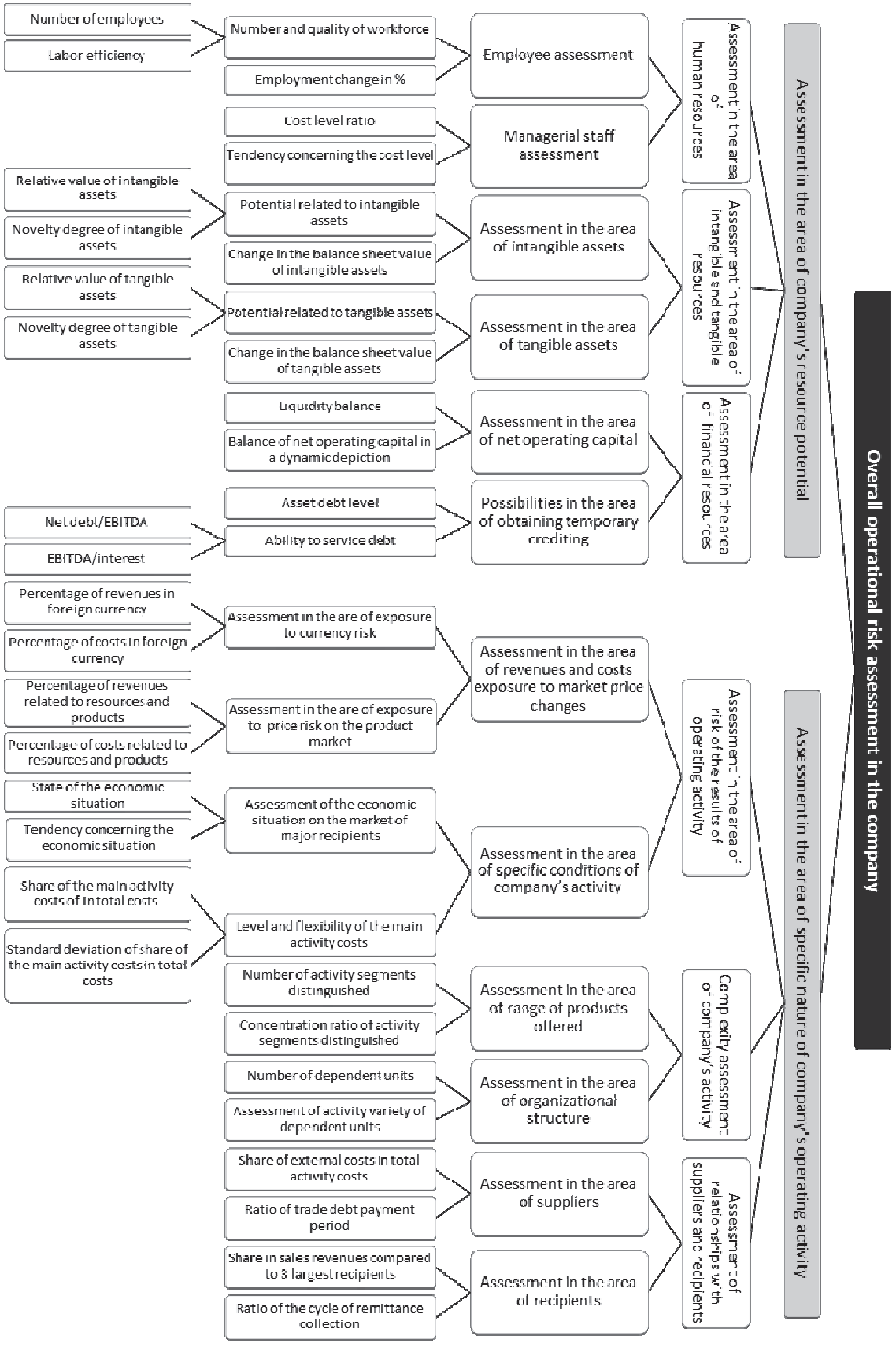

Fig. 8. Structure of the model of operational risk assessment in the company
Rys. 8. Struktura modelu oceny ryzyka operacyjnego w przedsiębiorstwie
Source: own work.

In the area of resources a potential risk assessment is conducted in relation to human, tangible, intangible and financial resources. Management competencies are of key character in **human resources**[13]. Their measurable reflection is the amount of cost level ratio[14] and tendencies concerning its changes in the company, which show the final efficiency and effectiveness of the management decision made[15]. Application of the measure formed in such way is additionally justified by the fact that in the Polish mining enterprises a high level of production costs is the main reason for the lack of competitiveness and the current economic crisis[16].

Apart from the management team, the level of operational risk is also affected by the number and quality of employees, which is included in the model suggested in the form of number of employees and work efficiency[17], a key assessment parameter of mining enterprises. Moreover, in the assessment of this part of human resources there are also changes in the employment level included. Adoption of this criterion is motivated by the fact that even a large and competent staff is sensitive to dismissal of employees and employment of new ones. Basically it is assumed that larger changes concerning employee rotation may lead to perturbation in the area of operating activity of the company, and therefore they have an unfavorable influence on risk level[18].

In the assessment of **tangible and intangible assets** two basic criteria were adopted: 1) change in balance sheet values of tangible assets and intangible assets and 2) the so-called development potential of both these assets. Such potential is assessed in the context of relative balance sheet value and degree of novelty expressed as a complement to one, as well as the depreciation rate of tangible assets and of intangible assets[19]. Taking into account the necessity of increasing investment outlays and increasing the level of innovativeness in the Polish hard coal mining industry, the aforementioned constituent risk measures are adequate and required in the holistic assessment of mining enterprises.

In the area of **financial resources** assessment, two classical parameters were used in the form of net operating capital and possibilities to obtain the temporary financing sources for operational risk assessment. In the case of net operating capital, we used the liquidity balance,

[13] See: Kuzior A.: Development of competences key to sustainable development, Zeszyty Naukowe Politechniki Śląskiej, s. Organizacja i Zarządzanie 2014, No. 75, pp. 71-81.
[14] Relation of own cost of sales to product, merchandise and material sales revenues.
[15] Compare: Nawrocki T., Rychlewski J.: Zmodyfikowany model oceny stabilności finansowej banku komercyjnego bazujący na koncepcji entropii, [in:] Stabilność systemu finansowego warunkiem rozwoju gospodarczego, t. 2, Owsiak S. (ed.), Wydawnictwo Wyższej Szkoły Finansów i Prawa, Bielsko-Biała 2012, p. 12.
[16] See: Michalak A., Turek M.: Ocena dynamiki i struktury zmian kosztów w przedsiębiorstwie górniczym, „Przegląd Górniczy" 2009, No. 9, pp. 11-15.
[17] More: Zieliński M.: Wartość pracy z perspektywy pracodawcy i pracobiorcy, [in:] Wartość w naukach ekonomicznych, Zadora H. (ed.), Wydawnictwo Politechniki Śląskiej, Gliwice 2004, pp. 115-128.
[18] Zieliński M.: Rynek pracy w teoriach ekonomicznych, CeDeWu, Warszwa 2012.
[19] See: Nawrocki T.: Innowacyjność produktowa przedsiębiorstw. Metodyka oceny na przykładzie spółek giełdowych, CeDeWu, Warszawa 2012, pp. 96-97.

which constitutes the difference between net operating capital and demand for net operating capital, or in other words, the difference between short-term investment and short-term liabilities of interest. Additionally, net operating capital balance was used in a dynamic depiction through calculating net operating capital balance on turnover days, meaning the difference between a net operating capital cycle and a cash conversion cycle. Taking into account the development of operating activity, it is more beneficial to possess a surplus of net operating assets rather than a shortage. Therefore, from the point of view of operational risk assessment in the company, the model suggested the highest values of the measures distinguished above mean lower operational risk.

In case of a possibility of gaining temporary financing sources, risk is estimated using the level of asset debt and ability to settle debts measured as a relation of net debt to EBITA (*Earnings Before Interest, Taxes and Amortization*) and EBIT (*Earnings Before Interest and Taxes*) to interest. In the Polish mining enterprises, which struggle with excessive debt and have low ability to service such debt, financial resources play a significant role in shaping the operational risk.

Risk assessment in the second examined area, related to the specificity of the activity conducted, involves three basic aspects. The first is the complexity of the activity conducted, oriented to the interior of the company. The second is cooperation with suppliers and recipients, directed at the relationship with the microenvironment. The third is exposure of financial results to changes in the macroenvironment. However, it should be emphasized that all the aforementioned aspects of risk assessment in the Polish mining enterprises are ignored, which has led the sector to a deep financial collapse in connection with intensification of industrial and general economic hazards observed in the last few years.

Accordingly, the **complexity of the activity conducted** is determined by product differentiation and organizational diversification. Therefore, in the assessment of this aspect the number of activity segments served and degree of their concentration are used for the production, assuming that the higher the production dispersion, the higher the operational risk. In turn, in the case of assessment of organizational diversification, the number of dependent units and activity conducted by them[20] was used, presuming that dispersion and the number of various dependent units complicate the conduction of operating activity and simultaneously increase the risk level.

Furthermore, in risk assessment of **supplier relationship,** the share of external costs in relation to total costs is used. A high share of these costs in relation to total costs shows a considerable dependence of the company on external factors and an enhanced level of operational risk. The second assessment criterion of the supplier relationship that is significant in operational risk shaping in the model suggested is the trade debt settlement

[20] Compare: Romanowska M.: Podstawy organizacji i zarządzania, Difin, Warszawa 2001, p. 206. Strategor, Zarządzanie firmą, PWE, Warszawa 2001, pp. 312-315.

period ratio, which allows estimation of the level of flexibility possible in the enterprise's contact with suppliers.

In risk assessment of the **recipient relationship,** the ratio of the short-term debt collection cycle is adopted to determine the negotiation position of the enterprise concerning granting trade credit. This is stronger when the operational risk connected with the subjective segment of assessment is lower. Additionally by identifying the share of the tree largest recipients in the sale revenues the dependence of financial results from recipients is assessed. The higher the dependence, the higher the operational risk.

The last segment of the model is concentrated on risk assessment **in the area of results on operating activity**, including the assessment of exposure of revenues and costs to market price changes and the assessment of specific conditions of company activity within the frames of this area. Thus, assessment of revenues and costs exposure to market price changes is conducted in two directions, in relation to exchange rate changes and in relation to raw material and product price changes. The ratios used in this area are, accordingly: percentage of revenues and costs in foreign currencies and percentage of revenues and costs concerning raw materials and products. In the assessment of these components it is assumed that the higher the share of foreign currency, raw material and product revenues and costs in their the total cost structure, the higher the dependence of operating results on external factors, which means a higher level of operational risk.

In turn, the assessment of specific conditions of company activity is conducted in the context of an economic situation on the market of major recipients determining demand for the products of mining enterprises as well as in the context of the level and flexibility of the main costs of activity. Regarding the economic situation, its level and tendencies are estimated. As for the main costs of activity, their share in total costs and standard deviation are estimated. The more concentrated and variable the structure of the total costs, the higher the operational risk.

Firstly in the presented model the sub-criteria are assessed within the frames of the distinguished basic assessment criteria of operational risk. These assessments will come from the values of the ratios calculated on the basis of data from financial statements or, when it is impossible to make such calculations, from the qualitative (descriptive) assessment stemming from the description/characteristics of the particular assessment criterion in the periodical report of the examined enterprise. Next, on this basis, using the fuzzy sets theory, the sub-criteria are assumed to obtain the aggregated results of the particular constituent assessments. Later these estimates will constitute the basis for calculating the main risk measures in the area of resource potential and specificity of the operational activity so that, based on these measures, it is possible in the last stage to obtain the overall operational risk assessment in the examined mining enterprise.

4. The procedure of using fuzzy logic in the suggested model of risk assessment

The process of creating a fuzzy model of operational risk assessment is conducted in four basic stages. **In the first stage** the input data for the model are collected. According to the assumptions made, the basic criteria of operational risk in the enterprise are fully based on generally available data, which can be obtained by analyzing the contents of periodic reports published by the enterprise. In this context financial statements are a particularly useful source of data.

In the second stage the form of fuzzy sets for the particular input variables is determined for the needs of the "fuzzification" module, and for those variables a set of basic terms is determined and a division of the space of its values is conducted. Due to the similarities in expressing the assessment of given variables in the natural language, for the needs of the fuzzy model under discussion it is suggested that the same dictionary of linguistic values is accepted for all the variables. The input variables can be divided into three fuzzy sets, {low, average, high}, and the output variables, in order to achieve more precise results, can be divided into five fuzzy sets, {low, low-average, average, average, high}. Furthermore, due to the ease of use and high versatility, it is suggested that a triangular, or if necessary a trapezoidal shape is adopted for the membership function of particular fuzzy sets in the case of input values $\mu(x)$ and output values $\mu(y)$.

Here it should be noted that the variables of the discussed fuzzy model can be divided into two groups. The first group consists of input variables, the values of which come straight from the financial statements of the enterprises and are in the range of 0 (or $-\infty$) to $+\infty$, depending on the character of the variable. On the other hand, the second group consists of variables that are the result of fuzzy reasoning and take values in the range of 0 to 1. In relation to the above, for the first group of variables the values describing the particular fuzzy sets (a, b, c for triangular membership functions and a, b, c, d for trapezoidal membership functions) should be determined based on consultations with experts or arbitrarily, if the creator of the model has proper knowledge in the area of the analyzed issue. However, in relation to the second group of variables, a uniform division of the range of its values can be used with triangular fuzzy sets.

The third stage covers the creation, for the needs of the "inference" module, of proper rule bases as well as the determination of the inference mechanism and the definition of the membership function of the outputs of the model. In case of a lack of proper experience in the area of the issue under examination, the knowledge of the needs of inferring in the analyzed fuzzy model should be gathered by conducting standardized interviews with experts. Here it should be noted that, depending on the nature of the final assessment, stock market analysts and investors (investment perspective on the operational risk of the enterprise),

representatives of oversight institutions (allocation perspective), or financing entities (creditors' perspective) could be those experts. Then such knowledge should be used for the creation of basic rules and of frameworks of databases, which are eventually completed through further consultations. After their adaptation, one should receive complete and ready-to-use rule bases.

For the needs of conducting fuzzy inference, in order to implement the conjunction of conditions in particular rules (of calculating the degrees of truth of protases), it is suggested that the *PROD* operation is used, which is given by the formula[21]:

$$h = \mu_{A1 \cap A2 \cap A3}(x_1, x_2, x_3) = \mu_{A1}(x_1) \cdot \mu_{A2}(x_2) \cdot \mu_{A3}(x_3).$$

In comparison to the other operators of the t-norm, e.g., the *MIN* operator, the *PROD* operator reacts to the changes of all x_i inputs of the model while having a small degree of calculations nuisance .

On the other hand in, order to find the resultant fuzzy sets for the particular rules (referred to as a reduction of the veracity of the apodosis of the rule by using the veracity of the protasis) and to merge the actions of rules into one output set, the use of the *SUM-MIM* scheme[22] is suggested:

$$\mu_{B^*}(y) = \mathrm{MIN}(\mu_B(y), h),$$

$$\mu_{wyn}(y) = \mathrm{SUMA}(\mu_{B^*1}(y), \ldots, \mu_{B^*\mathrm{K}}(y)) = \sum \mu_{B^*K}(y).$$

The basic advantage stemming from using the *SUM-MIN* scheme in the process of inference is that all of the component functions $\mu_{Bi^*}(y)$ from particular rules are taken into consideration during the calculation of the resultant function $\mu_{wyn}(y)$, and not, as takes place in the *MAX-MIN* scheme, only the function that has the highest degree of membership for a given output y value.

In the fourth stage, for the needs of the defuzzification module, the method of transforming the outputs of the model from fuzzy values into precise (not-fuzzy) numerical values is determined.

In relation to the previously suggested polygonal membership functions for the fuzzy sets in particular variables, defuzzification may be conducted, e.g., by using the method of the center of sums. In this case the resultant output value from the fuzzy model (y^*) is given by the formula[23]:

[21] See. Piegat A.: Modelowanie i sterowanie rozmyte, EXIT, Warsaw 2003, p. 130.
[22] Ibidem, p. 181-193.
[23] Ibidem, p. 205.

$$y^* = \frac{\sum_{i=1}^{l} y_i \sum_{K=1}^{m} \mu_{B^*K}(y_i)}{\sum_{i=1}^{l} \sum_{K=1}^{m} \mu_{B^*K}(y_i)} \quad (1)$$

where:

l – the number of elements of the discreet basic Y set,

m – the number of rules of the fuzzy model.

After conducting the quantization of the space of input and output variables, designing the knowledge bases and determining the mechanism of fuzzy inference as well as the method of defuzzification, one ends up with a ready-to-use fuzzy model of operational risk assessment in a mining enterprise.

5. Summary

The development of the model of operational risk assessment presented in this article is dictated by the needs for theory in the area of risk management in the enterprise and in practice, as well as the necessity of adapting management tools to the specific industry and the domestic economic, while at the same time maintaining the universality of methodological assumptions. The basic advantages of the designed model are as follows: it can conduct operational risk assessment without the need to use internal data from the enterprise that are not publicly available, and the universality of the criteria used makes it possible to conduct a comparative analysis and combine the synthetic and analytical assessments of risk gained from a gradual aggregation of constituent assessments by using fuzzy logic.

The presented model, apart from the obvious capabilities of diagnosing risk in *ex post* terms, also offers prognostic capabilities. By using it, one may estimate the results of making certain management decisions at the particular level of operational risk in the given segment of the assessment as well as in the entire enterprise as a result.

However, the presented assumptions in their current form are theoretical in nature and require further consideration, verifying the adopted criteria and detailed empirical research, including questionnaire surveys oriented to the development of the rule bases used for the needs of methodology of fuzzy sets.

The verification of the designed model in the conditions of the Polish hard coal mining industry will enable a full and multi-aspect operational risk assessment in this industry, which, given the conditions presented in the first part of this article, should be a priority task

and should be performed immediately. It especially concerns the necessity of industrial and systematic risk assessment, which until now has been ignored by the Polish mining industries.

Bibliography

1. Białas, M.: Pomoc publiczna dla górnictwa węgla kamiennego w świetle nowej decyzji Rady Unii Europejskiej, Materiały XXIII konferencji z cyklu Zagadnienia surowców energetycznych i energii w gospodarce krajowej, Zakopane 2011.
2. Bromiley Ph., McShane M., Nair A., Rustambekov, E.: Enterprise Risk Management: Review, Critique, and Research Directions, „Long Range Planning" 2014.
3. Gordon L.A., Loeb M.P., Tseng C.-Y.: Enterprise risk management and firm performance: a contingency perspective, „Journal of Accounting and Public Policy" 2009, Vol. 28.
4. Gu X., Wang J., Liu Y.: Water resistant features of high-risk outburst coal seams and standard discriminant model of mining under water-pressure, „Mining Science and Technology" 2010, Vol. 20, Iss. 6.
5. Hoyt R.E., Liebenberg, A.P.: The value of enterprise risk management, „Journal of Risk and Insurance" 2011, Vol. 78 No. 4.
6. Jang Ch-J., Xuan X., Jacson R.B.: China's coal price disturbances: Observations, explanations, and implications for global energy economies, „Energy Policy" 2012, No. 51.
7. Jonek-Kowalska I., Wolny M., Sojda A.: Analiza trendów i korelacji cen węgla kamiennego na rynkach międzynarodowych w erze dekarbonizacji, Zeszyty Naukowe Politechniki Śląskiej, s. Organizacja i Zarządzanie, Gliwice 2015.
8. Jonek-Kowalska I.: Bankruptcy risk a Polish mining enterprise - reasons, symptoms and consequences, [in:] Aktualne problemy podnikovej sfery 2013. Zbornik vedeckych prac. Aut.: S. Majtan a kolektiv. Ekonomicka Univerzita v Bratislave. Fakulta Podnikoveho Manazmentu. Katedra Podnikovohospodarska. Vydavatel'stvo Ekonom, Bratislava 2013.
9. Jonek-Kowalska I.: Data envelopment analysis w ocenie efektywności technicznej wielozakładowego przedsiębiorstwa górniczego, „Przegląd Organizacji" 2014, nr 3.
10. Kaplan R.S., Mikes A.: Managing risks: a new framework, „Harvard Business Review" 2012, Vol. 90, No. 6.
11. Khanzode V.V., Maiti J., Ray P.K.: A methodology for evaluation and monitoring of recurring hazards in underground coal mining, „Safety Science" 2011, Vol. 49, Iss. 8-9.
12. Kuzior A.: Development of competences key to sustainable development, Zeszyty Naukowe Politechniki Śląskiej, s. Organizacja i Zarządzanie 2014, nr 75.

13. Kuzior A.: Etyczna aktywność firm w dziedzinie ochrony środowiska, [in:] Aplikovana etika a profesionalna prax. Univerzita Mateja Bela v Banskej Bystrici. Fakulta humanitnych vied. Katedra etiky a aplikovanej etiki. Banska Bystrica: Fakulta Humanitnych Vied. Univerzita Mateja Bela, 2011.
14. Liu M-H., Margaritis D., Zhang Y.: Market-driven coal prices and state-administered electricity prices in China, „Energy Economics" 2013, No. 40.
15. Lorenz U., Grudziński Z.: Sytuacja na międzynarodowych rynkach węgla energetycznego. „Gospodarka Surowcami Mineralnymi" 2005, Vol. 21, No. 2.
16. Malko J., Wojciechowski H.: Polityka Unii Europejskiej w zakresie rozwoju energetyki zero-emisyjnej, [in:] M. Ściążko (ed.): Uwarunkowania wdrożenia zero-emisyjnych technologii węglowych w energetyce. Instytut Chemicznej Przeróbki Węgla, Zabrze 2007.
17. Marchetti A.M.: Enterprise Risk Management Best Practices: From Assessment to Ongoing Compliance. John Wiley & Sons, Inc., Hoboken, New Jersey 2011.
18. Michalak A.: Strategie finansowania przedsiębiorstw w branżach kapitałochłonnych na przykładzie polskich i światowych przedsiębiorstw górniczych, „Zarządzanie i Finanse – Journal of Management and Finance" 2013, Vol. 11, No. 1.
19. Michalak A., Turek M.: Ocena dynamiki i struktury zmian kosztów w przedsiębiorstwie górniczym, „Przegląd Górniczy" 2009, No. 9.
20. Nawrocki T.: Innowacyjność produktowa przedsiębiorstw. Metodyka oceny na przykładzie spółek giełdowych, CeDeWu, Warszawa 2012.
21. Nawrocki T., Rychlewski J.: Zmodyfikowany model oceny stabilności finansowej banku komercyjnego bazujący na koncepcji entropii, [in:] Stabilność systemu finansowego warunkiem rozwoju gospodarczego, t. 2, Owsiak S. (ed.), Wydawnictwo Wyższej Szkoły Finansów i Prawa, Bielsko-Biała 2012.
22. Olkuski T.: Zasoby węgla kamiennego – najpewniejsze źródło energii. „Przegląd Górniczy" 2011, nr 7-8.
23. Papież M., Śmiech S.: Causality-in-mean and causality-in-variance within the international steam market, „Energy Economics" 2013, No. 36.
24. Paszcza H., Białas M.: Pomoc publiczna dla górnictwa węgla kamiennego – przegląd oraz zagrożenia i perspektywy po 2010 r. Materiały XXIII konferencji z cyklu Zagadnienia surowców energetycznych i energii w gospodarce krajowej, Zakopane 2009.
25. Piegat A.: Modelowanie i sterowanie rozmyte, EXIT, Warszawa 2003.
26. Poplin G., Miller H.B., Ranger-Moore J., Bofinger C.M., Kurzius-Spencer M., Harris R. B., Burgess J.L.: International evaluation of injury rates in coal mining: A comparison of risk and compliance-based regulatory approaches, „Safety Science" 2008, Vol. 46, Iss. 8.
27. Romanowska M.: Podstawy organizacji i zarządzania, Difin, Warszawa 2001.
28. Strategor: Zarządzanie firmą, PWE, Warszawa 2001.
29. Yan Z., Wang X., Fu Y.: Study on Early Warning Model of Coal Mining Engineering with Fuzzy AHP, „Systems Engineering Procedia" 2012, Vol. 5.

30. Zieliński M.: Wartość pracy z perspektywy pracodawcy i pracobiorcy, [in:] Wartość w naukach ekonomicznych, Zadory H. (ed.), Wydawnictwo Politechniki Śląskiej, Gliwice 2004.
31. Zieliński M.: Rynek pracy w teoriach ekonomicznych, CeDeWu, Warszawa 2012.

Omówienie

Opracowanie przedstawionego w artykule modelu oceny ryzyka operacyjnego podyktowane jest zarówno potrzebami teorii z zakresu zarządzania ryzykiem w przedsiębiorstwie, jak i potrzebami praktyki, związanymi z koniecznością dostosowywania narzędzi zarządczych do specyfiki branżowej oraz krajowych uwarunkowań gospodarczych, przy równoczesnym zachowaniu uniwersalności założeń metodycznych. W proponowanym przez Autorów modelu oceny ryzyka w przedsiębiorstwie górniczym identyfikacja poszczególnych źródeł ryzyka ma charakter holistyczny i jest przeprowadzana w dwóch podstawowych obszarach. Pierwszy odnosi się do oceny ryzyka w ramach zgromadzonych w przedsiębiorstwie zasobów, drugi zaś specyfiki prowadzonej przez przedsiębiorstwo działalności operacyjnej, w tym równoczesnego wpływu na wyniki tej działalności uwarunkowań wewnętrznych i zewnętrznych.

Do podstawowych zalet opracowanego modelu należą: możliwość przeprowadzenia oceny ryzyka operacyjnego bez konieczności wykorzystania danych wewnętrznych przedsiębiorstwa, uniwersalność wykorzystanych kryteriów, pozwalająca na analizę porównawczą oraz połączenie ocen ryzyka syntetycznej i analitycznej, uzyskane dzięki stopniowej agregacji wyników cząstkowych przy wykorzystaniu logiki rozmytej.

Prezentowany model, poza oczywistymi zdolnościami do diagnozy ryzyka w ujęciu *ex post*, oferuje także możliwości prognostyczne. Przy jego użyciu można bowiem ocenić skutki podjęcia określonych decyzji zarządczych dla poziomu ryzyka operacyjnego w danym segmencie oceny, a w rezultacie także w całym przedsiębiorstwie.