The use of fuzzy logic in the operational risk assessment of mining companies

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Abstract. The main objective of this paper is to present the concept and practical application of the operational risk assessment fuzzy model. This model is an attempt to combine fuzzy methodology with financial indicators. When creating the basic assumptions of the model, the authors used a resource approach, treating human, material and financial resources, and the way they are allocated, as the detailed sources of operational risk. In addition, the model also takes into account the relational and organizational resources, as well as dependence of operational risk on the surroundings. In this article, the model has been verified by using it to perform an operational risk assessment in the mining industry on the example of coal mining companies listed on the Warsaw Stock Exchange.

Keywords: operational risk, fuzzy logic, fuzzy model, coal mining companies.

JEL Classification: G32, C69
AMS Classification: 94D05, 26E50

1. Introduction

Identification and measurement of operational risk is a complex and multi-threaded issue in which the basic problem is to anticipate economic events and their influence on the financial results of a company. In the subject literature, the methodology of risk assessment is most often presented in the context of econometric-statistical or probabilistic methods [8]. However, their use frequently refers to only some parts of a company's activity, e.g. investment risk or market risk. There is still a lack of clear, reliable and holistic methods of risk assessment of the company's activity that are characterized by comparability and easy application by all the company's stakeholders. Therefore, the main purpose of this article is to present a comprehensive conception and practical application of the operational risk assessment model based on fuzzy set theory [5], [10].

This model is an attempt to combine the methodology of fuzzy sets with the ratios of financial analysis. The presented model has been positively assessed in the theoretical part by domestic reviewers [4]. Currently, the authors are searching for further approaches to model improvement in the course of empirical research; thus, in this article, the model was subject to verification by way of using it for operational risk assessment in the mining industry, specifically the selected coal companies listed on the Warsaw Stock Exchange. The results of the conducted research enable an individualized assessment of operational risk, industrial comparisons and further model improvement.

2. Research methodology

In the proposed solution, taking into account the essence of operating activity, it was assumed that the operational risk could be analysed and assessed in two dimensions: resource potential and the specific nature of the business run. In the assessment of resource potential, there are three basic groups of resources, understood in a broad sense, involved: human resources, tangible and intangible resources and financial resources. In turn, in cases of risk assessment stemming from the specific nature of a company's operating activity, the focus was on the risk factors determining the operating results of the company, the complexity of the company's activity and its relationships with suppliers and recipients.

The structure of the suggested operational risk assessment model, along with the most detailed assessment criteria within the particular modules, is presented in Figure 1.

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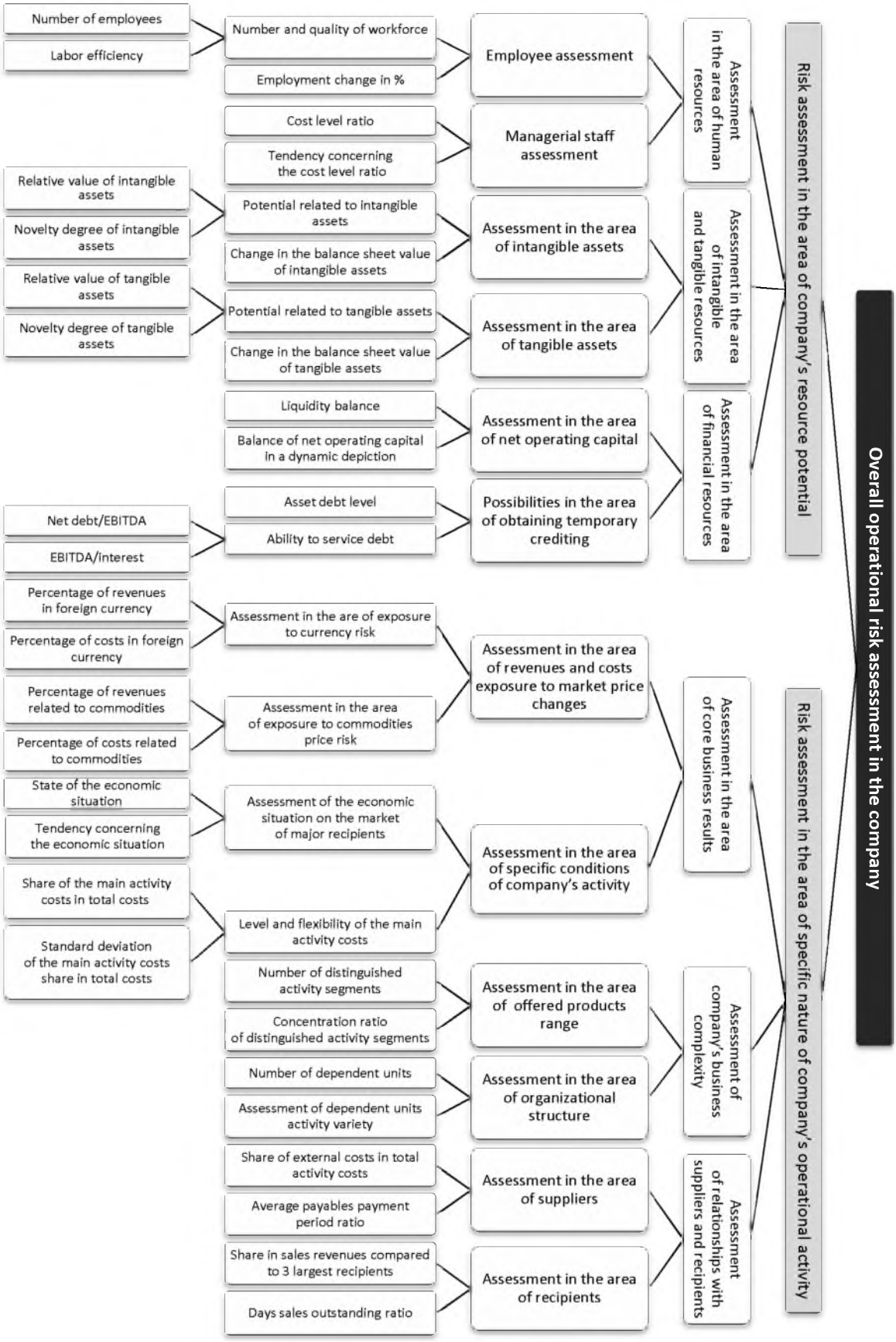

Figure 1 Structure of the operational risk assessment model
Source: Authors' work

In the proposed model firstly it is intended to obtain partial assessments within the distinguished basic assessment criteria of operational risk. These assessments will result from the ratios calculated on the basis of data from financial statements or, if no possibility exists to make such calculations, a qualitative (descriptive) assessment of a particular criterion stemming from the description or characteristics in the periodical report of the examined company. Next, on this basis, aggregated assessment results may be obtained in the areas of human resources, tangible and intangible resources, financial resources, core business results, company's business complexity and its relationships with suppliers and recipients. Furthermore, these results constitute foundations for calculating general risk measures in the areas of resource potential and the specific nature of the company's operational activity, so that in the final stage, on their basis, it is possible to achieve overall operational risk assessment for the analysed company.

The calculation aid in the suggested solution is based on the fuzzy set theory, which is one of the approximate reasoning methods [2], [3]. In classic set theory, the transition from the full membership of an element in a set to its total non-membership is bivalent (either the element is the member of a set or it is not), thus presenting imprecise concepts using such sets raising a number of issues. L.A. Zadeh, the author of fuzzy set theory, was the first one to notice that, when formulating the rule of inconsistency: *„complexity and precision bear an inverse relation to one another in the sense that, as the complexity of a problem increases, the possibility of analyzing it in precise terms diminishes*" [11]. In fuzzy set theory, it is accepted that the element may partially belong to a set and at the same time to its complement; therefore, the law of excluded middle does not apply here. In the fuzzy set, the transition from membership into a set to non-membership is gradual (this gradual change is expressed by the so-called membership function), thus these concept makes it possible to describe soft concepts and imprecise quantities, to which the assessment of the company's operational activity risk certainly belongs. From the formal point of view, above issues are expressed by the following definition of a fuzzy set [6]:

Definition 1. *A fuzzy set* A *in a certain space (area of consideration)* $X = \{x\}$ *(which is written as* $A \subseteq X$*) is a set of pairs*: $A = \{(\mu_A(x), x)\}$, $x \in X$, *where* $\mu_A(x)$: $X \rightarrow [0, 1]$ *is the membership function of fuzzy set* A, *to which each element* $x \in X$ *attributes its degree of membership in the fuzzy set* A, $\mu_A(x) \in [0, 1]$.

An important concept of fuzzy logic is the linguistic variable. Even though the mathematical formalism of this variable is relatively complicated, its intuitive meaning is simple – a linguistic variable is a variable, which values are not numbers but sentences in a certain language, identified in the semantic sense with particular fuzzy sets [7]. In turn, the basic mean enabling the presentation of the relations occurring between the accepted linguistic variables are fuzzy conditional sentences in the form:

IF x is A THEN y is B.

Usually, however, the relation between the same variables is described not by a single rule but by the so-called bank (base) of rules, which is treated in the process of fuzzy reasoning as a certain whole – a subsystem, the total effect of which is subjected to further processing. In the process of reasoning, for given inputs, all of the rules in the bank are activated, and the results of their actions are then merged into a fuzzy output set, which is the value of the variable y. The given bank of rules may describe the relations between the input and output of the entire system, or it can be an element of a more complex hierarchical structure [1]. The equivalent of the real system model in the fuzzy logic is a fuzzy-model. In literature, there are various types of fuzzy models characterized, but one of the most popular is the Mamdani model, which general diagram is presented in Figure 2.

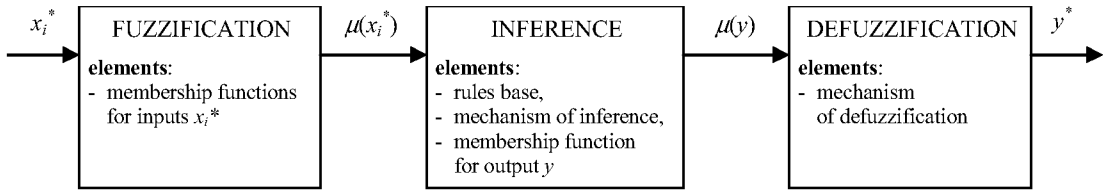

Figure 2 General diagram of Mamdani fuzzy model
Source: Authors' work, based on: Piegat A., Modelowanie i sterowanie rozmyte, EXIT, Warsaw 2003, p. 165

As the input of the fuzzy model x_i^* values are introduced, which in the FUZZIFICATION module are subjected to the fuzzification process – here, the membership degree of input values $\mu(x_i^*)$ to the particular fuzzy sets is calculated. Next, in the INFERENCE module, based on the received input membership degrees, fuzzy reasoning takes place, the end result of which is a resultant membership function $\mu(y)$ of the model output. The basis for the fuzzy reasoning is so-called rule base in the form of „IF – THEN" and an inference mechanism which determines the way of activating rules in the base, as a result of which membership functions

of the particular rules conclusions with the given values of fuzzy model inputs x_i^* are received, as well as the way for their aggregation into one resultant membership function of the entire base conclusion $\mu(y)$. Because this function most often has a fuzzy form, which makes the interpretation of the final result much more difficult, in many cases, there is a need to transform it into a precise value. This is done in the DEFUZZIFICATION module, where by the use of the chosen method a sharp (non-fuzzy) value of the model output y^* is calculated [9].

3. Detailed assumptions of the research

In order to verify the proposed model the operational risk assessment was conducted for two mining enterprises, organized in the form of capital groups, which shares are listed on the Warsaw Stock Exchange – Jastrzębska Spółka Węglowa S.A. (JSW) and Lubelski Węgiel „Bogdanka" S.A. (LW Bogdanka).

According to the adopted methodology, the basis for the operational risk assessment of mentioned above entities were the data acquired from the consolidated periodical reports (annual, semi-annual, quarterly) and other materials (presentations of results, marketing reports) published by these companies in the years 2011-2014. In relation to the construction of the operational risk assessment fuzzy model, based on Mamdani approach, the following assumptions were made:

- for all input variables of the model, the same dictionary of linguistic values was used, and their space was divided into three fuzzy sets, most often named {low, medium, high};
- for output variables of the model, the space of linguistic values was divided into five fuzzy sets named {low, mid-low, medium, mid-high, high};
- in the case of all membership functions to the particular fuzzy sets, a triangular shape was decided for them (Figure 3 and Figure 4);
- the values of the characteristic points of fuzzy sets (x_1, x_2, x_3) for the particular input variables of the model were determined arbitrarily, based on the distribution of analysed variables values and on the authors many years' experience in the area of financial and risk analysis;
- for the fuzzification of the input variables, the method of *simple linear interpolation* was used [1];
- fuzzy reasoning in the particular knowledge bases of the model was conducted using *PROD* operator (fuzzy implication) and *SUM* operator (final accumulation of the conclusion functions received within the particular rule bases into one output set for each base) [9];
- for the defuzzification of fuzzy reasoning results within the particular rule bases *Center of Sums* method was used [11].

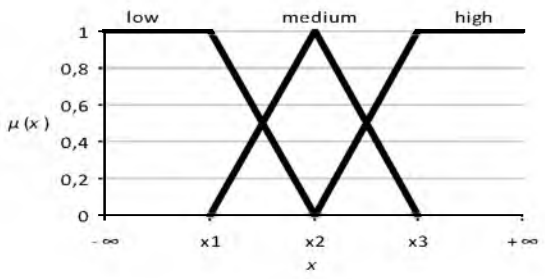

Figure 3 The general form of the input variables membership function to distinguished fuzzy sets. Source: Authors' work

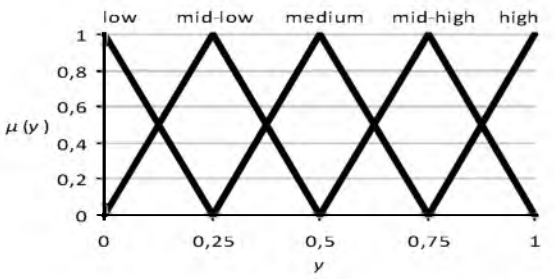

Figure 4 The output variables membership function to distinguished fuzzy sets. Source: Authors' work

Next, taking into consideration the general structure of the operational risk assessment model presented in Figure 1, the authors, based on their knowledge and experience in the area of the analysed issue, designed 29 bases or rules in the form of „IF – THEN" (27 bases with 9 rules and 2 bases with 27 rules), achieving this way a „ready to use" form of the operational risk assessment fuzzy model. The intermediate and final assessments generated by the model take values in the range between 0 and 1, where from the viewpoint of the analysed issue, the values closer to 1 mean a very favourable result (lower risk), while the values closer to 0 indicate a result less favourable (higher risk).

All calculations related to the presented fuzzy model were based on self-developed structure of formulas in MS Excel.

4. Research results

As emphasized in the methodological section, the final operational risk assessment in the examined mining companies consists of the results in the two basic areas: resources determining the operating activity,

and its specific conditions. The assessment results of the first one are presented in Figure 5. In the whole analysed period, a lower operational risk in the area of resources (expressed by a higher assessment value) characterizes LW Bogdanka. This enterprise is distinguished by the high and stable assessment results of human resources stemming from the highest labour efficiency in the Polish mining industry and very good cost level ratio. Nevertheless, it should be added that these two parameters are dependent in a great part on favourable geological-mining conditions. LW Bogdanka is characterised by a very low intensity of natural hazards and high thickness of deposits localized relatively shallowly. In this company, since the beginning of 2013, the situation concerning the assessment of financial resources has deteriorated, mainly due to a lack of compatibility of the need for net operating capital with its real estate. The assessment results in the area of tangible and intangible resources have decreased as well. In the second of the examined enterprises (JSW), the level of operational risk in the area of resources was clearly increasing in the year 2013 (lower assessment value). However, the company, over the whole analysed period, maintains a high and stable assessment result in the area of financial resources, what proves an effective financial management oriented to limitation of the economic fluctuation influence on financial conditions. Nonetheless, the assessment results in the area of human resources have been decreasing with time, connected with efficiency deterioration as a result of production reduction. In 2013, import of coking coal to Poland increased, mostly from Australia and the Czech Republic. The company is also under a strong influence of economic fluctuations on the European steel market. In the year 2013 the assessment results of tangible and intangible resources deteriorated in this company too.

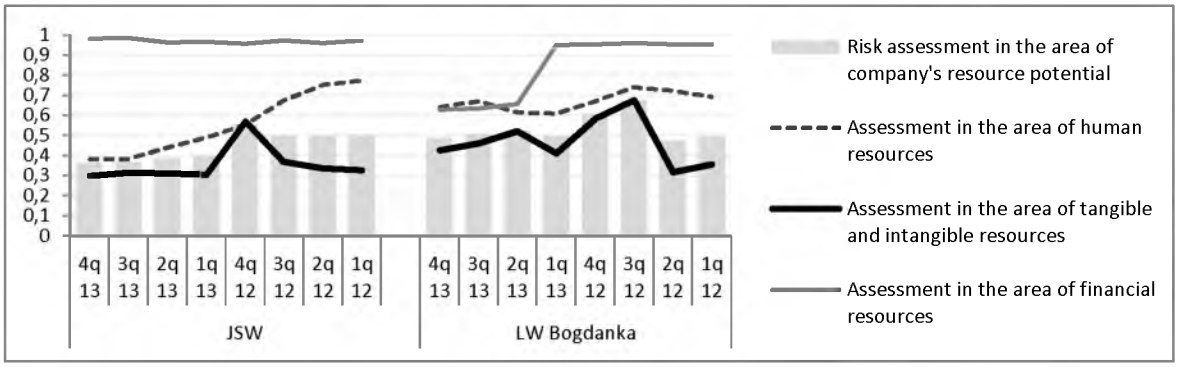

Figure 5 Risk assessment in the area of resource potential in the examined companies
Source: Authors' work

Assessment in the area of the specific nature of operating activity is quite stable over time in both companies and clearly lower in JSW. The latter mostly stems from a greater exposure of the company to the risk of market price changes and economic fluctuations on the market of coking coal, mainly driven by economic fluctuations on the market of this raw resource recipients. Risk in this area is also enhanced by the low cost flexibility and low assessment results of organizational structure, coming from larger complexity and activity diversification of dependent units. LW Bogdanka characterizes lower risk in the area of operating activity specific nature, mostly due to a lower exposure to currency and price risk and slight economic changes on the market of major recipients who are, in this case, the local energy producers in the sector of industrial energy.

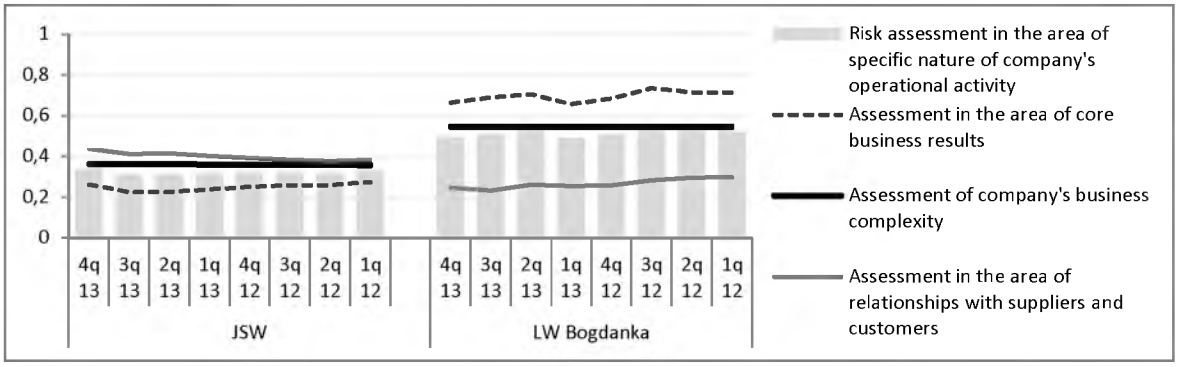

Figure 6 Risk assessment in the area of the specific nature of operational activity in the examined companies
Source: Authors' work

A resultant operational risk assessment presented in Figure 7 is an effect of assessment results in the aforementioned partial areas. Its variability in time is therefore shaped in great part by variability in the area of resources potential. The assessment of the company's activity specific nature, due to stability over time, only affects the level of the final assessment. In terms of results, operational risk is higher in the case

of JSW, the company providing resources for more demanding and geographically dispersed recipients. LW Bogdanka is characterized by highly assessed resource potential and lower exposure to market, price and currency fluctuations, which affect the lower level of operational risk.

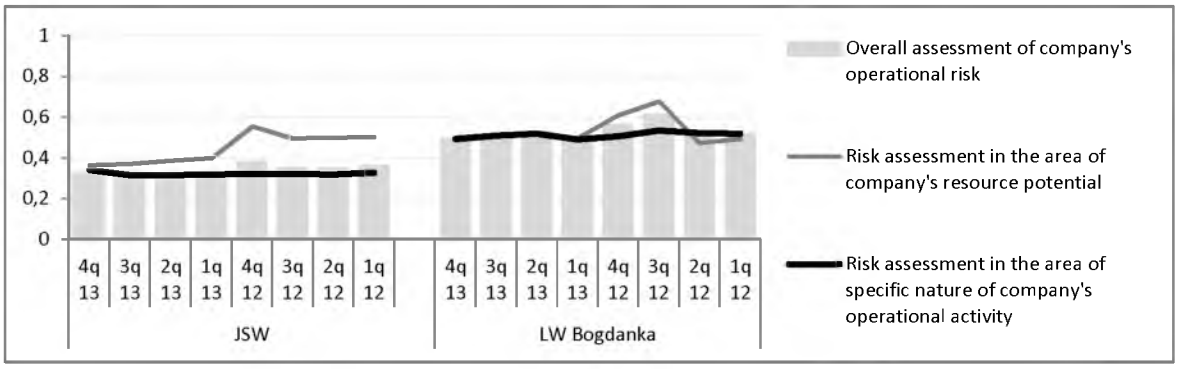

Figure 7 Overall assessment of operational risk in the examined companies
Source: Authors' work

5. Conclusions

The model of operational risk assessment, elaborated using the methodology of fuzzy sets, is characterized by the following advantages that partially enable reducing the defects of methods previously applied in risk identification and assessment in the company: combination of analytic and synthetic operational risk assessment, achieved through the use of sub-criteria that are later aggregated into a collective risk assessment; combination of quantitative and qualitative approach to risk assessment, manifested in a qualitative dimension of ratios used for risk measurement and qualitative method of risk diversification determination; possibility of conducting assessment by the external and internal stakeholders without the necessity of using the advanced calculation techniques; using for the assessment process data included in the generally accessible business periodical reports; providing reliability and flexibility at the same time due to the use of quantitative and qualitative data.

Operational risk assessment conducted using presented model allows the formulation of the following practical conclusions: operational risk in the whole examined period is higher in JSW than in LW Bogdanka, which is mostly caused by the lower results of risk assessment in JSW in the area of resource potential and higher exposure of this company to market, price and currency risk, as well as by the larger geographical dispersion of recipients; in both examined companies, operational risk clearly increased in the year 2013 in connection with the inflow of cheaper power and coking coal from import; risk assessments in the area of specific nature of company's operational activity in the examined entities are much more stable over time than risk assessments in the area of resource potential.

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