Contents

Economic aspects of the mining industry in the Slovak Republic

Pavol Budaj[1], ***Jana Klencová***[1], ***Alena Daňková***[1] and ***Jana Piteková***[1]

This paper analyses the economic aspects of the mining industry in the Slovak Republic. This study aims to point out the changes in the sectoral structure with a focus on the mining industry and its role in the economy of Slovak Republic. The analysed period is based on the time series provided by the current statistics for the years 2004-2016 using the revised ESA 2010, which represents the most recent internationally comparable accounting framework of the EU. The paper presents two selected analytical approaches to the evaluation of the mining industry in the V4 countries. The shares of individual sectors on the Slovak economy are surveyed on GDP and employment within the analysed period. At the same time, structural changes in the Slovak economy are analysed using selected indicators – the Krugman index of specialisation and Balassa concentration index. These indices are examined on the gross value added basis at constant prices for specific sectors in V4 countries. The result of this study is the quantification of the interrelations between selected indicators characterising the mining industry and the identification of the economic position of the mining industry in the Slovak Republic. The benefit of the study also consists in the quantification of inter-sectoral relations in the Slovak economy.

Key words: *mining industry, structural changes, gross value added, Krugman index of specialisation, Balassa concentration index*

Introduction

Every economy, including the Slovak Republic, is constantly changing its internal structure, i.e. in its internal configuration. After 1989, the Slovak Republic has undergone political, economic and social changes that have had a significant impact on its economy, as outlined in the National Strategic Reference Framework (NSRF) 2007-2013. The peak of these changes was the integration of the Slovak Republic into the EU on May 1st, 2004.

The process of economic transformation is defined in the economic encyclopedia as the process of transforming central planned economy into market economy. Economic transformation is a complex long-term process that brings a temporary decline of the economic activity along with the various adverse social consequences (Michnik, 1995). Under the transformation of the centrally planned economy to market economy, we understand a complex change of an initial socio-economic system. Therefore, transformation cannot be considered as a one-time or short-term act (Vincúr, 2007; Gavurova, 2016). According to Okáli (1999), the transformation is based on a change in organizational form of national economy in order to improve its production and allocation efficiency. The transformation process is considered to be completed if there is a functioning market in the country that coordinates economic activities, all reforms are completed, and the country achieves sustainable economic growth (Morvay, 2005). The conclusion of transformation can also be seen as a condition where the problems and challenges with which emerging economies are confronted are similar to those that emerge in other countries at a comparable level of development (Gelb, 1999).

The goal of ongoing changes should have a more efficient economy. An example of such change is a transformation process from centrally planned economy to market economy. By the transformation in this study, we understand the process of change from a centrally planned economy into the economy with an active market mechanism.

A transformation process can be done in two ways. The first way is so-called shock therapy, in which all the reform steps are carried out at one particular time. This method was chosen at the initial stage of the transformation of the conditions of the Slovak Republic. The second method is gradualism, which is based on gradual steps and changes in the transforming economy. As Roland (2002) states in his article, partial reform, usually in the framework of a gradualist strategy, has some clear disadvantages. It yields lower efficiency gains than a complete reform. There may be losses of complementarities between reforms. It does not resolve all uncertainty about future outcomes and thus yields less learning about the future. If partial reform is less expensive to reverse than full reform, political acceptability can be easier than for full reform because it provides an option for early reversal (Dewatripont and Roland, 1995).

An integral part of the transformation process is structural transformation, which is at the same time one of its key assumptions. It is the process that is demanding both in terms of the range of resources used and the time of its implementation.

The process of transformation of economies and defining the understanding of its underlying context is dealt with by several authors, which results in a large number of definitions of this category (Tošović, 2016).

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Dirgová (2014) focuses on the phenomenon of social transformation that is reflected in all areas of society. The transformation process of the social sphere has a permanent character which is unlimited in time, and it is, therefore, necessary to address current and prospective social processes and phenomena.

It should be noted that there is no generalisation of the view on the transformation process from the centrally planned economy to the market economy. Differences in understanding arise from different starting conditions and an existing potential of transforming countries. In our paper, we are focusing on the structural transformation in the conditions of the Slovak Republic, with the special focus on the changes in its sectoral structure in 2004-2016.

A large number of domestic and foreign debates are constantly being held on the subject of the transformation of economies (Dirner, 2016). One of these discussion forums was held on 25-26 June 2013 at the School of Slavonic and East European Studies, University College London on the topic *„Transition economics meets new structural economics“*. In the Journal of Economic Policy Reform, three major themes of this discussion forum are described. First, what is the relationship between transition economics (TE) a and New Structural Economics (NSE)? Second, if NSE is about the promotion of structural change, what then are the specific features of structural changes in the „transition region“, especially in the view of the strong influences of the EU on the growth of this region? Third, EU´s smart specialisation activities represent extremely important examples of new industrial policy: how does this relate to NSE? (Berglof et al., 2015).

J. A. Schumpeter belongs to the most well-known authors in the field of the structural change in the economy. He had developed the first structural theory with an emphasis on the innovations in technology that have an impact on changes in economic growth and structure of an economy. One of the leading forces influencing the structural change was an entrepreneurial innovation activity. The process of ever-changing structural changes was defined as a process of the creative destruction (Schumpeter, 2011).

Various indicators were developed for the measurements and assessments of structural changes in different sectors of an economy. In our paper, we are focusing on two selected indicators: Krugman index of specialisation (K-index), according to which we measure a structure of the country's economy in relation to the structure of EU countries. A researched country must be part of the group above (Krugman, 1991). The second indicator is a Balassa concentration index which indicates the concentration of the industry in relation to the average of the EU countries (Balassa, 1965). In addition to the indices mentioned, there is as well Lilien indicator which examines changes in sectors in terms of employment (Lilien, 1982) and the economic structural changes intensity index (Landesmann, 1999, 2003). Indexes recording changes in the structure of the economy were also applied in the studies of these authors: Wolf used these indices in Polish economy (Wolf, 2004), Midelfart-Knarvik were working with the Krugman index (Midelfart-Knarvik, 2000) and Brainard and Cutler applied the Lilien Index (Brainard, Cutler, 1993).

The presented paper aims to identify the economic aspects of the mining industry in the Slovak Republic. The paper follows on previous published papers on similar topic (Kršák et al., 2015) (Blišťan et al., 2015). We have chosen relevant macroeconomic indicators on the basis of the annual national accounts, through which we can better understand the importance of the examined sector. At the same time, the paper aims to quantify the interrelations between selected indicators characterising mining industry and identification of the economic position of the mining industry in the Slovak Republic.

The position of the mining industry in the Slovak economy

With respect to the aim of the presented paper, it is necessary to define the position of the mining industry in the sector classification in the conditions of the Slovak Republic. According to the classification of SK NACE Rev. 2, the official term for the mining industry is „Mining and quarrying“ (which is classified in section B). Mining and quarrying involve mining minerals naturally occurring as solid (coal and ores), liquid (petroleum) or gaseous (natural gas). Mining can be realised by various methods such as underground or surface mining, oil drilling, seabed drilling, etc. This section includes the additional services in order to prepare raw materials for the market. Within the above section, we work with so-called divisions 05, 06 where the mining and extraction of fossil fuels (coal, lignite, oil and gas) are included, and the divisions 07 and 08, which include mining and extraction of ores, various minerals and stones.

Despite the historical tradition of the mining industry, the Slovak Republic is no longer one of the countries with the developed mining industry. Countries in which the share of mining and processing of raw materials in the gross domestic product (GDP) is more than 25 % are classified as countries with the developed mining industry (by UNCTAD methodology).

The mining and quarrying in the Slovak Republic provide the important inputs, especially for the manufacturing industry and energetics. However, in the country the reserves of mineral and energy raw materials are limited. The possibilities of their utilisation are set in the document *Surovinová politika Slovenskej republiky pre oblasť nerastných surovín*. This document defines the objectives of the usage of the domestic mineral resources in connection with the long-term needs of economic and social development of the society with regard to the environmental aspects of the sustainable development (MH SR, 2004). As stated in this policy, while in the fuel-energy and ore raw materials, the Slovak Republic is permanently dependent on their imports. However, the mining of certain types of raw materials for industry and construction has positive economic importance. The mining of brown coal and lignite covers about 80 % of the domestic consumption.

As part of the Slovak Republic's energy policy, the domestic resources of brown coal and lignite are considered as a strategic raw material base, reducing the dependence on the imports of the primary fuel-energy raw materials. Domestic resources are also considered as the reserves for unforeseen situations and as the source of job opportunities. Due to the verified geological reserves of the oil and gas, it is not possible to expect the significant increase in domestic mining volumes in the future, and it will be necessary to continue to import these commodities. Slovakia is the second largest natural gas transit country in Europe after Ukraine. In the future, the main focus will be on the improving the gas storage services in the context of the liberalisation of the gas market.

A primary task remains to reduce the energy intensity to the level of the European Union countries. Taking into account the high level of the mining costs and processing costs of the domestic ore raw materials, their extraction is uneconomic (Malindžáková, 2014). The necessary ore commodities are imported. On the other hand, reserved mineral deposits are the most important group of minerals in the Slovak Republic. In 2015, geological reserves on reserved deposits reached 16 605 million tons, which mainly consist of non-ore commodities (12 586 million tons). During the year 2015, there was the slight increase in the mining of construction and non-ore raw materials. In long-term view (2000 - 2015), there was the significant decline in the ore raw materials mining (by 95.3 %) and the decrease in the extraction of energy raw materials by 50.5 %. The growth was recorded in non-ore mining (by 9 %) and construction raw materials (by 49 %). In 2015, the share of the mining of the energy raw materials in inventories amounted to 0.16 %, in the crude raw materials 0.01 %, in non-ore raw materials 0.09 % and 0.62 % in the construction materials (MŽP SR, 2016).

In the paper Malindžák et al. (2015), there is described the model for “In-process inventories calculation“ in the metallurgy production conditions. The model was designed considering the factors affecting the in-process inventories levels. The in-process inventories levels have to respect different efficiency of the aggregates in sequence, idle times, technological safety and the production continuity. For the calculation of the in-production inventories levels, a dynamic model was designed.

The most important non-ore raw materials in terms of export are magnesite, dolomite, rock salt, bentonite, limestone and barite. The magnesite industry with proven geological reserves of magnesite and built mining and processing capacities is one of the most important producers of basic refractory materials in the world (MH SR, 2004). Authors Ambriško et al. (2015) are dealing with the proposal to rationalise the transportation of the magnesite in the mining company.

According to the National Strategy for Sustainable Development of the Slovak Republic, the state of the environment and the use of raw materials resources in the Slovak Republic is unsustainable in a long-term view. The current state of the Slovak Republic's raw material base is characterised by the almost complete depletion of the ore raw materials, large supplies, but the different level of utilisation of non-ore and construction raw materials, as well as the overall state control reductions in the mining industry. The landscape and the environment impacts are extensive with respect to the mining of mineral raw materials. The mining represents one of the most serious environmental problems of the Slovak Republic (Uznesenie vlády SR, 2001). Straka, Bindzár and Kaduková (2014) use the multi-criteria decision-making methods for the needs of the mining industry, with emphasis on the decision-making process in the area of selecting the suitable waste dump location.

Material and methods

The classification of the sectors was based on the SK NACE Rev. 2, which represents the classification used in the conditions of the Slovak Republic, formerly referred to as OKEČ (Sectoral Classification of Economic Activities). According to this classification, we have aggregated the sectors into five groups, namely: sector A - Agriculture, forestry and fishing; the second group is industry: B - Mining and quarrying, C - Manufacturing, D - Electricity, gas, steam and cold air condition supply and E - Water supply sewerage, waste management and remediation activities; the third group is included separately in group C - Manufacturing; the fourth group includes the sector F - Construction and the fifth group includes the service sector: G - Wholesale and retail trade; repair of motor vehicles and motorcycles, H - Transport and storage, I - Accommodation and food services activities, J - Information and communication, K - Financial and insurance activities, L - Real estate activities, M - Professional, scientific and technical activities, N - Administrative and support services activities, O - Public administration and defense, compulsory social security, P - Education, Q - Human health and social work activities, R - Arts, entertainment and recreation, S - Other service activities, T - Activities of households as employers; undifferentiated goods - and services - producing activities of households for own use and U - Activities of extraterritorial organisations and bodies.

The database consists of the data from the Statistical Office of the Slovak Republic (SLOVSTAT database), which is based on the National Accounts System ESA 2010, which represents the coherent system of information and therefore allows mutual interconnection and comparability of the surveyed indicators. The European System of National and Regional Accounts ESA 2010 implemented from 1st September 2014 is the latest internationally comparable EU Accounting Framework for a systematic and detailed description of the economy. The differences in National Accounts methodology ESA 2010 compared to the ESA 95 are aimed towards capturing changes in economic reality in the conditions of increasing globalisation (ŠÚ SR, 2015). The most significant changes in this methodology were described by Eurostat in *Manual on the Changes between ESA 95 and ESA 2010* (EUROPEAN COMMISSION, 2013). Through ESA 2010 Slovak statistics work with more detailed data.

When analysing the selected structural change indicators (Krugman index of specialisation and Balassa concentration index) in the V4 and EU28 countries on an annual basis, we also worked with the data from the EUROSTAT for the examined groups. Specifically, the data on the gross value added at constant prices in the sectors breakdown.

We have obtained information from document *Bilancie zásob výhradných ložísk Slovenskej republiky (BZVL SR)*, which is produced annually by the Ministry of the Environment of the Slovak Republic and on the basis of information provided by the Main Mining Office.

By the analysis of the structural changes in the industry, we used selected structural indicators. The first was the Krugman index of specialisation, which illustrates the structure of the economy in the surveyed country in the relation to the structure in the EU28.

The Krugman index of specialisation is defined as the sum of all sectors in the absolute value of the difference between:

(B)

a) the share of sector *j* in country *i* on total gross value added at period *t*($Q_{ij,t}$)

b) and share of the same sector *j* on total gross value added (at constant prices) of all other EU countries at period *t* ($\overline{Q}_{ij,t}$) (Midelfart and Knarvik, 2000).

$$K_{i,t} = \sum_j \left| Q_{ij,t} - \overline{Q}_{ij,t} \right| \qquad (1)$$

The K-index value ranges between 0 and 2. The index value increases with the increasing degree of specialisation in the country. If the value equals zero, the country has the sectoral structure identical to the rest of the EU, so it is not specialised. When the maximum value is reached, i.e. 2 in the sectoral structure, the major specialisation prevails. If we divide the K-index by two and multiply by 100, we get the difference (deviation) between a) and b) in percentage. The analysis of sectoral differences between a) and b) shows how the particular components of the Krugman index of specialisation allow the better understanding of the role of the individual sectors in the countries.

The concentration index (Balassa index) expresses the sectoral specialisation of the economy from the other side. Specialization is the driving force of the sectoral concentration. This index reflects the share of a sector in the country concerned in EU28 production, in relation to the share of its whole economy in EU28 output.

Concentration index is defined as follows:

$$I_i^k(t) = \frac{Q_i^j(t)}{Q_{EU}^j(t)} \bigg/ \frac{Q_i^{\cdot}(t)}{Q_{EU}^{\cdot}(t)} \qquad (2)$$

where:

$Q_i^j(t)$ is gross value added at constant prices in country *i* in sector *j*,

$Q_{EU}^j(t)$ is gross value added at constant prices in all EU countries in sector *j*,

$Q_i^{\cdot}(t)$ is gross value added at constant prices in country *i*,

$Q_{EU}^{\cdot}(t)$ is gross value added at constant prices in all EU countries.

Index values above 1 indicate a high level of concentration of the industry, around value 1 the concentration of the industry is the same as the EU28 average, and values below 1 reflect the lower concentration in the sector than the average of the countries compared (Čutková, Donoval, 2004).

Results

The following part of the paper focuses on the analysis of the share of the individual groups of sectors in the generated GDP at current prices and total employment in the period 2004 - 2016. For the analysis purposes, we used the classification of the sectors into five main groups: Agriculture, forestry, fishing – sector A, Industry in total – sectors B, C, D, E, Manufacturing – sector C, Construction – sector F, and Services (sectors : G, H, I, J, K, L, M, N, O, P, Q, R, S, T, U). Sector B - Mining and quarrying due to reporting by the Statistical Office of the Slovak Republic is the part of the aggregate Industry in total.

Tab. 1. Development of the structure of created GDP and employment between 2004 and 2016 [%]

Sectors (SK NACE Rev. 2)	**2004**	**2006**	**2008**	**2010**	**2012**	**2014**	**2016**	**Average**
The share of sectors to GDP at current prices (%)								
Agriculture, forestry, fishing	3.6	3.2	3.7	2.6	3.2	4.0	3.4	**3.3**
Industry in total	26.9	28.0	25.8	23.9	24.1	24.3	24.6	**25.0**
Manufacturing	21.1	21.2	20.2	18.9	19.0	19.8	20.5	**19.7**
Construction	5.5	6.9	8.6	8.1	8.2	7.0	6.8	**7.3**
Services	53.5	52.1	52.6	56.3	55.8	55.3	55.3	**54.7**
Net taxes on products	10.5	9.8	9.3	9.1	8.7	9.4	9.9	**9.7**
The share of sectors in total employment [%]								
Agriculture, forestry, fishing	4.7	4.0	3.6	3.4	3.2	3.3	3.1	**3.6**
Industry in total	27.0	26.5	26.3	23.6	23.8	23.7	24.0	**24.9**
Manufacturing	24.1	23.7	23.9	21.3	21.6	21.6	22.0	**22.5**
Construction	6.8	7.5	8.1	8.5	7.8	7.4	7.3	**7.6**
Services	61.5	62.0	62.0	64.6	65.3	65.6	65.6	**63.9**

Source: own processing

Table 1 and the Figure 1 show that GDP growth in the Agriculture, Forestry, Fishing, Industry in Total and Manufacturing remained fairly stable over the period. The most significant changes are visible in the Construction and Services sectors.

In GDP structure, the highest share in the long-term consists of Services, as shown in figure 1. Services reached an average of almost 55 % of GDP of all sectors between 2004 and 2016. The second best-progressing sector was Industry in total, with a share ranging from 22 % in 2009 to 28 % in 2006. Agriculture, Forestry, Fishing and Construction achieved lowest shares of GDP. The share of the Construction sector in GDP has increased by 3.3 pp to 8.8 % (2009) from baseline (2004).

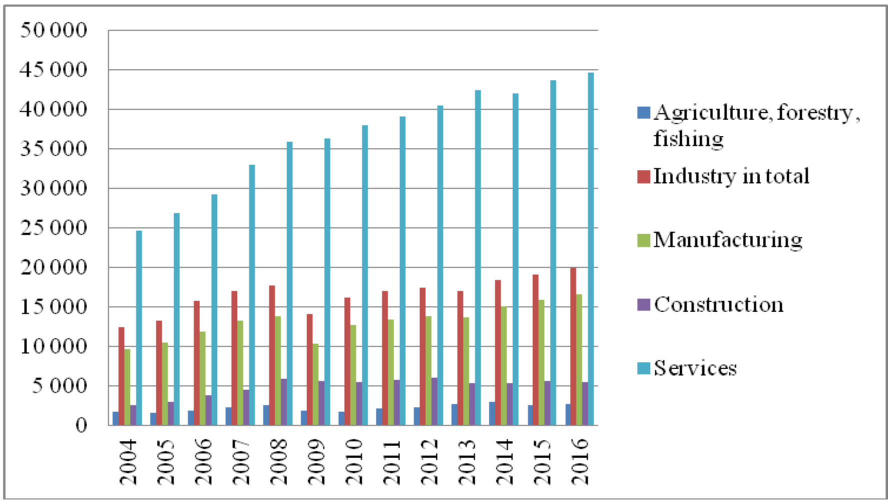

Fig. 1. GDP by sectors (SK NACE Rev. 2) (in mill. EUR, at current prices).

The industrial production in February 2017 increased by 2.6 % compared with February 2016. The development by SK NACE Rev. 2 influenced growth in mining and quarrying by 7.4%, electricity, gas, steam and air conditioning supply by 5 % and industrial production by 2.2 % (ŠÚ SR, 2017).

Recently there has been the gradual decline in the mining activity due to the increased prices of inputs to the mining activities and the recent consequences of the economic crisis in the Slovak Republic and the world.

The labour market situation in the Slovak Republic has undergone various structural and institutional changes. The data in Table 1 show similar employment developments, as in the case of GDP. Since 2000 (125 877) in the Agriculture, Forestry and Fishing sector, the value of the indicator has decreased significantly to 2016 (72 362). Total employment in this sector reached 96 476 (4.7 %) in 2004. There has been a decline in the number of the workforce moving to the Services sector, which has increased from 61.5 % in 2004 to 65.6 % in 2016. The different trend was typical for the Industry in total, except a few years when there was a slight increase. The decline in Industry in total was 3 percentage points higher in 2016 than the base year – 2004. Average values per Industry in total were 24.9 %, for the Services, with an average of 63.9 %. On the other hand, the Services recorded the steady increase in the employment over the monitored period.

Krugman index of specialization, Balassa concentration index

On the basis of the data on gross value added at constant prices for individual sectors of the economy obtained from the EUROSTAT database, we firstly compared (through the Krugman index) the degree of the sectoral specialisation of the Slovak Republic with other V4 countries in relation to EU28 countries. The data for 2016 were not available at the time of paper processing, and data for 2015 were incomplete, so we mostly worked with the data from 2004 to 2014.

Then, we pointed out the difference, or the similarity or even the consistency in the concentrations of the sectors in the monitored countries through the Balassa index.

Through the Krugman index, the European Central Bank carried out in 2004 calculations for the EU15 countries. The results of this analysis have shown that smaller countries are more specialised than larger countries, except Germany and Spain, which have emerged relatively more specialised as other countries of comparable size (ECB, 2004).

Production specialisation involves the process of differentiation of production activities, whereby individual sectors, production departments, enterprises and workplaces producing similar production, respectively, are separated and with similar technological processes. In the production process, there is an important role of integration of customer's requirements into product quality attributes, which is the basic precondition for systematic quality management (Madzík, 2016; Hrnčiar, 2017). The cognition, application and management of knowledge in manufacturing as well as non - manufacturing sphere of the national economy of every country create a basic competitive advantage of both, an organisation and a country. It is only possible to talk about the knowledge-based economy if knowledge, abilities and experiences become the main factor of production (Čepelová and Bernatík, 2013).

The sectoral specialisation can, therefore, be seen as the certain degree of concentration of employment and the value added within the sectors of the economy compared to other economies. In the long-term run, it has a significant impact on the productivity growth. However, the sectoral specialisation may influence economic growth even in the short term, as sectoral developments may be different due to the conjunctural cycle of the economy, and also depend on the link between the sectors and the world trade. The different production and product characteristics of the sector (product life, stock size and importance, capital intensity of production) can provide different responses to the structural shocks in the economy. As a result, the different lengths and amplitudes of economic cycles in individual countries, as well as their synchronisation, which is finally different between countries (Čutková and Donoval, 2004).

Tab. 2. Krugman's index of specialization.

Country	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Slovak Republic	0.247	0.263	0.270	0.267	0.313	0.273	0.280	0.292	0.292	0.255	0.326
Czech Republic	0.150	0.187	0.222	0.221	0.243	0.248	0.245	0.258	0.254	0.236	0.250
Poland	0.245	0.261	0.274	0.276	0.283	0.324	0.335	0.346	0.357	0.353	0.345
Hungary	0.169	0.161	0.158	0.184	0.192	0.187	0.184	0.181	0.168	0.152	0.169

Source: own processing

In the terms of gross value added data at constant prices in the mining industry in the V4 countries and their share in the total gross value added of the EU28 countries result, that the highest share was in Poland, in 2004 it was up to 4.14 %. By contrast, the lowest share of gross value added in the mining industry had Hungary in 2004 at 0.14 %. The Slovak Republic recorded an average of 0.55 % for the whole monitored period, including 2015.

As shown in Table 2, the sectoral specialisation has increased over the period 2004 - 2014 in all countries surveyed. The highest rate of specialisation on the basis of gross value added at constant prices was reached in Poland (0.345) in 2014, followed by the Slovak Republic (0.326) and the Czech Republic (0.250). In 2012, the Krugman index for Poland reached the level of 0.357, which was the highest value in the period under the review. Based on this development, we can conclude that the lowest degree of specialisation was reached in Hungary.

Table 3 shows the achieved results in the Balassa concentration index for 2004 - 2015 for the Slovak Republic. Based on the results, it is possible to determine whether the concentration in the sector is higher, lower or possibly the same as the EU28 average.

Tab. 3. Balassa concentration index for the Slovak Republic.

Sectors	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
A	1.96	1.95	1.98	2.08	2.08	2.04	1.74	1.99	2.11	2.40	2.72	2.34
B	0.49	0.55	0.41	0.61	0.67	0.75	0.62	0.72	0.72	0.73	0.72	0.77
C	1.11	1.17	1.17	1.18	1.21	1.20	1.35	1.33	1.33	1.32	1.50	n.a.
D	3.13	2.37	3.48	3.49	3.01	2.17	2.07	2.32	2.04	1.86	2.07	1.77
E	1.35	1.36	1.30	1.22	1.06	1.04	1.01	0.94	1.02	1.12	0.95	0.95
F	1.17	1.22	1.35	1.36	1.58	1.63	1.53	1.63	1.77	1.58	1.55	1.54
G - I	1.22	1.26	1.14	1.11	1.17	1.16	1.13	1.10	1.09	1.04	1.06	n.a.
J	1.01	1.01	0.99	0.96	0.87	0.97	0.92	0.91	0.97	0.88	0.79	n.a.
K	0.84	0.90	0.81	0.71	0.64	0.70	0.72	0.75	0.74	0.76	0.84	0.93
L	0.82	0.69	0.64	0.71	0.69	0.65	0.63	0.65	0.65	0.81	0.58	0.57
M - N	0.53	0.54	0.63	0.65	0.67	0.74	0.73	0.70	0.71	0.73	0.73	n.a.
O - Q	0.81	0.80	0.78	0.75	0.72	0.76	0.76	0.72	0.69	0.71	0.66	n.a.
R - U	0.70	0.83	0.80	0.88	0.65	0.87	0.86	0.91	0.96	0.95	0.96	n.a.

Source: own processing

As can be seen from Table 3, the Slovak Republic achieved, during the analysed period of twelve years, higher values than 1 for Balassa concentration index in the following sectors: A (Agriculture, forestry and fishing), D (Electricity, gas, steam and air conditioning supply), E (Water supply; sewerage, waste management and remediation activities), F (Construction). The analysis shows that these sectors have a higher share of the gross value added than the average of EU28 countries.

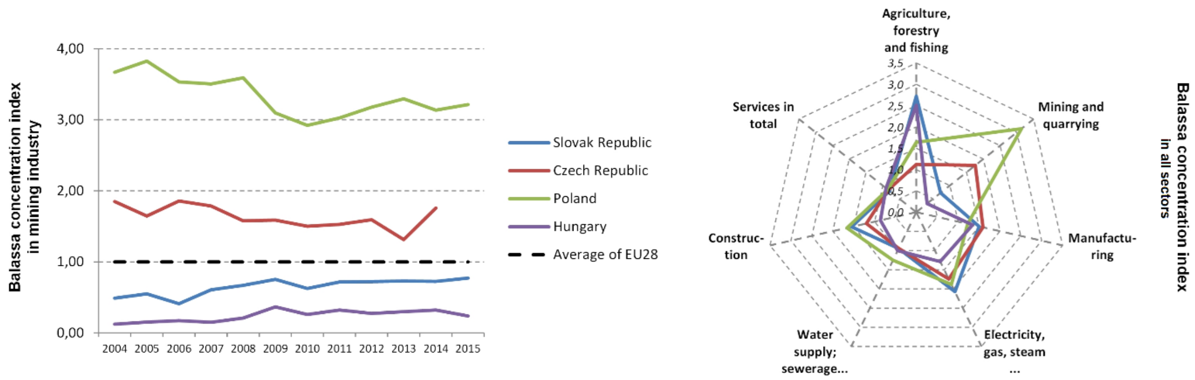

Fig. 2. Ballassa concentration index in V4 countries (left from 2004 to 2015; right in 2014).

In the base year of 2004 in the mining industry, the Balassa concentration index was from 1.85 (in the Czech Republic) to 3.67 (in Poland) times higher than the EU28 average. The highest concentration according to the above index was in Poland and the Czech Republic during the reporting period. At the end of the monitored period, this index in the Slovak Republic shows a concentration rate almost the same as the average of EU28 countries. The Balassa concentration index for Hungary shows that the concentration in the mining industry was the smallest in this country.

Conclusion

The submitted paper aimed to point out to the changes in the sectoral structure with a focus on the mining industry and its role in the economy of the Slovak Republic. Economic aspects of the mining industry were examined on the basis of selected indicators. As first we defined an economic position of the mining industry in the conditions of the Slovak Republic. Through the data on created GDP and employment between 2004 and 2016, we examined changes in the sectoral structure of the Slovak economy where the mining industry was analyzed within aggregate sector Industry in total. Subsequently, using the Krugman index of specialisation, we quantified the degree of sectoral specialisation within the V4 countries, which allowed us to make the comparison. The further result of this study is the quantification of the sectoral concentration with an emphasis on the mining industry using Balassa concentration index. These indicators are structural indicators, which are used by many foreign authors in their works. The benefits may also be considered by the study of cross-sectoral relationships across sectors.

This paper processed the data from the database of the Slovak Statistical Office (SLOVSTAT), as well as the Krugman index of specialisation and the Balassa concentration index from the European Statistical Office (EUROSTAT). It should be noted that the results achieved were largely influenced by the availability of data, in particular by the European Statistical Office, which did not provide data for 2016, and data for some sectors were not relevant for 2015 because they were incomplete. In the present study, two analytical approaches to the economic assessment of the mining industry within the V4 countries were presented. However, there are other appropriate tools and approaches that would allow broader coverage of this interesting scientific area. These approaches include the Lilien index (which tracks sectoral changes from the employment point of view), structural change intensity index, and generic approaches to structural deviation analysis.

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Study on mechanical properties of alkali-activated material before and after mechanical activation

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Slag is one of the by-products of energy industry which is suitable for secondary industrial processing. Although slag has been successfully used in industrial production for several decades, its use does not achieve the level of its potential. Slag can be used as alkali-activated materials and utilised in the synthesis of geopolymers. Geopolymers are inorganic polymeric materials with three-dimensional SiOAl frameworks synthesised from aluminosilicates which dissolved in the alkaline medium. This work describes the improvement of mechanical properties of alkali-activated binders – geopolymers made of slag. The effect of mechanical activation on mechanical properties of geopolymers was examined. Mechanical activation was made with a ball mill and different time of milling. Synthesis of geopolymers was carried out in drier at 80°C. Samples were made before and after mechanical activation. The differences in strengths of samples were examined. Mechanical properties such as compressive and flexural strength that was measured were the most significant attributes. Samples were tested after 7, 28 and 90 days. Results show that the mechanical activation is an important factor in the synthesis of slag based geopolymers, which has better properties after mechanical activation.

Key words: *slag, mechanical properties, geopolymers, strength, water absorption, mechanical activation*

Introduction

Ground granulated blast-furnace slag (GGBFS) is a coproduct of the steel industry by adding limestone to ore to remove non-ferrous contaminants, and it consists of four major chemical components: CaO, SiO_2, Al_2O_3 and MgO (Snellings et al., 2012; Zawrah et al., 2016). As one of the main by-products during the process of iron and steel making, blast furnace slag is discharged in a super-high temperature of 1450–1650 °C. (Wang et al., 2015).These components are highly reactive with alkaline solutions to form alkali-activated GGBS (Arai et al., 2017). Blast furnace slag is a residual product obtaining pig iron. If cooled rapidly, it will have an amorphous structure, and when grinded, it will show excellent binding properties with the portland cement (Ustabaş, 2018).

Slag can be used as alkali-activated materials and utilised in the synthesis of geopolymers. The term geopolymer was first used by Joseph Davidovits. He defined the material that is formed in inorganic polycondensation called geopolymerization. In geopolymerization reaction, three-dimensional structures of AlO_4 and SiO_4 tetrahedra are created. Later the term geopolymer was used for all alkali activated aluminosilicate (Davidovits, 1991; Škvára, 2007).

Geopolymers now represent a new group of organic substances, because they have significant environmental and energy potential. They belong to a group of the inorganic polymer covalently bound macromolecules with the chain consisting of -Si-O-Al-O-. Geopolymers are obtained from the chemical reaction of alumino-silicate oxides with sodium silicate solutions in a highly alkaline environment. As an alkali activating solution, a strongly alkaline aqueous solution of sodium or potassium hydroxide is most commonly used (Škvára, 2007; Xu et al., 2000).

The reaction mechanism and strength development of the geopolymer are influenced by the type and concentration of the alkaline solution, curing temperature, curing conditions and specific surface area. The alkali activator is designed to activate multiple calcium aluminium silicate minerals and is the most important factor in the hydration of these aluminium silicate minerals. Currently, the commonly used alkali activators include sodium silicate, sodium carbonate and NaOH (Kürklü 2016, Wang et al. 2016).

Geopolymers find a broad range of applications in the field of transportation, emergency repairs, metallurgy, coating, membrane materials, and nuclear waste disposal. Geopolymers have become a potential alternative binder to ordinary Portland cement (OPC) in some applications due to its sustainability criteria of lower emission of greenhouse gases and low energy consumption (Liew et al., 2017). Although significant commercial and technological potential, geopolymers' easy-brittle character limits their extensive applications, where great efforts are made to overcome such shortcomings. Numerous studies are dedicated to optimise the strength of geopolymer products and to understand the mechanism of geopolymerization (van Deventer, 2007; Zhang, 2015; He, 2013; Zhang, 2014).

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In last years, different studies have investigated the possibility of using different types of wastes mixed with fly ash or slag as raw materials (Mádai, 2015; Musci, 2014). The selection of the materials to create geopolymers depends on influences such as availability, disposal urgency, the difficulty for recycling and final applications (Toniolo, 2017). Research has shown that it is possible to develop geopolymer concretes based solely on waste materials activated directly, without the presence of Portland cement, utilising an alkaline activator. A major benefit of geopolymer concrete is that the reduction of CO_2 emission by 26–45 % with the replacement of PC with no adverse economic effects (Wardnoho et al., 2017; Karthnik et al., 2017).

The primary aim of this paper is to demonstrate that mechanical activation of GGBFS improves mechanical properties of all geopolymers made in our research.

Materials and Methods

The material used for alkali activation was blast furnace slag (BFS) and same material after mechanical activation in a ball mill (GGBFS). Milling was performed in laboratory ball mill with steel balls with different diameters. The laboratory mill used for mechanical activation had volume 30 dm^3 and was filled with steel ball with diameters ranging from 2 to 10 cm. Material for mechanical activation with steel balls formed 40 % of mill volume. Revolution was adjusted to 90 per minute. Mechanical activation was performed in two stages. The first stage was after 20 minutes and the second stage after 60 minutes. After grinding stage, d80 was 90 µm. Particle size distribution is shown in figure 1. The material was homogenised before alkali activation. No other treatment was applied to the material.

The chemical composition of BFS is shown in Table 1. The activation solution was prepared by mixing solid NaOH pellets with Na-water glass and water. Sodium water glass from the Kittfort Praha Co. with the density of 1.328- 1.378 g/cm^3 was used. It contains 36 - 38 % Na_2SiO_3 and the molar ratio of SiO_2/Na_2O is 3.2 - 3.5. Solid NaOH with the density of 2.13 g/cm^3 was obtained from Kittfort Praha Co. containing at least 97 % - 99, 5 % of NaOH.

The effect of three main parameters was examined: the amount of Na_2O from slag weight, SiO_2/Na_2O ratio in the activation solution on strengths of geopolymers and the amount of water content. Five different mixtures were designed in which amount of Na_2O was varying from 5 to 9, where SiO_2/Na_2O ratio and water content was constant. Another five mixtures where the SiO_2/Na_2O ratio was adjusted from 1.1 to 1.3 and other two parameters where constant. Last experiments setting was following: water to slag ratio was varying from 23 to 31 % and other two parameters where constant. The water to fly ash ratio was adjusted to 0.25.

BFS and GGBFS mixtures were stirred with activation solution for 10 minutes until the creation of homogenous mixture. The mixture was then filled into prismatic moulds with the dimensions 40x40x160 mm and compacted on the vibration table VSB-40 for 10 minutes at the frequency 50 Hz. The pastes were cured in a hot air drying chamber at 80 °C for 6 hours. After that, the samples were removed from the forms, marked, and stored in laboratory conditions until the moment of the strength test. The values of compressive strength were determined after 7, 28, and 90 days according to the Slovak Standard STN EN 12390-3. The compressive strength of the hardened samples was determined after 7, 28, and 90 days using the hydraulic machine Form+Test MEGA 100-200-10D.

Results

Chemical analysis of BFS is given in Table 1. Grain size distribution of BFS and after mechanical activation of slag material, before alkali-activation is given in Figure 1. Note the shift of distribution towards lower sizes, within the same range. The 80 % particle size of raw slag was 1,8 mm. During the mechanical activation, the particle size was significantly decreased, after 60 minutes of the milling process 80 % of the slag was finer than 90 µm.

Tab. 1. Chemical composition

Material	**SiO_2**	**CaO**	**MgO**	**Al_2O_3**	**Fe_2O_3**	**Other**
BFS [%]	40.3	37.01	12.1	8.51	0.3	1.78

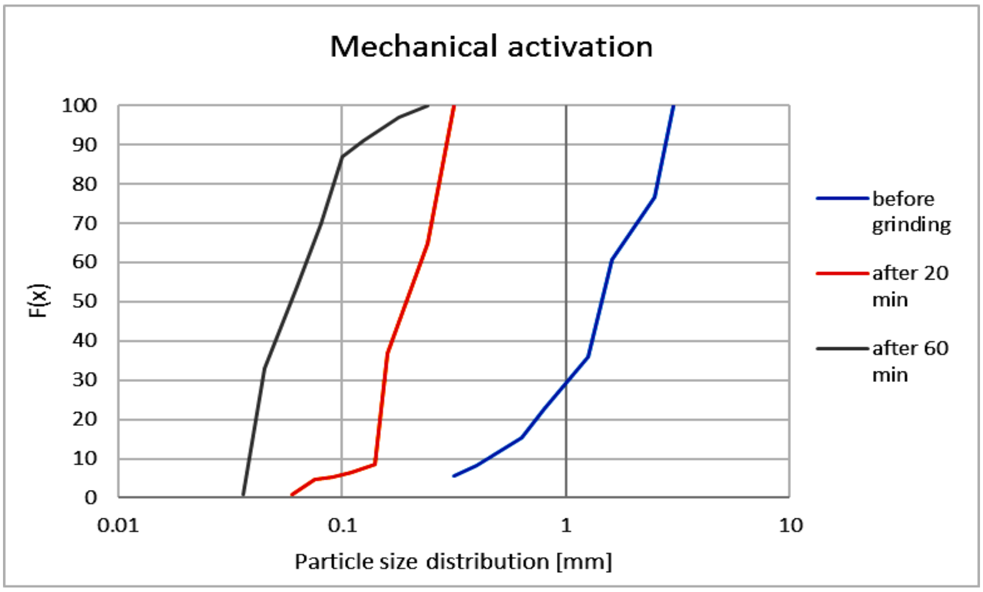


Fig. 1. Particle size distribution before grinding and after 60 minutes of grinding.

Surface morphology of GGBFS was measured by scanning electron microscopy MIRA 3 FE-SEM microscope (TESCAN, Czech Republic) equipped with a high-resolution cathode (Schottky field emitter) and with three-lens Wide Field Optics^{TM} design. Typical SEM micrographs of GGBFS after grinding are given in Figure 2. As shown, slag after mechanical activation in ball mill has plate-like and needle-like structures. SEM images have been taken at different magnification. The SEM images of GGBFS display rough and angular shape.

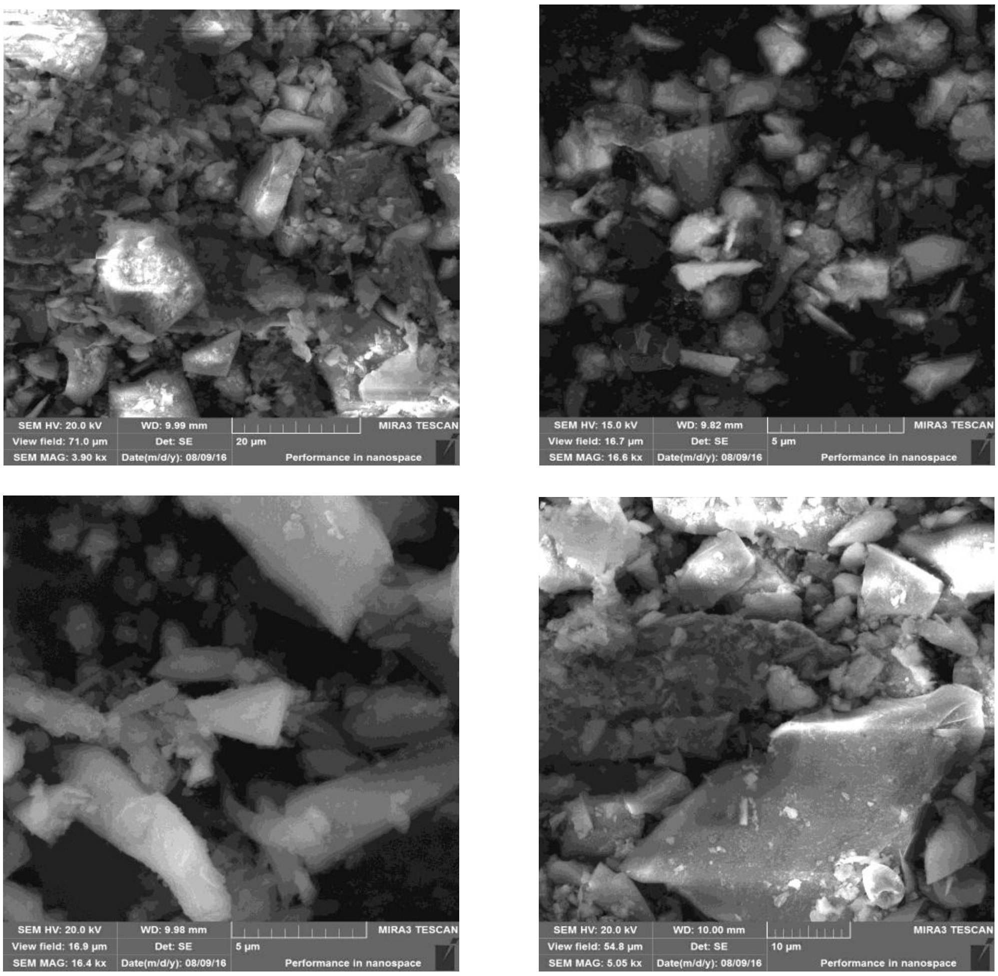


Fig. 2. SEM pictures of GGBFS.

In this study, mechanical activation and 3 parameters of alkali-activated materials were tested how they affect the strengths of hardened geopolymers. From the design of experiments, 28 samples were tested after 7, 28 and 90 days. Compressive and flexural strengths tests were made. These results are presented in this section.

Amount of Na_2O:

For the first series of alkali activation, samples were made by changing amount of Na2O in the mixture from 5-9, and the SiO_2/Na_2O ratio (1.2) with water to slag ration were constant (25). The focus was not only on mechanical activation but also on this parameter. Results are shown in Figures 3 and 4.

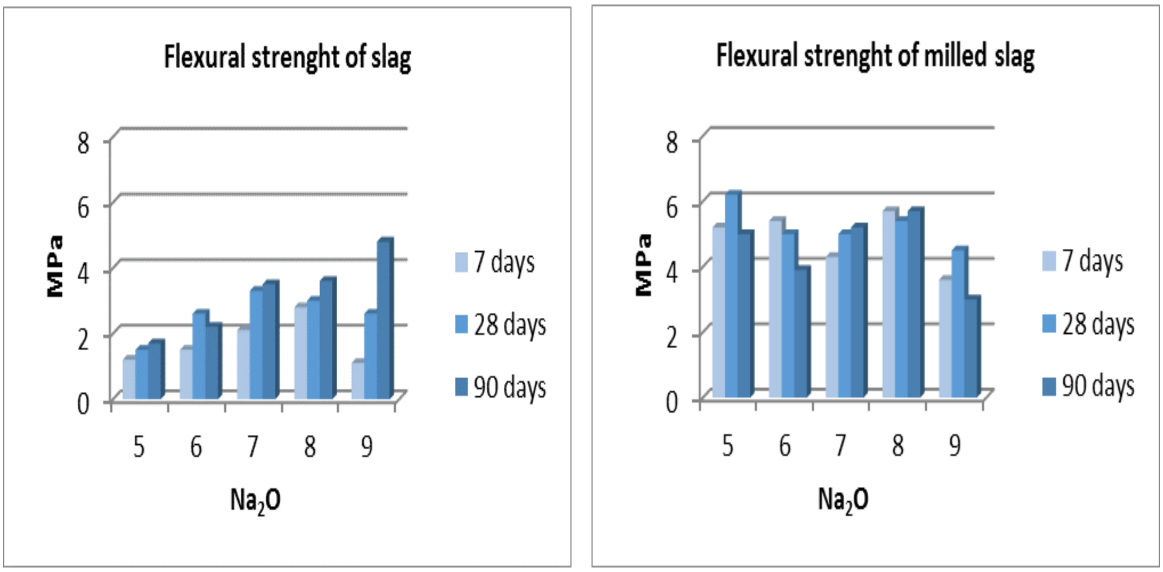


Fig. 3. Flexural strengths of BFS and GGBFS.

From the diagrams, we can see that mechanical activation helped geopolymers achieve bigger strengths, but the amount of Na_2O was lower. In BFS geopolymers it was opposite, the biggest strengths were when the amount of Na_2O was increased. The highest flexural strength with BFS was 4,8 MPa after 90 days of ageing the material made with 9 % amount of Na_2O. GGBFS achieved the highest flexural strength on 28th day 6,2 MPa.

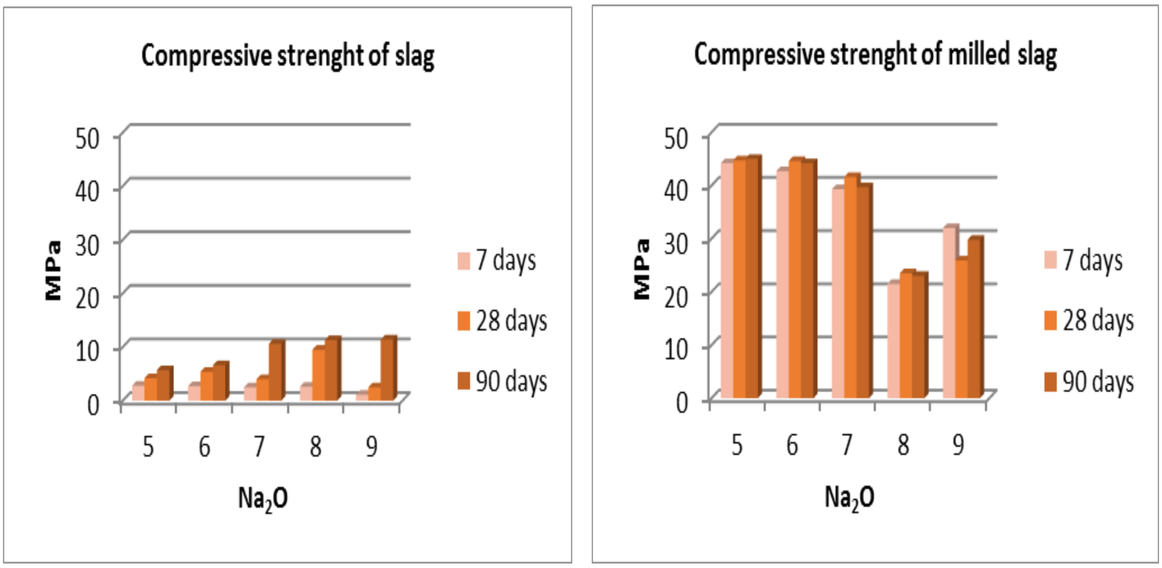


Fig. 4. Compressive strengths of BFS and GGBFS.

Compressive strengths results show that mechanical activation is essential to achieve higher strengths. In BFS samples strength grows over the time to achieve their maximum on 90th day and growth was obvious. After grinding strengths were much higher, but it not always grows in time. The biggest strength was in the sample made by 5 % of Na_2O in mixture 45 MPa. The samples made before mechanical activation with 9 % Na_2O has the highest strength 11,2 MPa.

Sio_2/Na_2O Ratio:

For the second series of alkali activation, samples were made by changing amount of SiO_2/Na_2O ratio in the mixture from 1.1 to 1.3, and Na_2O content (8) with water to slag ratio were constant (25). The focus was not only on mechanical activation but also on this parameter. Results are shown in Figures 5 and 6.

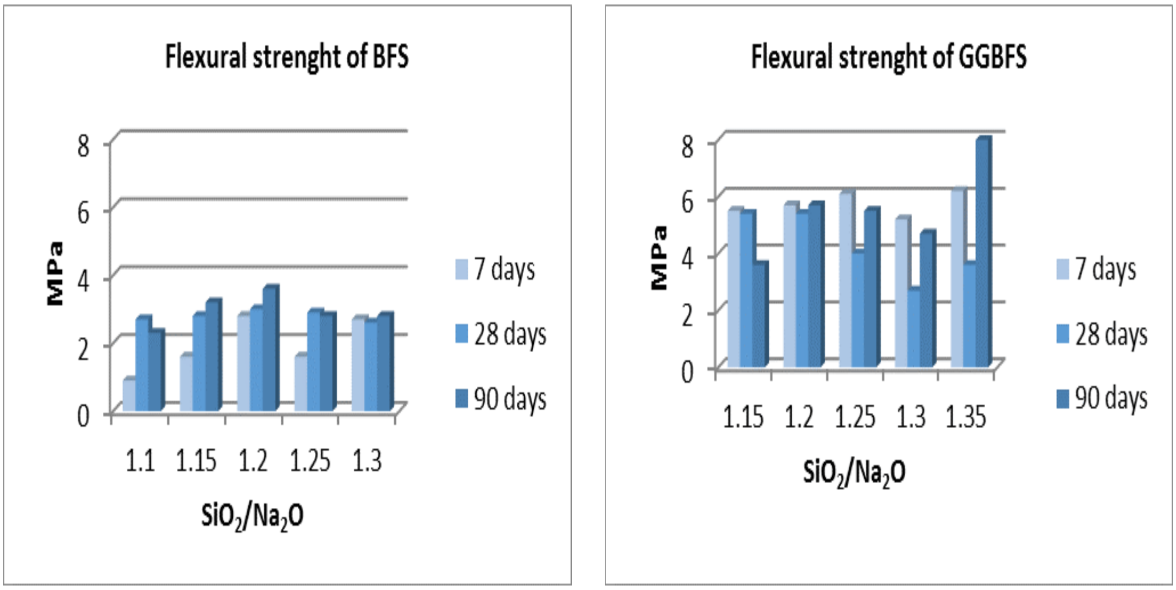


Fig. 5. Flexural strengths of BFS and GGBFS.

In this case, results show that SiO_2/Na_2O ratio has a negligible or minor effect on flexural strengths in BFS, and it is about same, but after grinding, the strengths are higher. The highest flexural strength was with 1.35 SiO_2/Na_2O ratio 8 MPa. Before MA the highest flexural strength was 3,6 MPa where the amount of SiO_2/Na_2O ratio was adjusted to 1,2. After grinding, the phenomenon of decreasing strengths over time occurred, but the strength increased significantly on the 90^{th}-day.

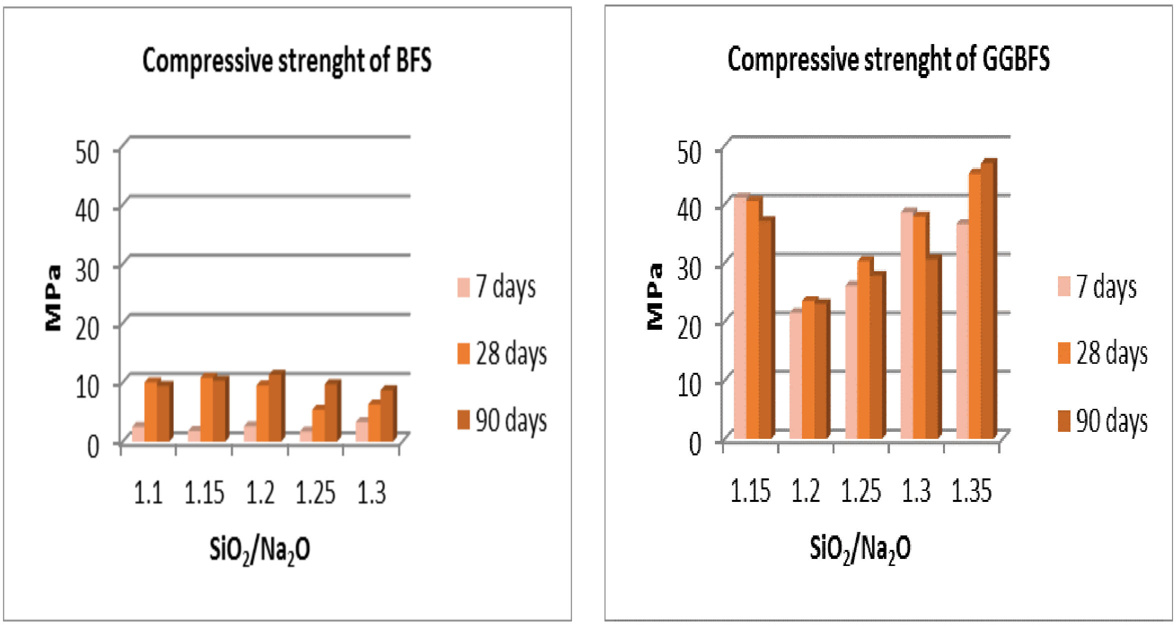


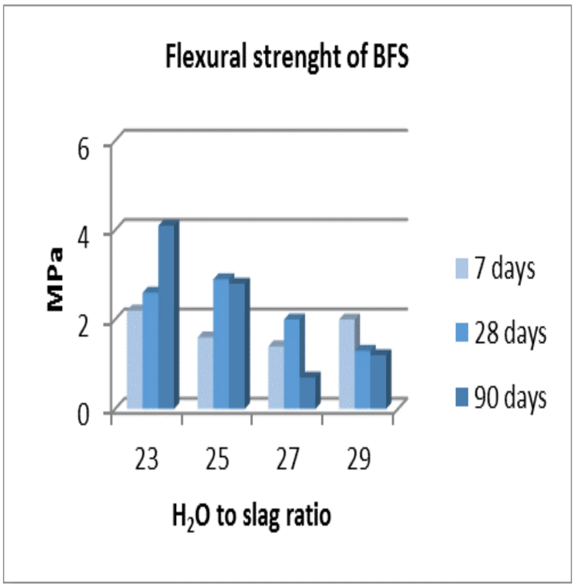
Fig. 6. Compressive strengths of BFS and GGBFS

Similar results were obtained after compressive strengths testing. The SiO_2/Na_2O ratio in BFS did not show any differences in different amounts, but strengths were increased over the time. The highest compressive was

11,3 MPa with 1,2 SiO_2/Na_2O ratio for BFS testing. Results after grinding shows the phenomenon as it was with flexural strengths. The highest strengths were not always on the 90th day but were much higher than before grinding. The samples with 1,35 SiO_2/Na_2O ratio after the 90th day achieved the highest strength from all samples during this set of testing 47 MPa.

Water to slag ratio:

For the last series of alkali activation, samples were made by changing water to slag ratio from 23 % to 31 %. The SiO_2/Na_2O ratio in the mixture (1.2) and Na_2O content (8) were constant. The focus was not only on mechanical activation but also on this parameter. Results are shown in Figures 7 and 8.



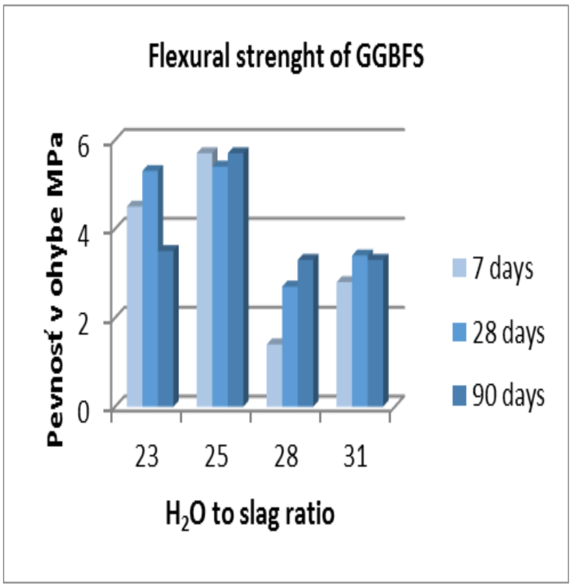
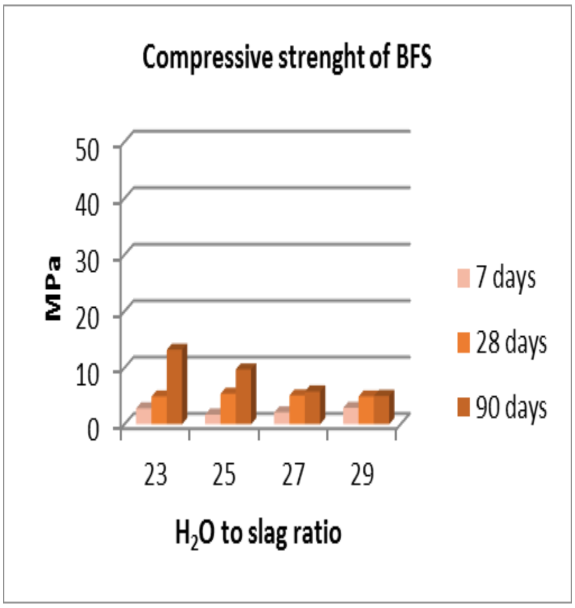


Fig. 7. Flexural strengths of BFS and GGBFS

As expected, the water content in mixture shows that when less water is in alkali activation, the higher strengths are obtained with our material. Also as from previous diagrams, we can see that grinding is an important factor because it improves strength also in this case. The best result for BFS was with 23 % water content 4,1 MPa flexural strength. For GGBFS it was with water content 25 % and on all days of testing flexural strength was similar 5,5 MPa.



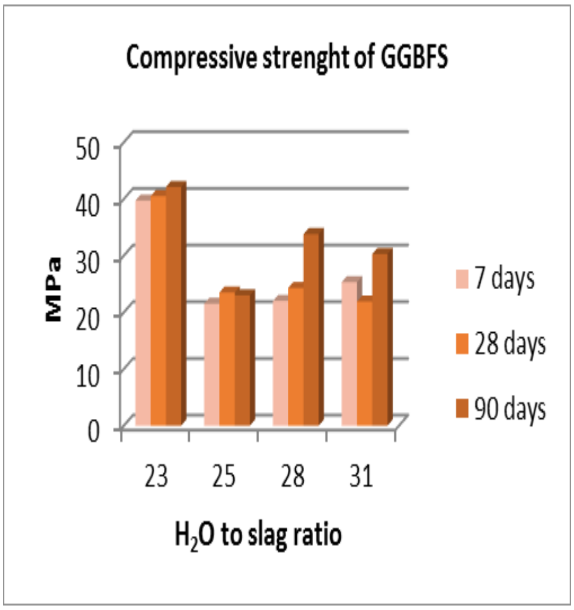


Fig. 8. Compressive strengths of BFS and GGBFS

Compressive strengths results show that when less water is in the mixture, the higher the strength will be. Almost all samples showed the biggest strengths at the 90th day. As in previous results, mechanical activation significantly improved mechanical strengths. The material before mechanical activation with lowest water content 23 % has the highest compressive strength 13,2 MPa. Compressive strength tests after mechanical activation show the highest strength with samples made by 23 water content 41 MPa.

Conclusion

Mechanical activation of the BFS by a laboratory mill leads to a reduction in particle size and an increase in the specific surface area. The mineral compositions of the BFS were not changed, but the crystal structure was effectively destroyed, resulting in a lower degree of crystallinity and less polymerisation of SiO_4. The amount of reactive silica and aluminium in the slag is improved by the combined effect of the decrease in particle size and damage to the microstructure; this promotes the geopolymerization process because the reactivity of the slag is enhanced.

The superior performances of geopolymers based on the properties of activated blast furnace slag, such as a high compressive strength and high flexural strength are attributed to the optimized distribution of particle size and increase in the amount of reactive constituents after mechanical activation, which result in an ordered and a compact intrinsic structure, as well as a deeper reaction. The improvements in the performance of the geopolymers depend on the increase in the reactivity of the blast furnace slag.

Alkali-activated materials – geopolymers, are a new generation of inorganic binders. Any aluminosilicate materials can be used to prepare geopolymers, including slag. Two series of geopolymers derived from a BFS were prepared. The geopolymers in this study have been prepared by the alkali activation solution consisting of NaOH, water glass and water to activate BFS. Mechanical activation is an essential approach to improve mechanical strength. In all tests and all different parameters change, one conclusion is obvious, that grinding significantly improve strengths, compressive and also flexural.

This study suggests that it is feasible to prepare high-quality geopolymers from blast furnace slag after mechanical activation.

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Quality and Effectiveness Evaluation of the Geological Services Using CEDAC Method

Andrea Sütőová[1], ***Kristína Zgodavová***[2] *and* ***Markéta Lajczyková***[3]

The paper deals with the development of the case-specific model for evaluation of quality and effectiveness of service provision and its systematic improvement. The modified version of the CEDAC (Cause-and-Effect Diagram with the Addition of Cards) method was applied for this purpose in the organization providing services in the field of environmental geology, and the EGEOS-PSI (Environmental Geology Service – Project Success Improvement) model was developed, which uses indicators of quality and effectiveness of the environmental geology services provision. The research was based on the case studies analysis of the existing projects in the organisation where preconditions of the effects (causes) on the project results were studied. Brainstorming was used to identify all the possible criteria (causes) affecting quality and effectiveness of the provided services and define the related KPSI (Key Project Success Indicators) for all the criteria while their importance was taken into account. The application of the proposed model enables to identify weaknesses in the processes of geological service provision and define effective improvements on the base of the results of quality and effectiveness evaluation. The proposed model can be applied in organisations providing services in the field of geology or other project organisation in order to improve their processes and project results while characteristics of individual services need to be taken into account in defining criteria and indicators of quality and effectiveness.

Key words: *Quality, Effectivity, Evaluation, Geological service, Key Project Success Indicator, Brainstorming, CEDAC, Improvement*

Introduction

The management of the prosperous organisations is aware of the fact that quality and efficiency are considered as a critical success factor. Quality and effectiveness evaluation of service provision process is essential for its management in the context of the PDCA (Plan, Do, Check and Act) cycle. Environmental geology services do not belong to traditional services. Project in the field of environmental geology is characterised by complexity as there are multiple simultaneously running processes (Cehlár et al., 2011). In order to improve quality and efficiency of the geological services, there is a need to implement suitable methods and tools and understand the key drivers affecting processes and results of environmental geologic projects.

According to (ISO, 2015) service is an output of an organisation with at least one activity necessarily performed between organisation and customer. There are many classifications of the services in the literature. Taken into account the nature of environmental geological services, we present the service classification according to (Lovelock & Wright, 1998), who classified services based on both the nature of the services act – tangible, intangible and who or what is the direct recipient of the service process – people, possession. Thus environmental geology service activities can be classified as follows:

- Tangible actions of service – remediation of soil or groundwater contaminated especially in the industrial estates (for example, hydrogeology and geochemistry).
- Intangible actions of service – laboratory analysis of water and soil, assessment of geological burden, processing geological project and reports, etc.
- Intangible actions of service, where recipients are people – consulting in the field of geology, engineering, etc.

Quality is defined as the degree to which a set of inherent characteristics of objects fulfil requirements (ISO, 2015). It means that quality level is a relative indicator reflecting the degree of the customer`s requirements fulfilment. Quality is related to effectiveness (Kang & James, 2006).

There is a popular quote from Peter Drucker in the management science: "Efficiency is doing things right; effectiveness is doing the right things" (BrainyQuotes, 2001). The term efficiency in context with the organisation has already appeared in Taylor`s publication "Conversations and Gospel of Efficiency" described in (Hays, 1959). Taylor tried to solve "nonefficiency" of day-to-day organisation activities. Defining the terms "effectiveness" and "efficiency" is difficult because there are many opinions, approaches and specific areas of

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use (Zajarskas & Ruževičius, 2010; CPE, 2017). We can talk about effectiveness in the fields of economy, social science, organisation theory, and also about efficiency in these fields, while in some cases and sources these terms are replaced.

Evaluation of effectiveness is a part of the organisation's optimisation methods, such as process audits or performance indicator system such as "Balanced Scorecard" (BSC).

In order to avoid discussion about the correctness of the used term "effectiveness" in our paper, the meaning of both words are explained in context with quality management system according to ISO 9001:2015 and project management according to ISO 10006:2017:

- Efficiency is a relationship between the result achieved and the resources used.
- Effectiveness is an extent to which planned activities are realised, and planned results are achieved.

Resulting from the definition mentioned above, we can use the term "effectiveness" in context with the monitoring of Key Performance Indicators KPI, respectively Key Project Success Indicators (KPSI).

The process of effectiveness evaluation includes knowledge of current state and knowledge of standard as well as comparing and formulation of the results. Thus the evaluation of any entity is a comparison of what exists with what should be – with some opinion on the quality optimum, for example, based on Kano model (Turisová, 2015; Mandzik, 2016). Evaluation of service quality and effectiveness is crucial for targeted improvement (Nenadál, 2001).

According to (Zeithaml et al., 1990) service quality is a difference between customer expectation of service and perception of service. To evaluate service quality, it is essential to define the characteristics affecting customer perception. The processes and activities are those, which affect the qualitative level of provided service and therefore main characteristics of processes need to be defined. This fact is reflected in the GAP Model of Service Quality introduced by (Parasuraman et al., 1985), which includes five possible GAPs within the processes of service provision. This model is the basis of the SERVQUAL method for quality service evaluation, which defines five dimensions and twenty-two characteristics of service quality (Parasuraman et al., 1988). Hower the SERVQUAL is not considered as a universal method for service quality evaluation. There are many modified version of these model in the literature. In some cases, only a partial adjustment of the quality characteristics is required, but other service sectors may need a complete change of dimensions and quality characteristics (Buttle, 1996). For our study, the SERVQUAL does not offer relevant dimensions and characteristics for the service quality evaluation.

Services in the field of environmental geology have specific characteristics. Processes of environmental geology service provision are complex and have an impact on the society. According to (Lajczykova & Zgodavova, 2013) defining project success is often associated with "deliver outcomes on time and planned budget". However, are those the success factors that are most important in the case of environmental geology projects from the perspective of all stakeholders? For identification of project success indicators from the perspectives of quality and efficiency and their systematic evaluation and improvement, the less known CEDAC (Cause-and-Effect Diagram with the Addition of Cards) method was modified, and the EGEOS-PSI (Environmental Geology Service – Project Success Improvement) method was developed.

Cause-and-Effect Diagram with the Addition of Cards

The CEDAC is a unique and straightforward approach for creative, participative problem-solving technique and it is also a tool for continual systematic improvement. The CEDAC method was first developed and used in Japan by the Standardisation Study Group of Sumitomo Electric Industries, and it was introduced and applied in many Japanese, North American and European companies, e. g. Weyerhaeuser, Pratt & Whitney, Allied Signal, Timken, Newell Rubbermaid, GM of Canada and many other production companies worldwide (GPT, 1996). The "father" of the method is Ryuji Fukuda who was honoured with the prestigious Deming Prize for his contribution to the field of productivity and quality improvement. He published the CEDAC in his book entitled CEDAC: A Tool for Systematic Continuous Improvement.

For improving quality and effectiveness of the services, it is essential to target the right problems, get the right people involved in solving them and make sure that the solution work, what is enabled by the CEDAC application in every organisation. The CEDAC encompasses three tools for continuous, systematic improvement: window analysis (for problems identification), CEDAC diagram (a modification of the classic fishbone diagram for analysing standard problems and developing standards), window development (for ensuring adherence to standards) (Fukuda, 1989).

Window analysis (1st stage of the CEDAC) is used for the study of specific data on different nonconforming results and categorisation of the data according to their management. Data are categorised according to the characteristics "Known", "Unknown", "Practiced" and "Unpracticed" into categories A-D, which are represented in Table 1 (Lajczyková, 2010). According to (Fukuda, 1989) favourable environment occurs when two conditions are met: (1) Proper practices (standards) have to be established, respected and practised, (2) All stakeholders have to understand these procedures and manage them in practice accurately.

Tab. 1. KPIs used in the organisation before the EGEOS-PSI implementation.

Category	Description of the event	Nature of the situation
A	Established – Known – Practiced	Ideal situation
B	Established – Known – Unpracticed	Problem with practice
C	Established – Unknown – Unpracticed	Problem with communication
D	Not established – Unknown – Unpracticed	Problem with standardisation

CEDAC diagram (2nd stage of the CEDAC) analysis the problem from two perspectives: from the view of the causes of the problem (Fishbone diagram is used) and subsequently from the viewpoint of improvement (improvement cards are used). Thus two sets of cards are added by the employees to the fishbone. One set of cards are known as fact (causes) cards, and another set is known as solution cards (Mahadevan, 2009). The side effect of a CEDAC diagram is a quantified description of the problem, with agreed and visual quantified target and continually updated results on the progress of achieving it. The solution cards are placed on the right of the fact cards. Those cards ensure that the facts are collected and organised before solutions are devised. The solutions are then selected and evaluated, and test results are recorded on the effect side. Each potential solution uses “a dots” system to discern various solutions: a) single dot (•) – the idea is of interest; b) two dots (••) – the idea is under the preparation; three dots (•••) – the idea is under the test. The successful improvement ideas are incorporated into the new standardised project procedures (Lisiecka & Burka, 2016).

Window development (3rd stage of the CEDAC) examines the actions of a CEDAC diagram and focuses on compliance with standards. In other words, this tool is designed to ensure, that every employee correctly understands and respects standard. Window development uses numerical method for effectiveness evaluation of the standard (Moore, 2007)**.**

On the base of the literature analysis, it is possible to conclude that CEDAC was used in many fields of the production to solve various problems (for example, the effect of inputs variability on the output, problem analysis and standard development). It is assumed that its application within the research in the field of environmental geology will be suitable and will help to extend its use in the non-production sector.

Methodology

Research methodology is based on the case studies analysis of the existing projects in the organisation providing services in the field of environmental geology, which served for the preparing of the model for further research. Case studies relate to the contracts of the Environmental and Geology Division (EGD). During 2012 – 2013, the major projects aimed at solving past environmental burdens were monitored. In 2013, further research developed the algorithm for the situations awareness and improvement of projects success (S) and thus for improving the Quality (Q), Effectiveness (E), Efficiency (I) and Traceability (T) (Zgodavová et al., 2001). This step was based on the review of project documentation and subsequent processing of the case studies. Direct application of the model and ongoing projects evaluation using EGEOS-PSI model took place during 2013 – 2017.

The proposed EGEOS-PSI model was developed on the basis of the CEDAC method for evaluation of quality and effectivity of the service provision and its improvement. Correct setting of indicators are crucial for the evaluation of the service provision process and targeted improvement. The aim was to monitor indicators, which affect rentability, customer perception and intensification of the remediation process and find other possibilities for improvement. In the case organisation, application of the CEDAC method enabled to define the Key Project Success Indicators from the perspective of quality and effectiveness which are most important for the stakeholders of environmental geology projects. In the case of projects, it is more suitable to replace the term Key Performance Indicators (KPIs) with the term Key Project Success Indicators (KPSIs) according to ISO 9004:2009 as a common term for criteria used to measure the results (financial and non-financial) of a project (Parker, 2013; ISO, 2009).

The CEDAC method application consists of three stages. For the research two stages of the CEDAC was applied for creation of the EGEOS-PSI in following steps:

- Forming of the project team involving the customer on the base of the principles of CDPM (Customer-Driven Project Management) and delegation of the project team leader. The aim is to include the employees in all steps of the CEDAC application.
- Defining the primary attributes of improvement. The attributes of improvement were the quality and effectiveness of the service provider. The project gives the duration of service provision and schedule of its realisation.

- Reviewing the case studies (selected projects of the organisation) and familiarisation with the processes realised within the case studies to understand main criteria affecting the project success.
- Leading of the brainstorming session to identify the effects on project success by the reviewed case studies and clustering the effects into individual categories. Definition of the related KPSIs in each category and weight estimation of the KPSIs taken into account the voice of the customer.
- Target value setting of the defined KPSIs and determination of the measurement method (frequency, responsibility, etc.) for estimation of the real value of the KPSIs.
- Proposal for the improvements by the project team and their categorisation according to their feasibility (using "dots" system).
- Implementation of the improvements and create new standards.

For the determination of overall effectiveness E_{SUM} of the service provision the equation Eq. (1) was used, where Ei is the value of the i^{th} KPSI, wi is the weight of the i^{th} KPSI and n is a number of KPSIs.

$$E_{SUM} = \sum_{i=1}^{n}(Ei.wi) \quad (1)$$

where

$$E_i = \frac{R_i}{P_i} \quad (2)$$

for indicators, where increasing of R-value (↑) increases the effectiveness

$$E_i = \frac{P_i}{R_i} \quad (3)$$

for indicators, where decreasing of R-value (↓) increases the effectiveness

R – real value
P – planned value

Case study: Application of the proposed EGEOS-PSI model

The mission of the organisation providing services in the field of environmental geology is rational exploitation of the geological structure. Accompanying negative function (and simultaneously project risks) can cause geological hazards e.g. unexpected subsidence, faults and destructive landslides, as well as a burden on the environment (contamination of water, soil, air or degradation of their ecological stability, etc.), utilisation of especially non-renewable or heavily renewable resources, etc. (Lajczyková & Zgodavová, 2013). The main processes of geological service provision can be simply described in the following sequential order:

- Design of geological services (technical consulting, e.g. designing projects using environmental technologies and pollution control, geological surveys, hydrological mapping, etc.).
- Realisation of geological services, including activities such as exploration drilling, geological surveys, engineering services and supporting activities e.g. remediation, technical testing and analysis, and of course the processing results (evaluating geological projects and processing final reports, processing and evaluating data from laboratory analysis, calculating, results evaluating, assembling diagnosis and other evaluating geological structures).
- Providing the results of geological surveys.

Primary activities in the EGD (Environment and Geology Division) of the case organisation are: geological surveys, design works, consulting works, environmental remediation works, laboratory works. Projects in the field of environmental geology are complex consisting of many processes. Control of these processes takes place according to the general principles of project management. Case study represents the organisation project in the field of environmental burdens removal. Process description of project realisation is defined in EGD working procedure. The working procedure is a controlled document of the second level within the established and certified Integrated Management System (IMS). IMS includes the Quality Management System in accordance with ISO 9001:2015, Environmental Management System by ISO 14001:2015 and Health and Safety Management System by OHSAS 18001:2007 in the monitored case organisation. The EGD working procedure refers to the controlled documentation of the second level (the corporate directions, etc.) and IMS manual (the first level in the structure of controlled documented information in the analysed company). The purpose of the working procedure is to determine principles, procedures and responsibilities for the service realisation in the EGD. The working procedure objectives are:

- to create the conditions for compliance with requirements specified in the contracts;
- to satisfy the needs and expectations of customers and stakeholders;
- to comply with legal and other requirements;
- to minimise environmental aspects and safety hazards.

Evaluation of quality and effectiveness of the geological services before the implementation of the EGEOS-PSI was realised according to the procedure of the EGD, which focused mostly on the evaluation of customer satisfaction after the completion of the project and criteria resulting from the contract. The KPIs (Key Performance Indicators) monitored by EGD before the EGEOS-PSI implementation are listed in Table 2.

Tab. 2. KPIs used in the organisation before the EGEOS-PSI implementation (Zgodavová & Lajczyková, 2013).

Quality			**Effectiveness**
Findings from control days during the project implementation	The level of customer satisfaction after the completion of the contract	The level of criteria in the contract (geological structures contamination, etc.)	The level of economic effectiveness

The brainstorming enabled to define criteria and KPSIs for the evaluation of quality and effectiveness of the service provision. Criteria were classified into following categories: 5M (Manpower, Machines, Materials, Methods, and Measurement), Environment, and Effectiveness. According to measurement units the defined KPSIs are classified into the following categories: Finance, Time, and Quality. The degree of KPSIs effect on project result is different, and the brainstorming also enabled to determine the weight of the individual KPSIs. The following KPSIs were defined in the research according to Table 3.

Tab. 3. KPSIs using in the organisation after the EGEOS-PSI implementation.

Effectiveness	related to material, products; labour and service costs ↓
	(1) Material costs; (2) Energy costs; (3) Product costs (Cost of equipment procurement, Other costs related to product; (4) Cost of transport; (5) Costs of cooperation; (6) Service costs (Costs of repairing, Costs of revision and preventive maintenance, Cost of equipment calibration, Cost of services in the field of control and examination); (7) Costs of nonconforming deliveries and services; (8) Costs of reworks; (9) Costs of delays (Cost of delays caused by supplier, Costs of delays caused by the customer, Cost of service delivery delays); (10) Labor costs (Costs per employee, Employee training costs).
	related to time fulfilment ↓
	(11) Fulfilment of work schedule, (12) Fulfilment of project schedule; (13) Delays caused by the customer; (14) Delay caused by the supplier.
	related to quality ↓↑
	(15) Number of official complaints; (16) Number of comments of external supervision; (17) Number of complaints related to nonconformity during the service provision; (18) Changes in documentation after customer requirement review; (19) Changes in documented information by customer requirement during the service provision; (20) Customer satisfaction; (21) Stakeholder satisfaction.

Figure 1 shows as an example of the selected KPSI number (5) "Cost of cooperation" with the planned and real values in 2016 and 2017 and the improvement solution, which was under the testing according to the "dots" marking system. Months from January to December represent milestones of the project and efficiency is shown as a percentage. The CEDAC diagram enables to present the deviation from the target values. After the implementation of an improvement, it is easy to monitor its effect.

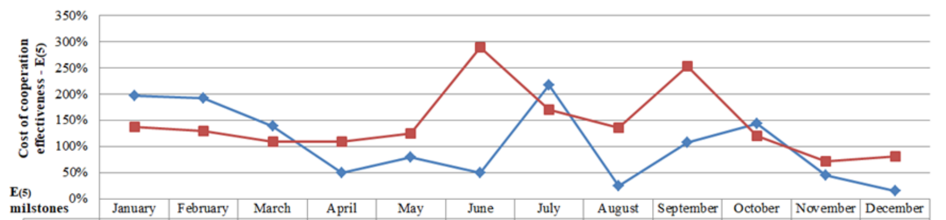
In the case of this indicator, there is an improvement of effectiveness level. In 2016, the effectiveness was only 67 %, and in 2017 it increased to the level of 114 %. The improvement solution was implemented as a standard.

Milestones	P [EUR]	R [EUR]	P [EUR]	R [EUR]
January	800	405	600	438
February	1000	520	800	617
March	1500	1081	1200	1096
April	750	1496	1500	1380
May	550	694	1000	805
June	700	1415	1200	415
July	800	367	800	470
August	300	1200	800	587
September	700	646	800	315
October	700	489	1000	835
November	800	1800	1500	2110
December	300	2000	2000	2479
Cost/year	8100	12113	13200	11547
E_5(sum)	67%		114%	

Cost of cooperation

• • •

Customer involvement is needed. Clear defining what will be ensured by the customer within the cooperation on his property where the services are provided while the next stage of the work schedule according to project documentation is discussed.



	January	February	March	April	May	June	July	August	September	October	November	December
2016	198%	192%	139%	50%	79%	49%	218%	25%	108%	143%	44%	15%
2017	137%	130%	109%	109%	124%	289%	170%	136%	254%	120%	71%	81%

Fig. 1. Detail of project monitoring by CEDAC diagram for the "Costs of cooperation.".

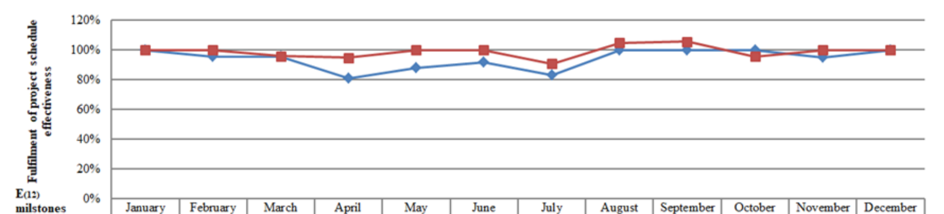
Time delays cause financial losses. Therefore, it is essential to reduce delays as much as possible. Figure 2 shows as an example of the selected KPSI number (12) "Fulfilment of project schedule ", with the planned and real values in 2016 and 2017 and the improvement solution, which was under the testing according to the "dots" marking system. In 2016, there were 36 days of delay mostly caused by the suppliers which had a negative impact on the final service delivery on time. The implementation of the improvement enabled to decrease this delay significantly. Finally, the improvement solution was implemented as a standard.

Milestones	P [days]	R [days]	P [days]	R [days]
January	19	19	21	21
February	21	22	20	21
March	21	22	23	23
April	21	26	18	19
May	22	25	21	21
June	22	24	22	23
July	20	24	20	21
August	22	22	22	23
September	20	20	19	18
October	21	21	22	24
November	20	21	20	20
December	21	21	19	19
Days/year	231	267	247	253
E_{12}(sum)	87%		98%	

Fulfilment of project schedule

• • •

Systematic human resource management, team building and, where necessary expanding the team.



	January	February	March	April	May	June	July	August	September	October	November	December
2016	100%	95%	95%	81%	88%	92%	83%	100%	100%	100%	95%	100%
2017	100%	100%	96%	95%	100%	100%	91%	105%	106%	96%	100%	100%

Fig. 2. Detail of project monitoring by CEDAC diagram for the "Fulfilment of the project schedule."

The inspection plan was created for easy recording of data for each milestone, including KPSIs divided into three groups according to Table 3. Table 4 shows the example of the overall inspection plan.

Tab. 4. Example of an overall inspection plan for the year 2016.

KPSI identification card		**Results card**		**Improvement card**		**Dots marking system**
Effectiveness	w_i	**Plan 2016**	**Real 2016**	**P/R % R/P %**	**Notes**	
related to material, products; labour and service costs	0.50					
(1), (2), (3), (4)	…					
(5) Costs of cooperation	0.05	8,100 [EUR]	12,113 [EUR]	67 %	Customer involvement is needed. Clear defining what will be ensured by the customer within the cooperation on his property where the services are provided while the next stage of the work schedule according to project documentation is discussed.	● ● ●
(6), (7), (8), (9), (10)	…					
related to time fulfilment	0.20					
(11)	…					
(12) Fulfilment of the project schedule	0.04	231 days	261 days	87 %	Systematic human resource management, team building and, where necessary expanding the team.	● ● ●
(13), (14)	…					
Related to quality	0.30					
(15), (16), (17. (18), 19), (20), (21)						

Overall effectiveness of the managing this project on the base of partial values of effectiveness is shown in Table 5. In 2017, overall effectiveness in comparing with 2016 increased by 16 %.

Tab. 5. Overall assessment of inspection plan using CEDAC.

Year	**2016**	**2017**
	Overall effectiveness of project management E_{sum} [%] according to Eq. 1	
[%]	81	97

Results and Discussion

Despite highly developed integrated management systems in the organisation and achieving a high quality of the products and project results, the organisation must be prepared for the evolving competition in the area of interest and the tightening up criteria for evaluation of environmental burdens. The organisation, which has a lot of "tacit knowledge", have to know how to transform them into useful information. The organisation must improve the quality of the resulting solutions, innovate procedures and learn to continue activities improvement and successful achievement in competitive surroundings. Based on the details that we have monitored during 2016 – 2017 and continuously analysed using EGEOS-PSI model, we found a major strategic task to improve "performance" of the organisation´s management system:

- To implement the standard ISO 9004:2018 (after the revision 9004:2009).
- To apply the principles and practices of project´s quality management according to ISO 10006:2017.
- To manage risks using ISO 31000:2009 respectively revised ISO 31000:2018.
- To utilise Barkley´s & Saylor´s, 2001 methodology "Customer-Driven Project Management" extended by the tools and methods of quality management and quality engineering as CEDAC method.
- To apply monitoring by KPSIs and proceed with the EGEOS-PSI methodology.

The EGEOS-PSI methodology is based on the CEDAC method. Therefore it can be considered as a suitable method for evaluation of quality and effectiveness for an organisation operating in the field of geology. The KPSIs and their weights can vary depending on the nature of the provided service.

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Environmental and geological impact assessment within a project of the North-South Gas Interconnections in Central Eastern Europe

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Security, environmental, technical, and economic factors form a basis for selection of routes for new high-pressure gas pipelines. Environmental protection and protection of inhabitants shall be factored in when designing a new gas pipeline route. In the European Union, the final gas pipeline route is determined based on the environmental impact assessment process (EIA). In general, when designing a gas pipeline route, it is necessary to consider especially the following factors: minimization of the gas pipeline length, minimization of interventions into the protected areas of national and European networks (for example, NATURA 2000), avoiding of urban areas of villages and cities, areas featuring high levels of groundwater, rocky and land sliding areas, protected deposit areas, mining and survey areas, protection zones of water sources, flood areas, and areas with possible presence of historical ammunition discoveries. A proposed route leading across the areas exposed to the risk of landslides and across mining areas shall be resolved already in the Intention that represents the first step within the EIA process, and it shall also be discussed with mining authorities and operators of protected deposit areas, mining areas, and survey areas. The final version of the gas pipeline defined in the Final EIA Opinion shall be implemented into the zoning and development plans of higher territorial units, cities, and villages. The Final EIA Opinion is binding for further legal approval proceedings concerning the pipeline project.

Key words: *transmission pipeline, natural gas, EU regulations, PCI, EIA, SEA*

Introduction

The Poland-Slovakia interconnecting gas pipeline is a pilot project in Slovakia within which Regulation (EU) of the European Parliament and the Council no. 347/2013 on guidelines for trans-European energy infrastructure is applied. The Regulation (2013) sets out a framework for identification, planning, and implementation of projects of common interest (hereinafter referred to as “PCI”) necessary for implementation of 9 strategic priority corridors of energy infrastructure in the area of power, gas, and oil for the entire European Union (hereinafter referred to as the “EU”).

In Annex VII to Regulation (2013), the gas pipeline interconnection between Poland and Slovakia is included in Cluster 6.2 - Interconnection between Poland, Slovakia, Czech Republic and Hungary with the related internal reinforcements, including the PCI: 6.2.1 Poland – Slovakia interconnection.

In Central Europe, the natural gas transmission has been historically realised from the east to the west, (Škuta et al., 2017). Therefore, priorities of the EU include development of the North-South gas corridor that will enable transmission of natural gas from the Baltic Sea from the liquid natural gas terminal (hereinafter referred to as the “LNG Terminal”) at Świnoujście, Poland, to the countries of Central and Eastern Europe as well as from the Adriatic Sea where an LNG terminal is planned at the Island of Krk, Croatia. The Regulation (2013) establishes the common interest procedure for PCIs while imposing a special responsibility to only one national competent authority in each Member State of the EU for coordination of the process of granting permits for PCIs and supervision over the process (Article 8) of the Regulation (2013), determines the minimum transparency and public engagement standards and the maximum admissible period of time for the legal permit granting procedure, (Ministry of Economy of the SR, 2013).

Poland – Slovakia interconnecting gas pipeline will enhance the energy security in both countries and form a basis for the establishment of the North-South gas corridor that represents one of the priority corridors within the EU´s energy policy entitled “Priority Corridor North-South Interconnections of Gas Pipelines in Central-Eastern and South-Eastern Europe”. This corridor will allow bidirectional flows of natural gas among Poland, Czech Republic, Slovakia, and Hungary and interconnection with LNG terminals in Poland and Croatia, (Central European University Press, 2000).

The Poland – Slovakia interconnecting gas pipeline is included in the 3rd PCI List of 2017, which enables the project to benefit from the financial support of the Connecting Europe Facility (CEF) funding instrument. Poland – Slovakia interconnecting gas pipeline will contribute mainly to:

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- Natural gas resource diversification and reduction of the level of dependence on the supply of natural gas from the Russian Federation;
- Improvement of technical reliability of the natural gas supply to customers through diversification of natural gas import routes;
- Possibilities for construction and connection of new underground gas storages in the region and enhancement of natural gas availability within that region;
- Utilization of the available capacity of the Slovak transmission system (implementation of new transit corridors in Europe may cause a reduction in the use of the Slovak transmission system and lead to the creation of new redundant capacities);
- Support for the process of integration of gas markets within the EU territory through the creation of the EU common natural gas market;
- Development of opportunities for access to the natural gas from the LNG terminal at Świnoujście, Poland, in connection with other projects such as the Slovak – Hungarian interconnector and the planned gas pipeline project "Eastring" (Regulation EU, 2013).

In addition to the Final Opinion under the Act no. 24/2006 on environmental impacts assessment, the major supporting documents within designing of the route in the Slovak territory are Slovak technical standard STN EN 1594: Gas infrastructure – Gas pipelines with the maximum operating pressure over 16 bar: 2014 Operating Requirements, Technical rule for gas TPP 702 10: High-pressure gas pipelines and connections issued in 2017, and Act no. 251/2012 on the energy industry and amendments and supplements to certain other acts, (Act, 2006; Slovak technical standard, 2014; Slovak Chamber of Commerce and Industry, 2017; Act, 2012; Ministry of Environment of the SR, 2016).

In Poland, the environmental impact assessment process is set out in Act no. 199 of 3 October 2008 on environmental information provision, environmental protection, and participation of the public in environmental protection and environmental impact assessment. The main supporting document serving to design the route in Poland is Decree no. 1055 of the Ministry of Economy of 30th July 2001 on the technical requirements applicable to gas networks. Another important document is the technical standard concerning designing of high-pressure gas pipelines of the GAZ-SYSTEM S.A. company - ST-G-002: 2008 Gas pipelines crossing terrain barriers (Act, 2008; Regulation, 2001; Technical standard ST-G-002, 2008; Woloszyn, 2004).

Moreover, thanks to the classification of the projects aimed at natural gas supply security enhancement and development of the national natural gas market as national priorities, the Act no. 84 of 24th April 2009 on investments into the regasification terminal for liquified natural gas at Świnoujście, from now on referred to as the "Special Purpose Act", was adopted in Poland. The Special Purpose Act is to increase the energy security of Poland and support the EU´s objective to create a common natural gas market. The reasoning stated in the Special Purpose Act specifies the following key tasks for the natural gas sector:

- diversification of natural gas supply resources via:
    - construction of a terminal for receiving of liquified natural gas at the Polish shore,
    - a direct pipe interconnection to Scandinavian natural gas sources (Norway),

- enhancement and interconnection of the transmission system (with neighbouring countries),
- the increase of the capacity of operated underground natural gas storages, (Act, 2009; Végsöová et al., 2017).

Materials and methods

Methodology for assessment of a selection of international gas pipeline routes

The impact assessment is stipulated by Convention of the United Nations Economic Commission for Europe on Environmental Impact Assessment in a Transboundary Context adopted on 25th February 1992 in Espoo, Finland (from now on referred to as the "ESPOO Convention"). The ESPOO Convention determined that signatory countries shall implement procedures for assessment of impacts in a transboundary context into their legal regulations. This Convention represented one of the major reasons for commencement in 1991 of the work on preparation of the Act (Act, 2006; Karimi et al., 2014). The Convention became valid on 10th September 1997. The purpose of the Convention is to implement the environmental impact assessment principle into national legislation of individual countries and to enable other countries to step, in a precisely defined manner, in the preparation of activities carried out outside their territories, which may have an unwanted impact on their environment, (E/ECE/1250, 1991).

The mandatory assessment of transboundary impacts is focused on the activities proposed within the territory of the Slovak Republic and specified in Annex no. 13 and the proposed activities specified in Annex no. 8 of the Act (2006) that may have a serious environmental impact beyond the state borders of the Slovak Republic. The subject-matter of the environmental impact assessment in a transboundary context will include the country of origin, i.e. the country within the territory of which the relevant strategic document is drafted, and the relevant activity is planned (the Slovak Republic in our case) and the party concerned, i.e. the country that may be affected by a significantly adverse impact of the drafted document and planned activity (the Republic of Poland in our case). Where both countries propose a joint planned activity (an interconnecting gas pipeline in our case), the assessment of transboundary impacts is carried out usually once upon the request of the country that notifies its planned activity first (Zvijáková et al., 2014; Blišťan, Pačaiová, 2011).

The initial considerations about the construction of a transit gas pipeline between Poland and Slovakia date back to the year 2000 when a feasibility study was drawn up for the "Belarus – Poland – Slovakia Interconnecting Transit Gas Pipeline". The purpose of the study was to check the possibilities for the construction of a gas pipeline with a connection to the JAMAL gas system, measuring and delivering station, and a connection to the existing network of transit gas pipelines at the Veľké Kapušany Compressor Station (from now on referred to as "CS") (Raclavský, 2008). The study was drawn up with the participation of representatives of Russian GAZPROM, and it was primarily intended to check the possibility for and profitability of natural gas transmission via a transit gas pipeline connecting transit corridors - Belarus (Kobrin) – Poland – Slovakia (Veľké Kapušany, CS).

The study suggested two border crossing points for the transit gas pipeline and those two alternatives were discussed by both parties. Both suggestions were based on the configuration of the protected zone of the "Carpathians" mountain range within the Polish territory so that the route of the transit gas pipeline avoids the areas declared as protected. The first state border crossing alternative concerned the area around the village of Lupków in Poland, which overlaps with the cadastral area of the village of Palota in Slovakia. The second state border crossing alternative was determined in the north-west from the city of Bardejov, in the cadastral area of the village of Tylicz, Poland, and the cadastral area of the village of Kurov, Slovakia.

The connection to the existing transit network in Slovakia was recommended in the Veľké Kapušany CS or the Jabloňov nad Turňou CS. The state border crossing across the cadastral area of the village of Čertižné supported by representatives of Slovenský plynárenský priemysel (from now on referred to as "SPP") was rejected by Polish representatives. The connection of the new transit gas pipeline to the existing transit network within the territory of Slovakia at the Jablonov nad Turňou CS was rejected by SPP due to significant investments made by SPP into the Veľké Kapušany CS and the line section of the gas pipelines between the Veľké Kapušany CS and the Jablonov nad Turňou CS in the 90's (Feasibility study, 2000).

This project had not been implemented due to the disagreement on the Polish side. In 2011, the European Committee emphasised the need to modernise and extend the energy infrastructure in Europe and to interconnect networks across boundaries in order to enhance the solidarity among the Member States, to create opportunities for alternative supply or transit routes and energy sources, and to develop renewable energy sources in competition with traditional sources. It was agreed that after 2015 no Member State should be isolated from European gas and power networks or deem its energy security to be exposed to the threat of a lack of relevant connections.

The importance of Poland – Slovakia interconnecting gas pipeline was confirmed on 22^nd November 2013 when Governments of the Slovak Republic and the Republic of Poland signed the Cooperation Agreement concerning the construction of a gas pipeline connecting the Polish transmission network and the Slovak transmission network. The Agreement follows the provisions of the Plan for development of the V4 regional gas market adopted on 16^th June 2013 by Prime Ministers of the Visegrad Group countries and in that Agreement, contracting parties undertake to support implementation of the Project and specify the mechanisms of cooperation among the contracting parties within the preparation and implementation of a project involving construction of a gas pipeline connecting transmission networks of Slovak Republic and Republic of Poland by strategic investors (transmission system operators eustream, a.s. and GAZ-SYSTEM S.A.) and the mechanisms for supervision over the preparation and implementation of the project, (Notice, 2014).

Comprehensive assessment of expected impacts of gas pipeline construction

The final route of the gas pipeline in both countries was determined based on environmental impact assessment processes under the Act (2006). The purpose of environmental impact assessment is to prevent negative consequences of various human activities on the environment and health. It is carried out via comprehensive and expert assessments of expected impacts of strategic documents during their preparation and before their approval and assessment of proposed activities on the environment before any decision on the place of their execution or before granting permit to such activities under special regulations, (Jachim and Kalisz, 2010; Erickson and Lazarus, 2014). The assessment results in a selection of an optimum alternative and draft measures to eliminate or mitigate negative impacts of strategic documents and assessed activities on human health and the environment. The scheme of steps within the process of assessment of impacts of the proposed activities within the EU is shown in Figure 1.

CA – competent authority (Ministry of Environment), DA – departmental authority (Ministry of Economy), PA – Permitting Authority, AC – Authority concerned, IE – Implementing entity (Eustream, GAZ-SYSTEM), PCP – Professionally competent person

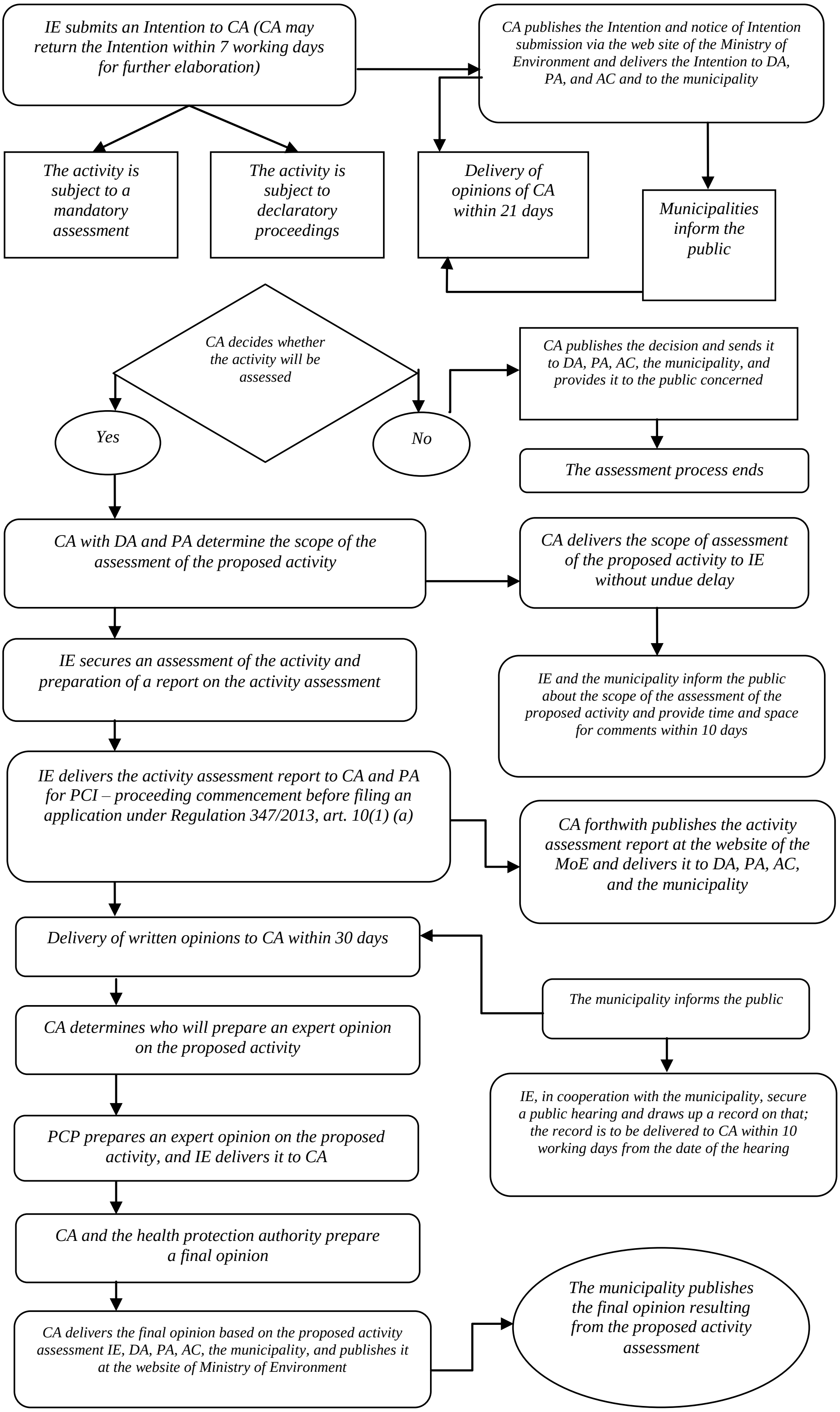

Fig. 1. Scheme of EIA process steps (Ministry of Economy of the SR, 2013).

Case study

Gas pipeline route alternatives

The proposal concerning possible routes of the gas pipeline is based on the common feasibility study of the Poland – Slovakia interconnection drawn up in 2013. The study considered three alternative routes (one in the west of Slovakia, and two in the east of Slovakia):

1. The alternative – a western route alternative featured the gas pipeline route leading from the existing Komorowice pipeline node in Poland across the state border in the Skalité/Zwardoń area and connecting of the gas pipeline to the Slovak transmission system at the Ivanka pri Nitre CS.
2. The alternative – an eastern route alternative featured the gas pipeline route leading from the existing Strachocina pipeline node, crossing of the state border in the area of Dukelský priesmyk, and connection of the gas pipeline to the Slovak transmission system near Košice.
3. The alternative – an eastern route alternative featured the gas pipeline route leading from the existing Strachocina pipeline node, crossing the state border in the area of Lupkov Pass, and connection of the gas pipeline to the Slovak transmission system at the Veľké Kapušany CS, figure 2 (Feasibility study, 2013).

The feasibility study recommended the 3. The alternative – the easternmost route for further development and environmental assessment because it was the most acceptable alternative as concerns the environment. The gas pipeline route is to start at the existing Strachocina pipeline node with an underground natural gas storage, then it is to continue and cross the state border via Lupkov Pass and end within the premises of the existing Veľké Kapušany CS which is the largest compressor station in the EU thanks to its total power capacity of 283 MW and is situated in Eastern Slovakia close to the borders with Ukraine. (Feasibility study, 2010; Feasibility study, 2013; EIA Documentation, 2015).

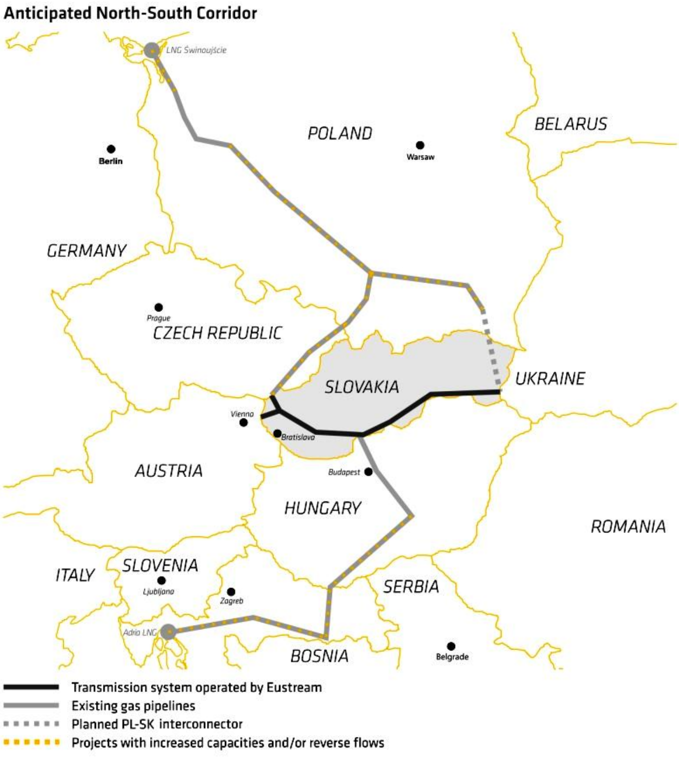

Fig. 2. North-South gas corridor (Karch and Olej, 2016)

The summary assessment of anticipated impacts in terms of their importance and periods of existence within construction and operation phase is evaluated in Table 1. The proposed gas pipeline route crosses several elements of the territory ecological stability system, multiregional and regional bio corridors, multiregional and regional bio centres, and hydric bio corridors of regional importance. The limit values marked with colours (red and violet) may be deemed to be extreme and of extraordinary importance. Criteria have been assigned with relative values representing the level of influence as compared with extreme values. Where possible, the difference as compared with the current situation or zero alternatives was factored in within the assessment of individual criteria (ENVICONSULT s.r.o., 2015).

Tab. 1. Assessment of anticipated impacts of gas pipeline construction (ENVICONSULT s.r.o., 2015).

CONSTRUCTION				**OPERATION**	
Impact significance				**Impact significance**	
Environment element	**Impact tape**	**negative**	**Positive**	**negative**	**positive**
Air	Emissions – mobile sources	[dark orange]			
	Dust pollutants	[dark orange]			
Groundwater	Intervention in source protection zones	[yellow]			
	Source polluting	[yellow]			
	Intervention into mineral water protection zones	[yellow]			
Surface water	Pollution	[yellow]			
	Barrier effect	[yellow]			
Rock	Geo-dynamic phenomena	[dark orange]		[magenta]	
	Pollution				
Relief	Modification of relief				
Soil	Permanent occupation	[yellow]		[orange]	
	Temporary occupation	[magenta]			
	Pollution				
Biota	Intervention in the Natura territory	[red]		[orange]	
	Intervention in protected areas of the national network	[red]		[orange]	
	Impact on fauna – birds, aquatic life	[orange]			
	Cutting off trees and bushes	[magenta]			[dark green]
Infrastructure	Transport	[orange]			
	Cultural and historical values				
Inhabitants	Impacts on health	[yellow]			
	Operational risks			[orange]	
	Social and economic activities		[light green]		[dark green]
	Other impacts – noise	[orange]			

Negative impacts:

- [white] - Insignificant impact, no impact
- [yellow] - Impact of little significance
- [orange] - Impact of medium significance
- [magenta] - Significant impact
- [red] - Very significant impact

Positive impacts:

- [white] - Insignificant impact
- [light green] - Impact of little significance
- [dark green] - Significant impact

The above-specified assessment shows that the period of construction of the gas pipeline will be accompanied by significant impacts on the environment due to temporary occupation of land, cutting of trees and bushes, and influences on protected areas. Commissioning of the gas pipeline will mean that the relevant environment will be rendered to its original condition to a substantial extent and except for the route leading across forest lands, it will represent only minor restrictions within the territory. The adverse impacts of construction and operation are not of a character and importance that may represent a barrier to construction of the gas pipeline. Emergency situations may have a more important effect, but such events will be subject to a system of preventive measures and emergency plans.

All impacts of the planned activity have been assessed in connection with valid legal regulations. Key regulations included the laws and decrees dealing with air protection, water protection, nature protection, waste management, health protection, agricultural land fund protection, protection of monuments, and zoning.

Direct and indirect impacts on the NATURA 2000 network

During construction of the gas pipeline, both direct and indirect impacts on the territory falling under the NATURA 2000 network could occur. The following Table 2 shows assessment of the importance of their effects and assessment as per individual alternatives (ENVICONSULT s.r.o., 2015).

Tab. 2. Assessment of the construction impacts on the NATURA 2000 network (ENVICONSULT 2015).

NATURA 2000 territory	**Assessment of the importance of impacts within individual alternatives**					
	1	**1A**	**2**	**2A**	**3**	**3A**
Number of NATURA 2000 areas with a significant negative impact of the Intention (-2)	0	0	1	1	2	0
Number of NATURA 2000 areas with a slightly significant negative impact of the Intention (-1)	8	8	6	6	6	8
Number of NATURA 2000 areas with the zero impact of the Intention (0)	19	19	20	20	19	19
Scatter	0.217	0.217	0.293	0.293	0.396	0.217
Standard variation	0.465	0.465	0.542	0.542	0.629	0.465

The following areas belonging to the NATURA 2000 network will be directly affected by construction and operation of the gas pipeline as concerns all assessed alternatives: SKCHVU011 Laborecká vrchovina (highlands), SKCHVU035 Vihorlatské vrchy (hills), SKUEV0387 Beskyd, SKUEV0763 Upper section of the Výrava river, SKUEV0049 Alluvial area of the river, SKUEV0386 Hostovické lúky (meadows), SKUEV0209 Morské oko (lake), SKUEV0205 Hubková, SKUEV0005 Drieňová, SKUEV0206 Humenská, SKUEV0050 Humenský Sokol, SKUEV0250 Krivoštianka, SKUEV0235 Stretavka. Other territories are outside the areas of direct or indirect impacts (ENVICONSULT s.r.o., 2015).

Impacts of construction of the gas pipeline on the geological environment

The impact of the project on the geological environment is specific due to the character of the project, i.e. it is a line project. The route length exceeding 100 km within all alternatives results in the presumption of a heterogeneous environment as concerns both the rock environment and relief.

The final alternative 1A (Table 4) leading from the state border up to km 50 crosses the territory consisting of flyschoid rock. The territory features landslides, slope deformations and areas prone to landslides. Within the pre-project preparation phase – during the engineering and geological survey, it is necessary to specify the active, potential, and stabilised landslides. The gas pipeline construction requires specifically execution of cuts and crossing of steep slopes; creation of a working lane disrupts the stability of the territory and any unsuitable intervention into the territory may activate landslides. Land reclamation of landslides is demanding both technically and economically, and it may pose a threat to the local infrastructure and the gas pipeline itself.

In connection with the construction of the gas pipeline within the zone featuring active landslides of slope deformations, it would be appropriate to install, at a relevant point, a tensometric monitoring system with remote data transmission that would carry out long-term tensometric measurements in order to determine additional tensions within the pipeline body caused especially by a change in the load, effects of both dry and wet soil, any possible slope deformations, possible changes in the marginal conditions along the route of the pipeline within the area concerned, and pipe temperature changes. Based on long-term tensometric measurements, a plan for slope rehabilitation may be prepared (ILF Beratende Ingenieure GmbH, 2016; Hongfang et al., 2015; CEEP, 2015).

Based on the data obtained from the slope deformation map (available online at http://apl.geology.sk/geofond/zosuvy/), active landslides are situated within the sections specified in Table 3.

Tab. 3. Active slope deformation landslides (ILF Beratende Ingenieure GmbH, 2016).

Alternative	**Stationing at km**	**Length in m**	**Impact extent**
1A	31.400 – 31.600	200	The direct crossing of an active landslide in the vicinity of village Ľubiša

According to the register of protected deposit areas and mining areas kept by the Košice District Mining Authority, within the 1A alternative, no contact with either protected deposit areas (from now on referred to as "PDA") or mining areas (from now on referred to as "MA") occurs (ENVICONSULT s.r.o., 2015).

Engineering and geological survey for gas pipeline construction purposes

Within the engineering and geological survey, a final summary and assessment of engineering and geological surveying works executed along the proposed route of Poland – Slovakia interconnecting gas pipeline from the border crossing point to the premises of the Veľké Kapušany CS and the sites of planned situation of block valve stations (from now on referred to as "BVS") and the metering station in Výrava (from now on referred to as the "MS"), (ILF Beratende Ingenieure GmbH, 2016).

The following was subject to a determination within the engineering and geological survey:

- engineering and geological and hydro-geological situation along the pipeline route;
- geo-dynamic processes within the pipeline route and its close vicinity;
- engineering and geological and hydro-geological situations at points of individual overpressures, flow transits and BVS;
- the situation within the MS Výrava premises;
- climatic conditions and seismicity within the territory;
- groundwater aggression as concerns concrete and steel structures;
- soil classification at the site under valid standards;
- determination of soil and rock workability along the gas pipeline route and within technological objects;
- preparation of a map with engineering-geological regions.

According to the well-arranged engineering-geological map, the surveyed area belongs to the Carpathian flysch region, the area of flysch mountain ranges – Ondavská vrchovina, the region of neogenic vulcanites, the area of vulcanic rock – Vihorlat, and the region of neogenic tectonic sinks, the area of inner Carpathian lowlands – Východoslovenská nížina.

The following regions are determined in the map of engineering-geological regions:

Regions where the rock of the pre-quaternary base reaches the surface of the territory or where covering quaternary formations are not thicker than 2 m:

- Sf i- flysch rock region with a major content of claystone;
- Sfip – flysch rock region with the claystone-sandstone ratio approx. 1:1;
- Stp – flysch rock region with a major content of sandstone;
- Ni – fine-grain sediments region.

Regions where covering quaternary formations, the thickness of which exceeds 2 m, reach the surface:

- Fh - region with mountain stream deposits D – deluvial deposits region;
- P – region with proluvial cones and deposits Ft- region of Pleistocene river terraces Fn- region with lowland stream deposits;
- Fs – region with crescentic lakes Es – region of Eolic loess;
- Ao – region with waste dumps (without distinction).

Soil samples from 163 monitoring bores, 8 out of that from the MS Výrava premises, were tested in an accredited laboratory that examined the grain size analysis, humidity – A method, plasticity limit, liquid limit – Casagrande method. Soils from the surveyed territory are of the 2nd to 4th workability class classified under standard STN 73 3050.

The section of the final 1A alternative from the state border up to km 50 is significantly affected by slope defects that have been plotted in the map of engineering-geological regions based on studying of archived materials and terrain mapping. Within excavations, increased attention is to be paid to possible slope movements. Construction works should be carried out in dry periods and as per smaller sections where possible in order to not leave trenches open for a long time.

The section of the final 1A alternative from km 50 to the Veľké Kapušany CS is sporadically affected by slope defects that have been plotted in the map of engineering-geological regions based on studying of archived materials and terrain mapping. Construction works should be carried out in dry periods and as per smaller sections where possible in order to not leave trenches open for a long time, (ILF Beratende Ingenieure GmbH, 2016).

Results and Discussion

Selection of the gas pipeline route within the territory of Slovakia

The activities related to the environmental impact assessment have been carried out under the supervision of the Ministry of Environment of the SR (from now on referred to as "MoE SR") since the MoE SR is the competent state administration body under Sec. 1 and Sec. 2 of Act no. 525/2003 that regulates state administration in the area of environmental care and amends and supplements some other acts, as amended by subsequent regulations, as well as the competent authority under Sec. 3 (k) of the Act (2006). An important change, when compared with the past, is based on the fact that according to an adopted amendment to the Act (2006), results of the environmental impact assessment are binding upon the investor in the project. The route corridor under the Final Opinion (Ministry of Environment of SR 2016) is, under the Act no. 314/2014 that amends and complements the Act (2006) is binding for further approval proceedings since 1st January 2015 in the Slovak Republic. An important change and obligation for the project investor is the obligation to execute at least one public hearing before the commencement of the environmental impact assessment process in compliance with the Regulation (2013) in order to inform the public about the project Intention.

According to Annex no. 13 to the Act (2006), gas pipelines with large-diameter pipes are subject to a compulsory assessment as to their impacts on the environment in a transboundary context. The Ministry of Environment of the SR has notified under the Espoo Convention its Polish counterpart who determined the requirements applicable to the transboundary environmental impact assessment in the opinions sent by the General Directorate of Environmental Protection and the Regional Environmental Protection Directorate in Rzeszow of February 2015. The main requirement concerned an alternative location for border crossing to avoid or mitigate expected barrier effect on wildlife. Therefore, three alternative state border crossing points in Lupkov Pass have been defined altogether. Alternative border crossing points have been proposed by the State Nature Protection Authority of the SR (from now on referred to as the "SNPASR") and the Polish operator of the transmission network - GAZ-SYSTEM S.A. company cooperating with experts from Regional Environmental Protection Directorate in Rzeszow. Furthermore, a request for assessment of impacts on the nature protection interests within the Polish border area has been presented.

The international assessment of impacts on the NATURA 2000 network in respect of Poland – Slovakia interconnecting gas pipeline was carried out in compliance with Articles 6.3 and 6.4 of Directive of the Council No. 92/43/EEC of 21 May 1992 on the conservation of natural habitats and wild fauna and flora. The length of the route leading across forest lands was taken into account in respect of the NATURA 2000 territory. As concerns individual alternatives on both the Slovak side and the Polish side, it is not possible to compare them mutually based on species because on the Slovak side, there are forest habitats and more homogenous environment (fir-beech forests), and therefore the species bound with wetlands (Dactylorhiza majalis) and open areas (butterflies) are not present there. This does not mean a lower quality of habitats. Within the assessment, the species diversity of individual habitats and biodiversity of terrestrial vertebrates, not only important species in European terms (Ministry of Environment of the SR, 2006), have been factored in. In addition, it occurs that the species protected by national law within the territory of Poland can be found in Slovakia too, but they do not belong to the species under protection of Slovak law.

In December 2015, one of those three alternatives was selected – the common southern border crossing point – C (proposal by SNCASR) based on an agreement with companies Eustream, a.s. (from now on referred to as "Eustream"), and GAZ-SYSTEM S.A. (from now on referred to as "GAZ-SYSTEM"), which meets the requirements of environmental protection authorities both in Poland and in Slovakia. The southern state border crossing point was proposed and preferred by SNCASR given the Protected Country Area of Eastern Carpathians where the territory concerned is situated. Point C that is approximately 1 km southwards from the railway tunnel connecting Medzilaborce and Nowy Łupków was, during an on-site inspection executed by both companies, precisely surveyed and marked and its coordinates will be a part of the Connection Agreement between both transmission system operators (from now on referred to as "TSO").

The proposed gas pipeline route was primarily based on the shortest connecting line between the point at the state border crossing with Poland and the Veľké Kapušany CS. The proposed route was supposed to secure minimum interventions in the areas sensitive in terms of protected areas of all categories. Within the statutory EIA process that such a gas pipeline is subject to, 6 alternatives were suggested in total (3 original alternatives 1, 2, and 3 from the Intention and 3 newly suggested alternatives 1A, 2A, and 3A that are based on the original alternatives assessed within the Intention, but due to their extent, they were deemed to be independent and equal) (Karch and Olej, 2016).

Based on the result of the environmental impact assessment process under the provisions of the Act (2006), the Ministry of Environment of the Slovak Republic recommended execution of the proposed project "Poland – Slovakia interconnecting gas pipeline" after achieving compliance with the requirements and implementation of the measures specified in the recommended requirements applicable to the phase of construction and operation of the proposed activity and upon execution of a post-project analysis through biota monitoring to the required extent. The uncertainties that occurred during the process of environmental impact assessment and presented requirements were to be solved within further approval process (zoning and building proceedings) under special regulations, (Karch and Olej, 2016).

Based on the prepared Expert Opinion (Badík, 2015) and established facts and consultations with the author and proposer of the Assessment report, an on-site inspection of the territory concerned, comments contained in opinions, public hearings, and negotiations of the project investor with the municipalities and organizations concerned, the adjusted final alternative 1A specified in Table 4 was recommended (ENVICONSULT s.r.o., 2015).

Taking this into account, implementing results of the Espoo consultation with Polish authorities, Ministry of the Environment of the SR granted the Final Opinion (Ministry of Environment of the SR, 2016) on implementation of the proposed activity, and recommended the point C for connection to the Polish side, with the route's continuation from point C along the 1A alternative until the end of the section at the Veľké Kapušany CS; at the village of Lackovce, the 1A alternative is to be diverted more southwards. Under the recommended condition no. 10 contained in the Final Opinion, it was necessary to discuss the final route with 4 municipalities that expressed their disagreement within the environmental impact assessment process. After three-party discussions among the village of Pozdišovce, the city of Michalovce and the Eustream company, the final 1A alternative was amended as concerns the cadastral area of Šamudovce so that the gas pipeline route leads along the western side of the village within that cadastral area. Due to this route change, the final alternative does not lead across the cadastral area of the Krásnovce village, but instead, it leads across the cadastral area of the Vrbnica village. In addition to that, the final alternative crosses the Bánovce nad Bebravou mining area with the consent granted by the NAFTA, a.s. Company and the Košice Regional Mining Authority.

Tab. 4. Villages affected by the gas pipeline route within the territory of Slovakia (Ministry of Environment of the SR, 2016).

Alternative	Region	District	Municipality
Alternative 1A	Košice	Michalovce	Oreské, Staré, Zbudza, Nacina Ves, Petrovce n/Laborcom, Michalovce (Topoľany), Suché, Michalovce (Močarany), Pozdišovce, Šamudovce, Vrbnica (formerly Krásnovce), Lastomír, Žbince, Sliepkovce, Budkovce, Drahňov, Vojany, Čičarovce, Krišovská Liesková, Veľké Kapušany
	Prešov	Medzilaborce	Palota, Výrava, Čabalovce (only a high-voltage electricity connection), Svetlice, Zbojné
		Humenné	Rokytov pri Humennom, Jabloň, Koškovce, Hankovce, Ľubiša, Veľopolie, Udavské, Kochanovce, Lackovce, Hažín n/Cirochou, Ptičie, Chlmec

Gas pipeline technological solution

Based on agreements of transmission system operators in both countries, the following specifications have been determined for the Poland-Slovakia interconnecting gas pipeline:

- Route starts at the Veľké Kapušany CS
- State border crossing point – the cadastral area of the Palota village (Lupkov Pass)
- The route ends at the Strachocina CS, Poland
- The route length max. 164 km (Poland - 58 km and Slovakia - 106 km),
- Nominal pipe diameter DN 1000
- Maximum operating pressure 7.35 MPa from Veľké Kapušany CS to MS Výrava and 8.4 MPa from MS Výrava to Strachocina CS
- Capacity in the direction from Slovakia to Poland 6.128 billion Nm^3/year (at 101.325 kPa and 20 °C)
- Capacity in the direction from Poland to Slovakia 5.052 billion Nm^3/year (at 101.325 kPa and 20 °C), (Ministry of Environment of the SR, 2016)

An optical fibre cable (from now on referred to as "OFC") will be laid along the route for the gas pipeline control system and the transfer of data to support systems. The proposed gas pipeline control system collects data from the gas pipeline route for the existing technical dispatching centre in Nitra. Remote monitoring and control of the MS Výrava and BVS is considered.

The distances between BVSs are approximately 25 km. The number and situation of BVSs have been proposed based on hydraulic calculations and simulations carried out to find an optimum solution to the line section of the gas pipeline as concerns the speed and pressure relations and in connection with the bi-directional natural gas transmission and possibilities for land purchases.

The major technological objects within the Poland-Slovakia interconnecting gas pipeline are:

- **Metering Station (MS)** that will allow bidirectional automated measurement of quality and amount of the natural gas transported via the Poland – Slovakia gas pipeline**.** The natural gas transit will be carried out in both directions, i.e. from Slovakia to Poland and from Poland to Slovakia. The MS will be situated in the Slovak Republic, in the vicinity of village Výrava.
- **Optical Fibre Cable (OFC)** will allow construction of a telecommunication optical fibre network serving to transfer control system data, to make phone calls among individual network nodes, and to transfer data from individual structures along the route of the Poland – Slovakia gas pipeline. The protective pipe with OFC will be laid in a separate trench along the entire length of the gas pipeline and situated approximately 4 m away from the pipeline axis on the west side.
- **Block Valve Stations (BVS)** will consist of ball valves DN 1000 with hydraulic-pneumatic drives, the total bypass DN 300, exhaust flues DN 300, emergency protective equipment, and the devices for remote control from the technical dispatching centre in Nitra. Gas pipeline sections between two BVSs will not be longer than 30 km. Connection points for a mobile compressor pump will be at disposal. BVSs will be located within the premises of villages Šamudovce, Chlmec and Hankovce.

- **Cathodic Protection Stations (**from now on referred to as "**CPS")** will provide active cathodic protection of the gas pipeline**.** At points where the gas pipeline will cross other buried metal lines, interconnecting objects will be built ensuring electric potential set-off between the lines. Close to CPSs impressed current anodes will be installed as buried rails. Construction of 3 CPSs along the gas pipeline route and 1 CPS at the Veľké Kapušany CS is designed. They will be situated within the premises of the BVS Šamudovce, BVS Hankovce, and the MS Výrava.
- **Cleaning Chambers (**from now on referred to as "**CC")** intended for cleaning of the gas pipeline and inspection of its technical conditions during operation. CCs will be bidirectional (so-called "pig receivers/launchers) allowing insertion and pulling out of cleaning pistons or monitoring devices into and out of the gas pipeline. CCs will be situated within the MS Výrava (1 chamber on the pipeline in the direction to Poland and 1 chamber on the pipeline in the direction to the Veľké Kapušany CS) and within the Veľké Kapušany CS (1 chamber at the point of connection of the pipeline to the Veľké Kapušany CS), (Ministry of Environment of the SR, 2016; Act, 2012).

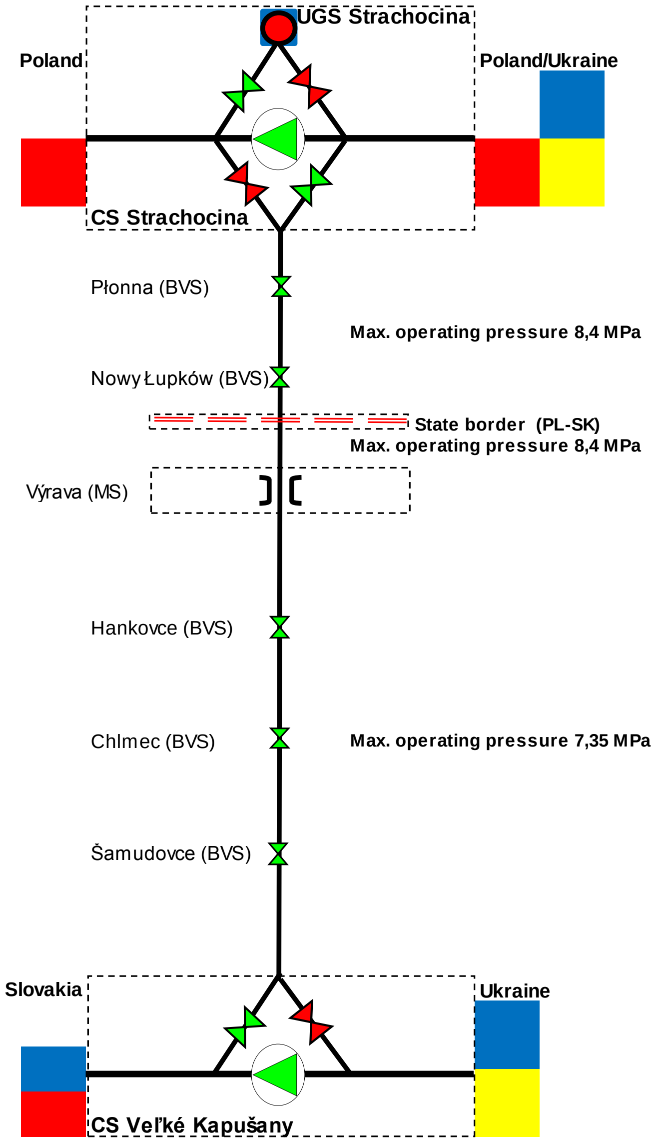

Fig. 3. Scheme of the Poland – Slovakia interconnecting gas pipeline

Conclusion

In Central Europe, the natural gas transmission has been historically realised from the east to the west. Therefore, priorities of the EU include development of the North-South gas corridor that will enable transmission of natural gas from the Baltic Sea, from the Polish liquid natural gas terminal at Świnoujście, to the countries of Central and Eastern Europe as well as from the Adriatic Sea where an LNG terminal is planned at the Island of Krk, Croatia.

The Slovak TSO Eustream received the Slovak Ministry of the Environment's Final Opinion on Poland - Slovakia interconnection gas pipeline project on 21st January 2016. The environmental impact assessment process was completed by Polish TSO GAZ-SYSTEM on 28th April 2017. The Final Opinion represents the final summary of the entire process of environmental impact assessment and is valid for 7 years from its issue, (Ministry of Environment of the SR, 2016). The results of the EIA of the proposed activity show that the recommended alternative of the proposed activity specified in the Final Opinion is acceptable after factoring in the relevant measures as concern overall (negative and positive) impacts on the environment. Provided that the proposed measures aimed at prevention, elimination, mitigation, and compensation of adverse environmental impacts of the proposed activity are accepted and implemented and based on a thorough post-project analysis, the implementation and operation of the proposed project may be considered to be environmentally acceptable.

The final alternative 1A involves the connection point C from which the route continues to the end point of the section at the Veľké Kapušany CS, Table 5. Near the village of Lackovce, it is necessary to divert the 1A alternative more eastwards, i.e. behind the existing shooting range area, while complying with 74 recommended conditions determined for the construction and operation of the proposed project. The 1A alternative is approximately 100 km long. More complicated preconditions for construction of the gas pipeline along its route are based on the vertical and horizontal relief of the land, terrain morphology, etc. within the territories of the district of Medzilaborce and Humenné and the northern part of the district of Michalovce (the area of Humenské mountain range and Krivoštianky). Východoslovenská rovina (flatland) offers seemingly simpler conditions. The relief of highlands, upland, foothill, and hilly areas of the "North" featuring erosion grooves (the Prešov region and the northern part of the Košice region) creates more demanding conditions for any line project route, including a gas pipeline; especially the valleys within the Laborec river network are to be made use of. In next project stages (zoning and building proceedings), the final gas pipeline routing will be defined within the 1A alternative corridor where the route might be diverted by up to 50 m on each side, (Ministry of Environment of the SR, 2016).

Based on the above experience, we suggest that national legal regulations (for example, Building Act, Act on Important Investments, Energy Act) explicitly define PCI projects under Annex VII of the Regulation (2013), which will be assigned the status of projects in national public interest. This would clearly define the "Priority Status" of PCIs, i.e. that all competent authorities shall ensure prompt settlement for project investors of documents in compliance with valid laws so that they are able to meet the deadlines under Article 10 of the Regulation (2013). We deem speeding up, and increased efficiency of approval proceedings for European energy projects in a transboundary context to be very important and the implementation of Regulation (2013) into the laws of the relevant Member State should contribute towards this objective.

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Spent Magnesia-Carbon Refractory Bricks from Steel Production: Potentiality of MgO-Clinker Recovery

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The work is focused on the quality of spent refractory materials (MC 98/10) from the slag line of steel ladles, which are freely dumped, and the effect of their dumping in a landfill on the environment. The degradability of the spent refractories in water is an indicator of their corrosion extent. The stability of corrosion products was evaluated by batch leaching test in water and weak acid medium (pH = 5.95 and 4.21; liquid: solid = 10). The conductivity and changes of pH in the medium were measured. Crushed new magnesia-carbon bricks increase the pH value of leachates to 9 – 9.5, the spent refractory from the core of the bricks generates pH = 10 – 10.5 and that of the material from the corroded surface of bricks shifts pH up to 12. The alkali ions (Na^+, K^+, Ca^{2+}) are eluted from the spent refractories. The increase of pH value to 11–12 leads to the saturation of solution with Ca^{2+}, Al^{3+} and sulphur ions, and to the stabilisation of heavy metals in the solid compounds. Because the MgO-clinker particles concentrate in the coarse-grained fraction the re-use of size fraction > 1 mm from spent MC 98/10 bricks as raw materials is hopeful. The recycling processes are being verified, and economic analysis is being prepared.

Key words: *leaching, pH value, magnesia refractory, redistribution, concentrate*

Introduction

The steel industry is a major consumer of a wide range of the refractory materials. Worn lining in ladles, basic oxygen furnaces and other furnaces is replaced permanently. As mentioned in the works (Malfliet et al., 2014; Fang et al., 1999), at the end of the 20th century, there were more than 3 million tonnes of refractories produced per year only in the USA and 80 thousand tonnes in the European Union. Statistics and technical works indicate that at present the steel industry recycles only a small part of spent refractory materials, approximately 1 – 10 %, mostly used as a slag conditioner or roadbed materials. Most of the spent refractory materials are freely dumped without previous treatment.

Pressure to improve the environmental sustainability and the growing price of virgin raw materials, force the operators to reduce the quantity of annually dumped spent refractories. For example, to increase the refractories quality and apply their prolonged use or recycling and also to reuse the spent refractories as raw material for new refractory or ceramics bricks (Malfliet et al., 2014; Hanagiri et al., 2008; Schutte, 2010; Nakamura et al., 1999; Kwong and Bennett, 2002).

On the one hand, the study of spent refractory properties helps to understand the corrosion processes under high temperature in the aggregates and their use in the production of the metal and refractory materials. On the other hand, the degree of the brick deterioration by the corrosion determines the options for their secondary utilisation. The works (Vadász et al., 1995; Arianpour et al., 2010; Conejo et al., 2006; Luz et al., 2013) are devoted to the pre-treatment and utilisation of spent refractories. Because the determining factor for the use of the corroded ceramic materials is their chemical and phase composition, each of the grain fractions of the crushed spent material must be analysed before its use into new ceramic masses (Malfliet et al., 2014; Hanagiri et al., 2008; Arianpour et al., 2010). The works (Fang et al., 1999; Arianpour et al., 2010; Othman and Nour, 2005) mention that a small part of crushed spent magnesia refractories can be added into new masses in the production of magnesia refractories and works (Conejo et al., 2006; Luz et al., 2013, Strubel e al., 2015) suggest their usage as a slag foaming conditioner.

This work deals with the spent magnesia-carbon (MgO-C) bricks the slag line of steel ladles. The magnesia-carbon unfired bricks are applied into the working linings of basic steel production units, electric arc furnaces, and of course for steel ladles slag lines, everywhere where the high resistance to molten metal and resistance to slag corrosion is required. These refractories are resisting to 1700 °C temperature and possess low wetting ability by liquid phase (STN EN ISO 10081, 2003). These bricks, containing up to 10 wt. % of carbon, are the optimal refractory material for the zone of the molten slag attack. The MgO-C bricks consist of sintered magnesia bound

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by resin. Depending on the application, the bricks can contain up to 98 wt. % MgO (periclase), and residual carbon from 7 to 30 wt.%. To prevent the burning up of carbon, the antioxidants are added to the refractory mass (Staroň and Tomšu, 2000).

The aim of the work was to define which elements of spent periclase-carbon bricks (MC 98/10) from the steel ladle lining are leached by water, to predict the impact of landfilling on the environment and to review the recycling possibilities of such spent refractories. For this reason, the samples were prepared from the surface and core of the corroded bricks that were leached separately in de-ionised water and a weak acid solution (pH = 4.21; simulating the acidic rain).

Materials and Methods

Materials

The sinter magnesia (min. 98 wt.% MgO; ϕ = 0 – 5 mm) is the base of the MC 98/10 brick. Magnesia is combined with the organic bond which after burning creates approx. 9.5 wt.% of C. The tests were implemented with new and spent MC 98/10 refractory bricks coming from the lining of the steel ladle (after 95 runs of the casting).

The mortar from the bottom of spent bricks was easily removed before the preparation of the samples. One group of samples was prepared from the core of the spent bricks (mark KB), the second from the surface (mark KS), the removed corroded layer was approx. 20 mm thick. The reference grainy sample was prepared from new bricks (mark KN). These materials were crushed to the grain size < 2.5 mm. The specific surface (Quantachrome NOVA-1000; gas-N2 methods B.E.T.), magnetic ratio and loss on ignition (1000 °C/1 h) of grainy samples are shown in Table 1.

The results of classical soil chemical analysis of samples from surface and core (KB, KS) are shown in Table 2. The phase analysis was determined only for the samples from the brick core by XRD diffractometer (Rigaku MiniFlex 600), and the record (Fig. 1) was evaluated using the Quality Analysis software PDXL 2 and ICCD mineral and ceramics database**.**

Leaching test

Stability of the spent refractories in aqua medium was tested by batch leaching under the recommended conditions by Method of 1312 and Nordtest Report 539 (Method 1311, Method 1312; Baun et al., 2010). The samples were leached in de-ionised water (pH = 5.95 ± 0.05; conductivity σ = 2 $\mu S.cm^{-1}$; ORP (oxidation-reduction potential) = 100 mV) and/or in the weak acid solution (pH = 4.21 ± 0.05; σ = 18 $\mu S.cm^{-1}$; ORP = 245 mV). Acid solution was prepared from dilute solution of sulphuric acid/nitric acid mix (6/4 wt.). The pH value, conductivity and ORP were measured (Digital pH/ORP/D.O.Multi-9310) during the leaching in different times (1 – 120 h).

The batch tests were carried out with liquid-to-solid ratios (L/S) = 10 at the room temperature (t = 21 ± 2 °C). The liquid medium (50 ml) was added to 5 g dose of the dry sample of defined particle size fraction into the PE-bottles. The PE-bottles were stirred on rotator "Multi RS-60 biosan" at 15 rpm during tests. The tests were 3 – 5 times repeated and average values are shown in Tables 3,4 and Fig. 2. After filtration of the leachates, the concentrations of ions were measured by the inductively coupled plasma-atomic emission spectroscopy (ICP-AES/ iCAP 6000 Series).

Results

Characterisation of spent refractory

The corroded surface of a spent MC 98/10 bricks was rough, markedly corroded but without extensive metal deposits. The grainy black sample changed colour at ignition (Tab. 1). The losses on ignition point indirectly to the carbon content in the samples. The samples from brick core exhibited the higher loss on ignition. The magnetic proportion is very small (Tab. 1, 2).

The XDR pattern (Fig. 1) of the sample from spent brick core confirmed the dominant content of periclase (MgO) and graphite/carbon (C).

Tab. 1. The basic characteristic of samples from spent MC 98/10 bricks.

Sample	Mark	Magnetic ratio [wt. %]	Loss on ignition L.I. [wt. %]	Colour change after ignition	Specific surface area Sa [m^2g^{-1}]
core	KB	≈ 0	10.18	black→ light grey	2.4
surface	KS	0.5 – 1.5	8.75	black → ochreous	1.8

Tab. 2. Chemical analysis of particle size fractions of spent MgO-C: KB – brick core; KS - corroded surface; L.I. - Loss on ignition.

Samples	Chemical analysis [wt. %]										
	Al_2O_3	SiO_2	MgO	CaO	Fe_2O_3	Na_2O	K_2O	SO_3	MnO	Cr_2O_3	L.I.
KB 0-2.5 mm	4.4	1.8	80.8	4.2	1.5	<0.05	<0.05	0	<0.25	0.1	9.2
KB 0-1 mm	6.5	3.2	72.1	2.8	0.9	-	-	-	-	-	11.2
KB 1-2.5 mm	3.8	2.1	83.4	1.6	1.8	-	-	-	-	-	7.0
KS 0-2.5 mm	5.6	1.4	62.6	19.7	1.5	0.15	<0.05	0	<0.25	0.9	8.2

The results of the chemical analysis of samples in Table 2 show the degree of the brick damage. The differences in the compositions between surface and brick core reflect the elements attacking the lining ladle in the area of the slag line. In the surface layer of spent brick (KS) the MgO content is reduced by about 20 wt.%. However, the content of CaO increased greatly, and that of Al_2O_3 increased only slightly. It is logical that the sinter magnesia cumulates in the coarser fraction (1-2.5 mm) and its concentration even increases after the carbon burns out.

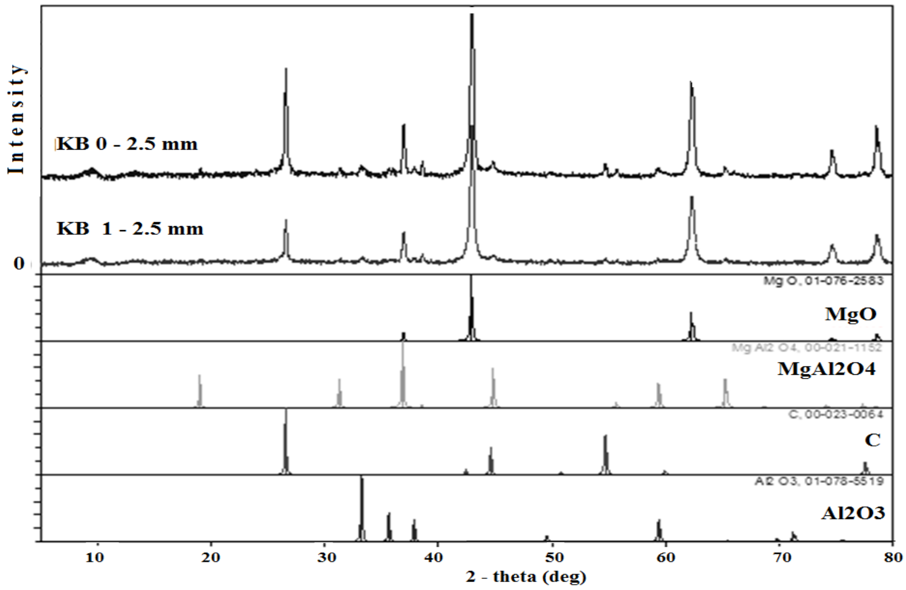

Fig. 1. XRD patterns of spent MC 98/10 from the brick core and diffraction lines of pure compounds.

Stability of MC 98/10 refractories and corrosion products in aqua medium

Prepared grainy samples from the spent MC 98/10 bricks for batch leaching tests were characterised by specific surface (Tab. 1). The fine carbon causes higher values of the specific surface of grainy samples.

One indicator of the degree of the corrosion of the material is the difference in extractability of the component. Conductivity grows with ion concentration of the solution, and the increased content of alkali ions (Na, K, Ca, Mg) shifts the pH value into the alkaline range.

Batch test with leaching medium replacement (medium – deionized water: pH = 5.95)

Fresh medium was carried out during the leaching of the KN, KB and KS samples during the time period of 1 h and 24 h. The pH value, conductivity and concentrations of major elements in solutions are listed in Table 3.

Although after the water renewal, the conductivity (σ) and concentration ions in leachates decreased, the pH values constantly increased. Material MC 98/10 itself belongs to the alkali refractories and creates the environment with pH = 9 – 9.5. There are not such significant differences between the sample of new material (KN) and sample from the core of spent brick (KB) as in the case of the samples from the core and surface of spent bricks (KB vs KS). Permanently high Ca^{2+}, Al^{3+} and sulphur content in the leachates points to the corrosion degree in the concrete parts of bricks. The results confirm that the corrosion of bricks was caused the alumina-calcareous slag and that sulphur, sodium and potassium elements attacking the surface penetrate into the brick core. The alkali and alkaline earth metals (Na, K, Ca, Mg) increase the alkalinity of leachates.

In addition to the elements listed in Table 3, also Pb, Cr, Zn and Cu elements have been measured, and their concentrations were on the detect-ability limit (0 – 0.02 $mg.l^{-1}$).

Tab. 3. Comparison of concentration, pH value and conductivity of leachates from new and spent MC98/10 bricks; leaching medium was changed after 1 h and 24 h (initial pH –5.95).

Sample/ Leaching time		Concentration of elements in leachate [mg.l^{-1}] Al^{3+}	Si^{4+}	Mg^{2+}	Ca^{2+}	$Fe^{2+/3+}$	Na^{+}	K^{+}	S-ions	pH (± 0.2)	Conductivity σ [μS.cm^{-1}]
KN	1 h	11.7	0.75	5.15	8.56	0.01	1.50	0.17	0.35	9.50	95
	1-24 h	12.8	0.12	1.98	14.9	0.00	0.77	0.21	0.05	9.58	92
	24-48 h	12.1	0.10	0..89	13.1	0.00	0.45	0.20	0.00	9.35	79
KB	1 h	28.7	1.02	3.10	31.3	0.13	4.09	7.20	2.90	10.00	197
	1-24 h	86.8	1.02	2.16	50.5	0.05	1.18	1.77	1.65	10.17	255
	24-48 h	41.1	0.70	1.95	29.2	0.05	0.00	0.65	0.86	9.94	169
KS	1 h	370	2.23	0.66	232	0.02	5.47	4.20	2.90	11.88	1572
	1-24 h	247	1.77	0.34	176	0.03	4.60	1.00	2.34	11.69	1335
	24-48 h	210	2.17	2.14	187	0.05	1.71	0.48	2.70	11.80	1412

One-stage batch leaching test in mediums of deionised water and weak acid water

The results of the leaching without exchange of mediums, deionised water and weak acid solution, are presented in Table 4 and Fig. 2. Of course, the character of periclase-carbon refractories eliminates acidity of medium immediately and shifts the pH into the alkaline region. Therefore the results of leaching in water (pH = 5.95) and weak acid solution (pH = 4.21) are similar; the ion concentrations are only a bit higher in leachates of the weak acid solution than in water. The increasing conductivity is in correlation with the increasing concentrations of ions in the solution.

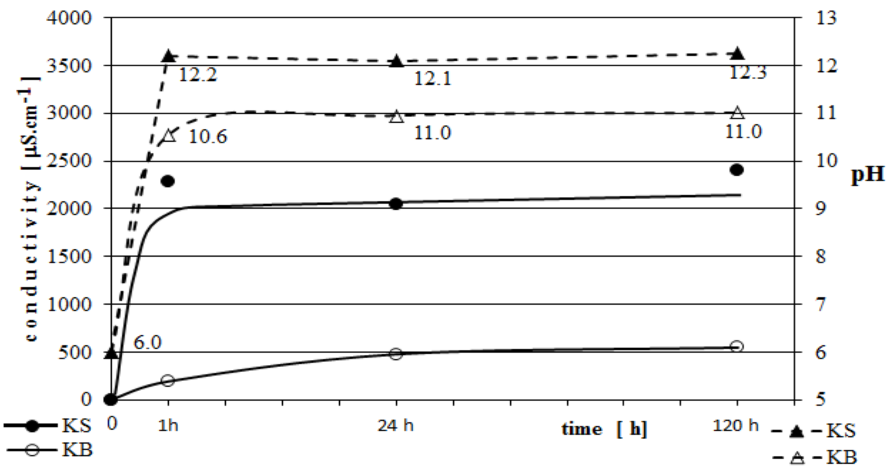

Fig. 2. Changes of conductivity and pH in leachates with leaching time of spent MC 98/10 refractories in water: batch test without change of leaching medium – initial pH = 5.95; KS – sample from the surface; KB – sample from the core of brick.

Comparing the test results with and without replacement of leaching mediums indicates a supersaturation of solution already during the first hour of leaching in case of the sample from surface bricks.

In addition to elements presented in Table 4, the contents of Pb, Cr, Zn, and Cu ions were also measured. Only Zn was detected in concentration max. to 0.15 mg.l^{-1} in leachates and the others monitored heavy metal ions were not detectable.

Tab. 4. Concentration of ions in leachates after 24 h of leaching of spent MC 98/10 in water – W (initial pH = 5.95) and acid solution – A (initial pH = 4.21; sulphur in initial acid solution = 0.5 mg.l^{-1}).

Samples	Concentration of elements in leachates [mg.l^{-1}] Al^{3+}	Si^{4+}	Mg^{2+}	Ca^{2+}	$Fe^{2+/3+}$	Na^{+}	K^{+}	S-ions	pH (± 0.2)	Conductivity σ [μS.cm^{-1}]
KB /W	115	1.89	0.87	78.8	0.04	4.98	7.85	2.36	11.0	480
KB / A	99.0	1.52	2.34	80.7	0.07	6.12	10.9	3.33	10.5	345
KS /W	265	2.40	0.28	208	0.01	9.36	5.20	3.60	12.2	2005
KS / A	294	2.36	0.63	257	0.02	14.0	10.1	2.83	12.0	1836

It is also necessary to mention that spent MC98/10 samples changed initial pH = 1 of leaching medium (H_2SO_4 + HNO_3) to 9.1 – 9.5 during 1 hour of the leaching and no leachates contained detectable amounts of Pb, Fe, Cr, Zn, and Cu (concentration above 0.01 mg.l^{-1}).

Differences in composition of coarse and fine particle size of the sample from the spent brick core
(medium – acid water: pH = 4.21)

The weight ratio of the 0-1 mm and 1-2.5 mm grain size fractions in the crushed samples (0-2.5 mm) was 50 – 60 wt. %: 40 – 50 wt.%. As shown in Table 2, the coarser fraction (1-2.5 mm) contains more MgO and less CaO, SiO_2, Al_2O_3. The value of loss on ignition suggests the carbon presence and that its content is lower in comparison to the finer fraction. The results of phase analyses as well as confirmed it as well (Tab. 5).

Tab. 5. X-ray analysis results from the brick core of spent MC 98/10.

Phase	Content [wt.%]		
	KB 0-2.5 mm		KB 1- 2.5 mm
Periclase (MgO)	80 – 87	<	88 – 91
Graphite (C)	5 – 10	>	2 – 4
Spinel ($MgAl_2O_4$)+ Corundum (Al_2O_3)	11 – 6	>	(4 – 6)

The results obtained at leaching of ⟨0-1⟩ mm and ⟨1-2.5⟩ mm grain size fractions if medium (weak acid; initial pH = 4.21) was replaced in different time intervals are shown in Table 6.

Tab. 6. Concentration of ions in leachates from brick core (KB) and surface (KS) at the end of leaching cycles; replacement of medium - weak acid solution (pH = 4.21; content of S in initial solution = 0.5 mg.l^{-1}).

Samples / Leaching time	Concentration of elements in leachates [mg.l^{-1}]							
	Al^{3+}	Si^{4+}	Mg^{2+}	Ca^{2+}	Na^+	K^+	S-ions	pH
KB 0-1 mm/ 1h	20.8	1.17	1.97	46.2	9.00	10.4	7.64	10.05
KB 0-1 mm/ 1-24h	41.3	1.57	0.58	92.4	2.22	2.16	3.91	10.80
KB 1-2.5 mm/1h	11.2	1.54	3.55	24.6	4.71	4.57	3.57	9.80
KB 1-2.5 mm/1-24h	26.3	1.14	0.75	71.5	1.72	1.47	2.11	10.75
KS 0-1 mm/ 1h	253	3.54	0.13	339	11.1	4.50	5.21	12.25
KS 0-1 mm/ 1-2h	236	3.38	0.31	323	4.51	1..16	4.61	12.10
KS 0-1 mm/ 2-24h	224	3.09	0.50	295	3.90	0.57	4.31	12.15
KS 1-2.5 mm/ 1h	135	2.22	0.70	209	4.00	1.66	4.50	12.00
KS 1-2.5 mm/ 1-2h	154	2.26	0.36	213	2.52	0.41	3.69	11.95
KS 1-2.5 mm/ 2-24h	213	3.23	0.86	301	3.60	0.66	4.29	12.15

The pH values of leachates from the different grainy samples are similar. After each replacement of the medium, the pH value returns to the alkaline region rapidly. In case of the KB samples the pH increased up to 10 – 10.5 for 1 hour of leaching and in case of KS sample even up to 12, and with the exposure time, the pH practically did not change. Unlike the pH value, there are marked differences between the conductivity of leachates from the fine and coarse fraction. The conductivity corresponds to ions concentration in leachates. The leachates from the brick surface contain 5 to 10 times higher concentrations of Ca^{2+}, Al^{3+}, Si^{4+} than from the brick core. However, the Na^+, K^+ and sulphur contents are comparable. Among the heavy metals (Pb, Zn, Fe, Cr, Cu) only Fe and Zn have been detectable, and their concentrations were under 0.08 mg.l^{-1}.

Discussion

The behaviour of spent magnesia-carbon refractory in a landfill

The results of this study, the chemical analysis of MC 98/10 samples prepared from the core and surface of corroded refractory bricks (Tab. 2) and analyses of leachates (Tab. 3,4,6), confirmed that the refractories do not belong to the hazardous waste group.

Unused magnesia refractories create an alkaline environment (pH 9.5). In case of the leaching of crushed spent brick in a small quantity of the liquid, the pH can rise to 12. Major extractive elements, Ca^{3+}, Al^{3+} and sulphur, come from slag. At the beginning of the leaching process, the Na^+ and K^+ ions elute very intensively because Na^- and K^-compounds are less stable in water. The continuous extraction of Ca^{2+} from spent refractory causes the constant shift of the pH value to the alkaline region (pH = 10 - 11).

The alkaline medium is highly corrosive to silicates and alumina-silicates though it prevents the dissolution of heavy metals. This means that the slag and corrosion compounds (Ca-Al-Si-O) are attacked. The shift of pH to alkaline region causes the gradual dissolving of Al-precipitate and increases the amount of $Al(OH)^{4-}/AlO^{2-}$ ions in the solution (Jenny, 1980). This explains the higher Al concentration in the leachate at pH > 10.

The $Fe^{2+/3+}$, Pb^{2+}, Cr^{3+}, Cu^{2+} and Zn^{2+} concentrations are very low in alkaline leachates (pH = 9 – 10). The work (Monhemius, 1977) dealing with the solubility of metal hydroxide explain the conditions under which heavy metals will not be released in the aqueous medium. The ion concentrations in the aqueous solution depend on the pH values as well as the electrode potential, which create all components of the solution. The measured values of the redox potential of the leachates were within the range of -80 to 10 mV (t = 20 °C). For measured ion concentrations (Al = 270 $mg.l^{-1}$; Ca = 400 $mg.l^{-1}$, Si = 2.8 $mg.l^{-1}$, S = 3.2 $mg.l^{-1}$ and Mg = 0.25 $mg.l^{-1}$) the Eh-pH diagram in the region of pH = 10 – 12 and E = –80 - +10 mV, predicates the following condensed phases: calcium-alumina-silicate-hydrate and gypsum [calculated by HSC/(Roine et al., 2011)]. If the leaching media are not changed continuously, then the saturation and precipitation occur. The spent MC bricks in the landfill have a similar influence on the heavy metals ions sorption as cement and concrete which are also an alkaline character (Kozáková et al., 2013, Plešingerová et al., 2015). The precipitation processes are very difficult and are affected greatly by the weather change in the landfills.

Spend refractory as secondary raw-materials

The main purpose of the recycling of the spent refractories is to recover a secondary raw material and minimise the landfills. Generally said, the recovered secondary raw materials are of the lower quality. For the recycling of the spent refractories, the most corroded parts of bricks must be mechanically separated in the stage of the lining demolishing.

From tested spent MC 98/10 bricks the enriched fraction (particle size > 1 mm) by sinter MgO can be obtained by disintegration and size separation (Tab. 2). The phase and chemical composition of the brick core are in correlation with the original refractory material. Carbon and alkali enrich fine fraction.

Leaching tests of magnesia-carbon refractories carried out in an aqueous medium pointed at the extent of the corrosion on the surface and in the core of bricks. The leaching amounts of Na^+, K^+ and S-ions from the surface and core are relatively low (Tab. 6). That confirms the intense diffusion of alkali and sulphur ions into bricks. Recovery of the secondary raw materials is dependent on the content of Na, K, Ca and Fe substances. The concentration of Na^+ and K^+ in the fraction class 1 – 2,5 mm of spent refractory are low (Tab. 2).

Recycling of sinter magnesia from spent MC 98/10 requires *i)* to remove mortar from the bottom part and the more corroded top surface of bricks (CaO content in leachates from the corroded surface is 5 times higher than from core); *ii)* to disintegrate and separate coarse fraction (particle size > 1 mm). Even if a magnetic part in debris is small, the magnetic separation is necessary. Burning of the material, which will remove carbon and this should increase the MgO content up to 90 – 93 wt.% in (1-2.5) mm fraction (Tab. 5). The phase and chemical composition, thermal stability, size and shape of particles, will determine the use of fractions.

The results mentioned above can serve as a starting point in searching for the utilisation of the spent MC 98/10 bricks as secondary raw material. The use of spent refractories depends on the processing cost and quality of the recovered coarse fractions.

Conclusion

Tested MC 89/10 lining from steel ladle was corroded by slag. On the strongly corroded surface of bricks, the content of Ca and Al compounds is higher, but there is the only small amount of magnetic components. The Na, K and sulphur are present in hundredths of wt.% only. The surface layer is difficult to separate from the less corroded brick core.

Magnesia-carbon refractories (MC 89/10) create the leachates with pH = 9 – 9.5. The corrosion of the slag accelerates leachability of corrosive compounds, what causes an increase of pH up to 12, independently of initial pH (4.21 – 5.95) of leaching medium. The content of extracted Ca^{2+} ions into water causes increasing of pH value. In addition to Ca^{2+}, sulphur, Al^{3+}, Na^+, K^+, less Si^{4+} and Mg^{2+} are leached. Ions of Na^+ and K^+, which are present in the surface layer and also in the core, are partially washable. The tendency to move and maintain pH in the alkaline region inhibits dissolving of the heavy metals from compounds. If the leaching medium is not continually renewed, then it becomes quickly saturated with Al^{3+}, Ca^{2+}, Mg^{2+} and Si^{4+} ions.

The C-content and impurities in the spent magnesia refractories predetermine debris to their use for the decontamination of the acid soils/water. This method of processing is not costly, but a portion of refractory materials is lost. It will be necessary to recycle material from MC bricks for recovery of MgO clinkers in the future. The recovery of the coarse fractions enriched by MgO-clinker (90 wt.%) requires the purification, i.e. disintegration, separation of coarse fraction, washing out and burning. The utilisation of the fine and dusty fractions as an additive to the slags depends on their physical and chemical properties.

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Process approach in the mining conditions

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The essential element of any system within an organisation is a process. The role of a process is to create values, which are generated by the transformation of inputs into outputs. Considering the fact that nowadays products are created on the basis of demand-management of the production, this transformation has to be managed in a way that the expected results are achieved at the output. It means the product will be in accordance with the specification (customer´s requirements). Without achieving this accordance, it is not possible to ensure customer´s satisfaction. The facts mentioned above are valid regardless of whether it is an organisation of production or non-production character. The application of the process management philosophy is possible also for the mining industry. The mining process is a process the realisation of which is financially very demanding. The most important part of process management is its planning. Planning activity determines 80% of the resulting effects. They are even more applicable to the mining process. Determining and selecting a suitable mining deposit is a strategic pillar for the planning of mining process. Understanding and application of process management is a necessary condition in order to achieve the success of mining organisation on the market.

Keywords: *Mining Process, Mineral Deposit, Process Approach, Process Control, Management.*

Introduction

Improving companies´ success means improving companies´ processes. Process approach in companies is nowadays a key to effectivity, economy and productivity. Conducting business process improvement (BPI) initiatives is a topic of high priority for today's companies. However, performing BPI projects has become challenging. This is due to rapidly changing customer requirements and an increase of inter-organisational business processes, which need to be considered from an end-to-end perspective. (Johannsen, 2017).

Organizations are increasingly concerned about business process model improvement in their efforts to guarantee improved operational efficiency. Quality assurance of business process models should be addressed in the most objective manner, e.g., through the application of measures, but the assessment of measurement results is not a straightforward task, and it requires the identification of relevant indicators and threshold values, which are able to distinguish different levels of process model quality. Furthermore, indicators must support the improvements of the models by using suitable guidelines (Sánchez-González, 2017). Improving the operational effectiveness and efficiency of processes is a fundamental task of business process management. There exist many proposals for process improvement patterns as practices that aim at supporting this goal. Selecting and implementing relevant process improvement patterns are therefore an important prerequisite for establishing process-aware information systems in enterprises (Lohrmann, 2016).

Creation of company processes management system has to be led in the sense of added value, which is created by these processes, to ensure their efficiency and effectivity with the aim of their continuous improvement. Process approach means adapting to customers´ requests and satisfying them, manufacturing products or providing services to customers, which is expected.

Material and methods

The application of process management philosophy depends on the process knowledge. It is important to know what activities are involved in the process, as well as what inputs are necessary for the implementation of the process in order to achieve the expected product. In the case of mineral extraction, the most basic inputs to this process are as follows:

- land (where mining will take place),
- amount of mineral raw material (bearing size)
- quality of mineral raw material,
- storage conditions,
- physical and chemical conditions,

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- geology (such as flooding and cleavage);
- rock stability conditions,
- mining technology (machines and equipment),
- mining technique (availability of methods, mining procedures and practice);
- skilled workers,
- financial resources (credits, subsidies, co-financing by the customer, etc.).

All of the above inputs are the basis for a layout of the mining procedures, the individual activities by means of which the raw material will be mined. All this is an important assumption that the mineral raw material is of interest and that the output that will be formed by the extracted raw material is intended for a particular customer. The implementation of the process in practice is always based on the requirement of the customer's interest. Today there are no companies that would realise processes with uncertain sales of their products without knowing their customers. This is still more applicable in raw material mining because the implementation of this process is economically one of the most demanding processes at all. For this reason, the overall suitability of the mineral raw material deposit must be determined before the mining itself (Fig. 1).

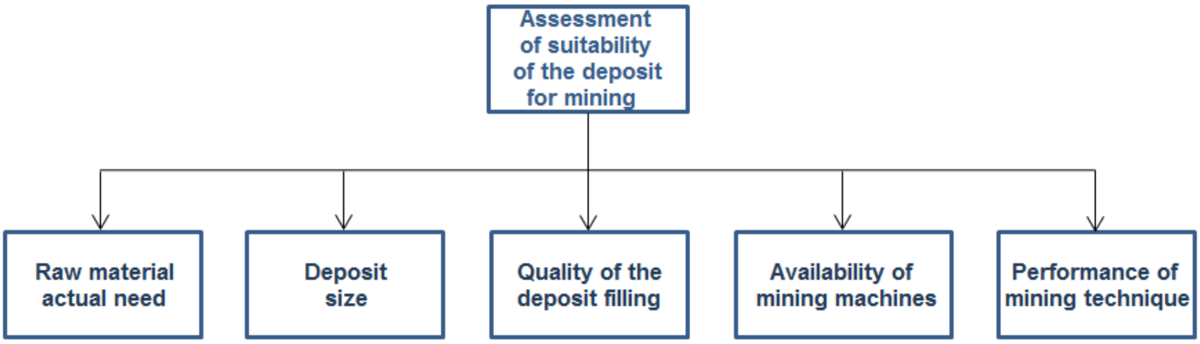

Fig. 1. Scheme of the deposit for mining assessment.

The deposit examination is the process by which the information on its usefulness is obtained. The deposit is basically located in the earth crust where the mineral raw material is extracted taking into account all economic and technological aspects. The earth crust is an earth surface cover the depth of 10-15 km. This range applies to the continents, in the place of the seas and oceans, the earth crust is known to the depth of 8 km.

Depending on this assessment, the individual mining procedures (activities) required to mining the raw material is also proposed.

It is also necessary to know the process of extraction from the point of view of each of the successive activities that make up it. These include, for example, the following activities:

- drilling works,
- blasting works,
- loading,
- transportation,
- crushing.

These activities are dependent on the input examination as well as on the knowledge of the customer specification related to the extracted raw material. This specification typically includes:

- amount of extracted mineral raw material,
- quality of raw material (fractions – individual representation).

Based on the above, the basic model of the mineral extraction process could look as follows (Fig. 2).

Figure 2 shows a basic model of the process that can easily map all the necessary inputs. These inputs can be grouped by affinity by applying the affinity diagram. This will result in a reduction in inputs, however not in terms of their total number, but in terms of the individual categories.

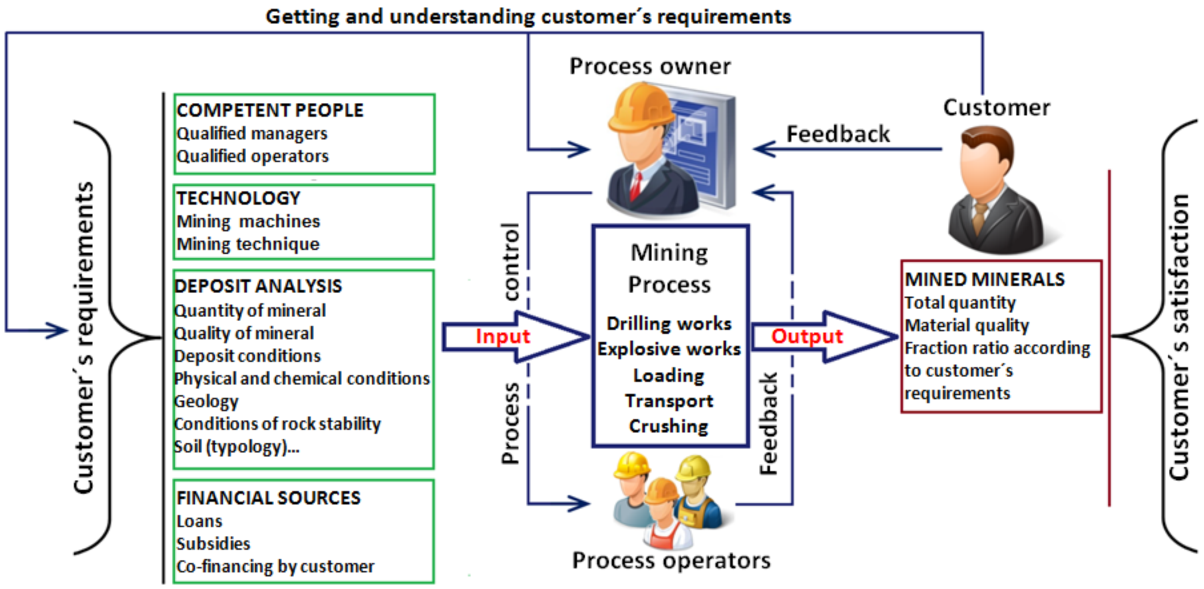

Fig. 2. Model of the mining process.

Results and discussion

The process modelling is based on the basic ideas, namely:

- the process has inputs (divided into several categories, the most commonly used in practice: people, machines, method, measurement, material, money, market, environment, information);
- the process consists of activities that are related or run simultaneously in order to achieve a transformation of inputs to outputs;
- the process has outputs (those represent products and/or services).

The input to the mining process

Referring to Figure 2, there are four basic groups of inputs that are essential to ensure the mining process. With the complexity of the mining process, the number of input categories may be too small. However, the purpose of categorising is to create a reduced number of inputs for easier management.

People

The basic input is presented by people. They are competent workers, starting with those who carry out individual activities at the extraction of raw materials, ending with the top managers responsible for the mining which should be in accordance with the customer specification, but also with the legislative requirements that apply to specific mining. In the figure, workers are illustrated directly above the process. It should be remembered that workers are one of the inputs to the process but hold the function of regulators, it means that they manage the process (individual activities) in the sense of approved mining procedures with respect to the customer requirements, legislation or land use planning in the region where raw material mining will be planned.

Today's business conditions are certainly characterised by rapid and unpredictable changes in both the environment and the company. In these business conditions, companies primarily need to remain flexible in order to manage to follow up changes in the environment, maintain their competitive advantage and remain competitive. Therefore, human resources in a company are strategically managed by defining a strategy of the development of human resources in the company, so it can be said that human resources in a company unquestionably become a part of the strategic management of the company (Karabasevic, 2015).

Machines

Another important input into the process of extracting raw materials are machines generally (in the picture as technology). This term is to be understood as technology, such as technical equipment for mining - machines and equipment such as, for example, loaders, bulldozers, excavators, conveyors, manipulators, etc. The second aspect of technology, as a category of input to the mining process, is technology - the mining technique chosen to extract the raw material. The procedures and instructions that define the correct course of these activities should be developed for each mining work. The content of individual procedures and instructions is based on the mining project.

Material

Any process without financing cannot be functional. This is still more applicable to the raw materials mining. The mining is so complex and financially demanding that it is unrealizable without funding by credit, subsidies, or co-financing by the customer. Therefore, it is necessary to consider the possibilities of real financing of the mining process before the mining itself.

Money

Any process without financial cannot be functional. This is all the more so when mining raw materials are extracted. Mining is so complex and financially demanding that it is unrealizable without funding for loans, subsidies, or co-financing by customers. Therefore, it is necessary to consider the possibilities of real financial support of the mining process before mining itself.

Mining process

In defining the mining process, it is appropriate to identify all the necessary activities of which the process itself is composed or by which it is formed. From the point of view of the simplified illustration, Figure 2 shows the basic activities that characterise the mining process, such as drilling, blasting, loading, transportation, crushing. The management of the mining process is carried out by the management of each of its activities.

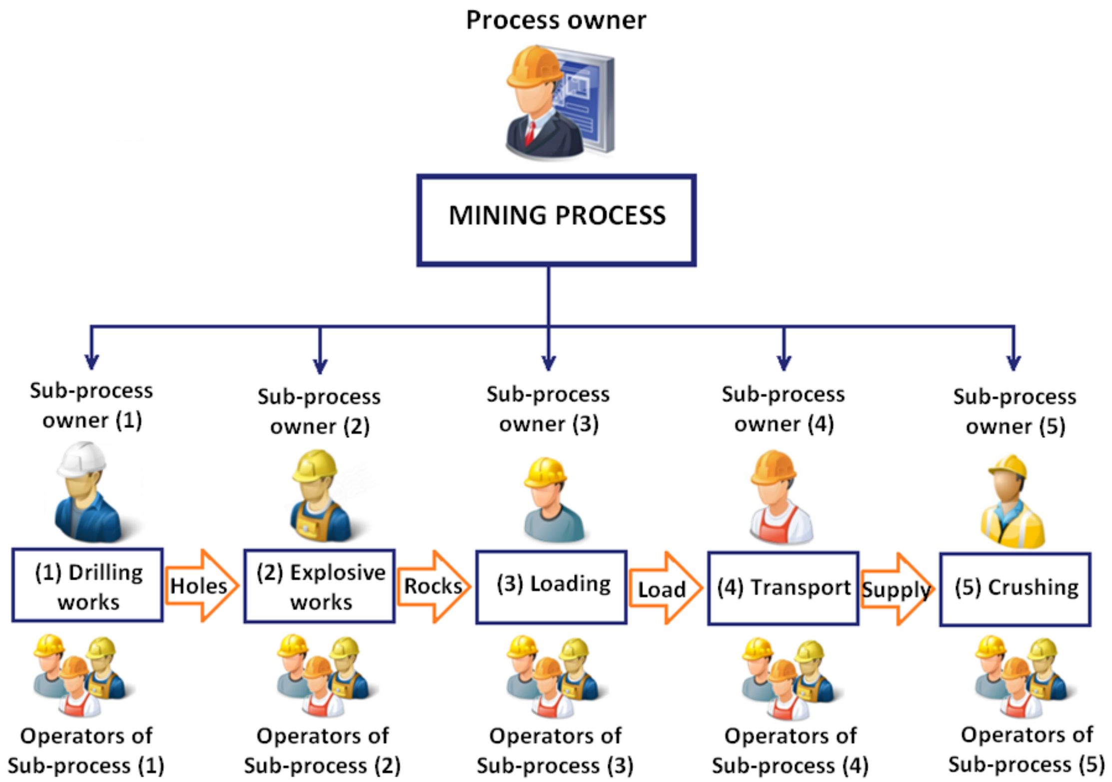

Fig. 3. Scheme of mining process management.

The basic condition of management of processes is the need to measure them. Unless the process is monitored through defined indicators, it is not possible to manage and subsequently improve this process. Therefore, it is very important for each activity to identify indicators that will give feedback to the process owner (process manager). The same principle can be applied to individual activities (Fig. 3). The operators of individual activities perform work according to the procedures and instructions while monitoring data within their activities. By their subsequent processing and analysis, they will serve for the responsible person to manage and improve it. The owner of X activity is responsible for his actions. Therefore, it is important to monitor and analyse data that provide him with information on its course and, if appropriate, give rise to action if the activity does not develop favourably with respect to the expected objectives. The same principle applies at the level of the whole process where the owner - responsible for the mining process on the basis of indicators in individual activities can evaluate the mining process as a whole.

The output from the mining process

The basic idea of process approach is that output from the first process is the input for next process. In mining process it means:

- Outputs from first sub-process (drilling works) are all holes needed as inputs for next sub-process (explosive works).
- Outputs from second sub-process (explosive works) are all free rock preparing for next sub-process (loading).
- Outputs from third sub-process (loading) are all transported free rock preparing for next sub-process (transport).
- The output from fourth sub-process transport) is a supply of free rocks for next sub-process (crushing). Crushing is the final sub-process of the mining process. The output from this is the final product for the customer. A necessary condition is: the product must conform with customer requirements. It means the required quality and quantity of fractions (Fig. 3).

The basic condition of process management is the necessity of its monitoring and measuring. Unless a process is monitored based on defined indicators, it is not possible to manage and subsequently improve such a process. Therefore, it is very important to define indicators for particular processes, which will provide their owner with feedback about its course. It is possible to use the same system with particular sub-processes (Fig. 3). Operators of particular sub-processes do the work according to the processes and instructions while monitoring (collecting) data. These will, being subsequently processed and analysed, serve the sub-process owner for management and improvement. Based on various trends of monitored indicators in time, it is possible to take measures should the sub-process not develop favourably with respect to the expected aims. The same principle is valid on the level of the whole mining process when the owner – responsible for the mining process based on indicators in particular sub-processes can evaluate the mining process as a whole.

The output from the mining process is a mined raw material that has to meet customer requirements. These relate in particular to the quantity and quality of the mineral raw material. The amount is determined by conventional weight or volume units (such as a tone or m3). The quality indicator of the extracted raw material refers to its fractions (grain size). This means that the representation of the individual fractions, as well as the amount of raw material used in the individual fractions, is assessed. When looking at the simplified scheme of the related activities of the mining process (Fig. 3), it is obvious that each of these activities contributes to the resulting perceived quality of the extracted raw material. Looking at the model of the mining process (Fig. 2), it can be seen that the whole mining process begins with the exploration of the deposit. In particular, it is a geological examination which includes an assessment of the physical and chemical conditions. Just on the basis of this examination, the process of individual mining activities can be chosen. The deposit examination is, therefore, the first and very important step that provides information on the fact which drilling method will be right. Although the geological examination is very important in terms of setting up other procedures related to the extraction of raw materials, the information from it can be compared to the statistically processed data obtained from serial production. In either case, the data does not give a 100% picture of the facts; it is still just sampling. This means that the image of the whole complex (condition of the deposit, or the manufactured parts) is only assumed on their basis. From this point of view, it is very important to determine the parameters that affect the resulting quality of the extracted raw material.

Conclusion

The management of any organisation has to be built on the management of its processes. In reality, it means clearly specified processes, which means knowing the inputs into the process, activities the process will consist of, and outputs. A very important factor is getting feedback which will provide information whether there are expected inputs at the input, whether the process is realised by planned activities and whether at the output, there is a product which meets customer´s requirements.

Mining of raw minerals differs significantly from other industrial processes. Each deposit is unique; it means that it is characterised by other geological conditions and an organisation that decides to exploit the mineral raw material cannot change these characteristics. They have to be simply respected, and their potential influence in planning the mining process must be taken into account. These are the conditions created by Mother Nature itself. In the case of other industrial processes, the organisation itself creates the conditions for their implementation.

The basic geological characteristics that make up the initial input into the mining process are mainly:

- the concentration of mineral raw material in the rock,
- quality of mineral raw material,
- conditions of rock stability,
- storage condition,
- physical and chemical conditions,
- flooding,
- cleavage and others.

Looking at the geological characteristics of a potential mineral deposit, they can be divided into two groups, namely:

- characteristics with an impact on the course of the exploitation (such as flooding, the presence of gases, stability conditions, etc.),
- characteristics with impact on the resulting quality of raw material used (concentration of mineral raw material, quality of mineral raw material, grain size - mineral raw fractions, etc.).

The impact of flooding or the presence of various impacts can significantly affect planning as well as the actual course of the mining process. However, the presence of water or gas does not have an impact on the resulting quality of the extracted raw material. Therefore, the mining organisation must take into account their impact on the process in order to ensure working conditions that comply with safety regulations in accordance with the legislation applicable to mining work. Although these geological characteristics do not affect the quality of the raw material, their impact on the process must also be seen in terms of financial costs, since the potential deposit should, in that case, be rid of excess water that may have a negative impact on the overall stability of the rock. Similarly, this also applies to the occurrence of gas, which can either be discharged from the deposit or the workers are equipped with breathing apparatus. The financial costs associated with the occurrence of the above geological characteristics of the deposit should be understood both as a part of providing a different technique minimising the negative impacts on the course of the mining and its overall prolongation in terms of time.

The influence of the grain size of the mineral material present in the deposit has a significant effect on its final quality. If the grain size of the mineral raw material in the deposit is greater than required, in such a case its treatment can be assured by crushing process to achieve the desired size.

If the grain size is smaller, there may be a situation that the customer's interest will not be satisfied. In this case, the chance is to offer this raw material to the same or another customer, but at a lower price.

The impact of the mining processes is in strong interaction with the input geological characteristics of the deposit since the individual mining processes are planned and subsequently implemented. As stated above, the grain size is one of the characteristics that significantly influence the resulting quality of the output - the raw material, but from the exploitation of the deposit potential to obtaining the resulting mineral raw material of the required quality, it is necessary to mine it. It is just the initial mining processes that are crucial in determining the final quality. This is primarily about drilling and blasting work. In case the mineral raw material is in the desired grain size, it is crucial to choose the correct procedure for the following processes as they can significantly affect the resulting quality of the raw material.

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Flood vulnerability assessment of Bodva cross-border river basin

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The disasters of the past few years have shown the importance of prevention and preparedness, not only in Hungary and in the Slovak Republic, but all over the world. In 2010, the floods of the rivers Hernád/Hornád, Sajó/Slaná and Bódva/Bodva caused serious problems for these nations, affecting several settlements with thousands of inhabitants. The inhabitants and enterprises of the targeted area come in for the results from the flood risk assessment, by having a more secure environment. The methodology is applicable in other water courses in Hungary and in the Slovak Republic as well in the other countries. The aim of the presented study was to assess the distribution of flood-risk potential at the regional scale. A progressive approach integrating geographical information system (GIS) with method of multicriteria analysis (MCA) – analytic hierarchy process (AHP). In the analyses, the most causative factors for flooding were taken into account such as monthly precipitation, soil type, land use, basin slope. A case study of flood vulnerability identification in the Bodva catchment area has been employed. Spatial estimation of flood-risk potential should be one of the basic steps for complex geo-ecological evaluation and delimitation of landscape considering water resources management, groundwater pollution, prediction of soil erosion and sediment transport and some other important landscape-ecological factors. The obtained results indicate that AHP method shows good results as related to the existing floods in the recent years in Bodva catchment.

Key words: *flood vulnerability, geographical information system, multicriteria analysis*.

Introduction

The disasters in Hungary and Slovakia are linked mostly to extreme weather. The number and effects of natural disasters increased significantly and caused more loss than ever before. The floods of May and June 2010 in the valley of Bodva and other rivers flowing from Slovakia to Hungary demonstrated the importance of time during an emergency and the necessity of new systems and methodologies to reduce the damages, protect human lives and material goods (Blišťanová et al., 2016; Zeleňáková et al., 2018).

The increase in damage due to natural disasters is directly related to the number of people who live and work in hazardous areas and where their property is accumulated (Petrow et al., 2006; Van Alphen et al., 2009, Kiss et al., 2014). Flood risk analysis provides a rational basis for prioritizing flood protection and flood management activities. Risk analysis can take many forms, from informal methods of risk ranking and risk matrices to fully quantified analysis joined with modelling (Merz et al., 2010). The multi-criteria analysis method (MCA) is widely used scientific approach, which may be implemented in the GIS environment for risk-mapping of populations or regions and for identification of risk zones (Blistanova, Blistan, 2014). An analytical hierarchy process (AHP) is one of the most widely used multicriteria method based on the pair-wise comparisons in order to create a ratio matrix and estimate a ranking or weighting of each of the evaluated criteria (Saaty, 1980). Multicriteria analysis (MCA) methods have been applied in several studies in flood risk assessment. Chandran and Joisy (2009) introduced an efficient methodology to accurately specify the flood hazard areas in Vamanapuram river basin using GIS. Yalcin and Akyurek (2004) applied a GIS and multicriteria analyses to evaluate the flood-vulnerable areas in south-west coast of the Black Sea by the ranking method and pairwise comparison method. Tanavud et al. (2004) assessed the risk of flooding and identified efficient measures to reduce flood risk in Hat Yai Municipality, southern Thailand using GIS and satellite imagery. Yahaya et al. (2010) identified flood vulnerable areas in Hadejia-Jama'are river basin Nigeria by using a spatial multicriteria evaluation technique – pairwise comparison method, analytical hierarchy process and ranking method. Scheuer et al. (2011) present an approach to modeling multicriteria flood vulnerability in the city of Leipzig in Germany, which integrates the economic, social and ecological dimension of risk and coping capacity. Meyer et al. (2009) developed a GIS-based multicriteria flood risk assessment and mapping approach and applied it for the River Mulde in Saxony, Germany. Kandilioti and Makropoulos (2012) applied three MCA methods: analytic hierarchy process, weighted linear combination and ordered weighting averaging in GIS environment to produce the flood risk map of the Greater Athens area and validated it for its central and the most urban part. Ramlal and Baban

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(2003) used GIS to map the extent of the flooding area, estimate soil loss due to erosion and estimate sediment loading in the rivers in the Caparo River Basin in Trinidad and Tobago. Scolobig et al. (2008) applied social multicriteria evaluation to analyze a recent case of controversy in flood mitigation in Malborghetto-Valbruna (Northern Italy) and to improve flood-mitigation decision processes. Two different multicriteria decision rules, a disjunctive and an additive weighting approach, were utilized for an overall flood risk assessment in the area (Şerban et al., 2016). Kenyon (2007) introduced study builds on existing deliberative processes to develop a new participant-led multicriteria method to evaluate flood risk management options in Scotland. The results show that participants preferred regeneration or planting of native woodland to other flood management options, and least preferred building flood walls and embankments (Simonovic, 2002). Wang et al. (2011) used a semi-quantitative model and fuzzy analytic hierarchy process weighting approach for assessment of flood risk in the Dongting Lake region, Hunan Province, Central China, an area where flood hazards frequently occur. The obtained results can provide useful information for decision makers and insurance companies. Papaioannou et al. (2015) presented a framework for mapping potential flooding areas incorporating geographic information systems, fuzzy logic and clustering techniques, and multi-criteria evaluation methods. Results show that multiple MCA techniques should be taken into account in initial low-cost detection surveys of flood-prone areas and/or in preliminary analysis of flood hazard mapping. Rahmati et al. (2015) assessed the efficiency of analytical hierarchical process to identify potential flood hazard zones by comparing with the results of a hydraulic model. Four parameters via distance to river, land use, elevation and land slope were used in some part of the Yasooj River, Iran. The results showed that the AHP technique is promising of making accurate and reliable prediction for flood extent. Therefore, the AHP and geographic information system techniques are suggested for assessment of the flood hazard potential, specifically in no-data regions. Romanescu et al. (2016) examined the vulnerability of the population and buildings of a village situated in the eastern part of the Eastern Carpathians by applying the multicriteria method, areas with high flood vulnerability were pointed out in the Sucevita catchment.

The flood vulnerability model to be developed gives the possibility to forecast the flooding risks which means highly valuable information for both Slovakian and Hungarian Disaster Management Directorates and Water Management Companies as well as for inhabitants of the area. The results of this paper will help to flood risk management in the study area and support the decisions of the actions of inhabitant flood protection and present a valuable knowledge for research in the field of flood risk mitigation.

Study area

Bodva River rises in Slovakia, on the southern part of Slovenské Rudohorie (the Slovak Ore Mountains) at the foot of the 1187 m high peak Osadník. The total catchment area is 1733 km^2, of which 867 km^2 in Hungary. 97 towns and villages are located in the catchment area, including 42 in Slovakia. Bodva Valley can be divided into the following sections:

- Upper Bodva Valley: narrow and deep valley of ore mountain above Medzev; expanding swampy valley in the atrium of ore mountain;
- Košice basin;
- Bottom Bodva Valley: valley of uniform width above Perkupa (Hungarian "upper valley"); Gorge Szalonna; Basin Szendrő; Gorge Szendrőlád; Entrance to the Slaná valley, near Edelény.

The river flows 111 km and after the village Boldva mouths into Slaná River, in its river kilometre 69.3. Several millennia of human presence in the basin Bodva and conversion of land as a result of his actions reflect current coverage of the country. As a result of human activity occurs in excessive downstream communities including grassland. Such territories include the once cultivated arable land and orchards extending the border villages. Marshy meadows and continuous alder stands can also be found along waterways. These were previously much more widespread, but because of the machining of fertile valleys along streams, most of them narrowed only a narrow area along the flow. Mining activity (coal, iron ore), which was previously characterised for the basin and its adjacent areas, no longer exists, except in mining gypsum. There is no major industrial plant near the river. Water quality in Bodva River influences Hungarian sources of pollution and also pollution originating from the territory of Slovakia. To protect water quality, it can be considered fortunate that in the river basin there is practically no industrial production, therefore polluting industrial process is not significant. There are no specific data on the pollution that gets into Bodva. A role of runoff and precipitation are important regarding the pollution characteristics; due to changes in the flow the pollutants are mixed with water in different/changed ratio. From an agricultural area, pollution gets into the groundwater and then to the river by a splash of fertilisers and plant protection products/nutrients.

The studied region – Bodva watershed (Fig. 1.) – covers a rural area with inhabitants living mostly from agriculture. Tourism potential is also evident and prioritised.

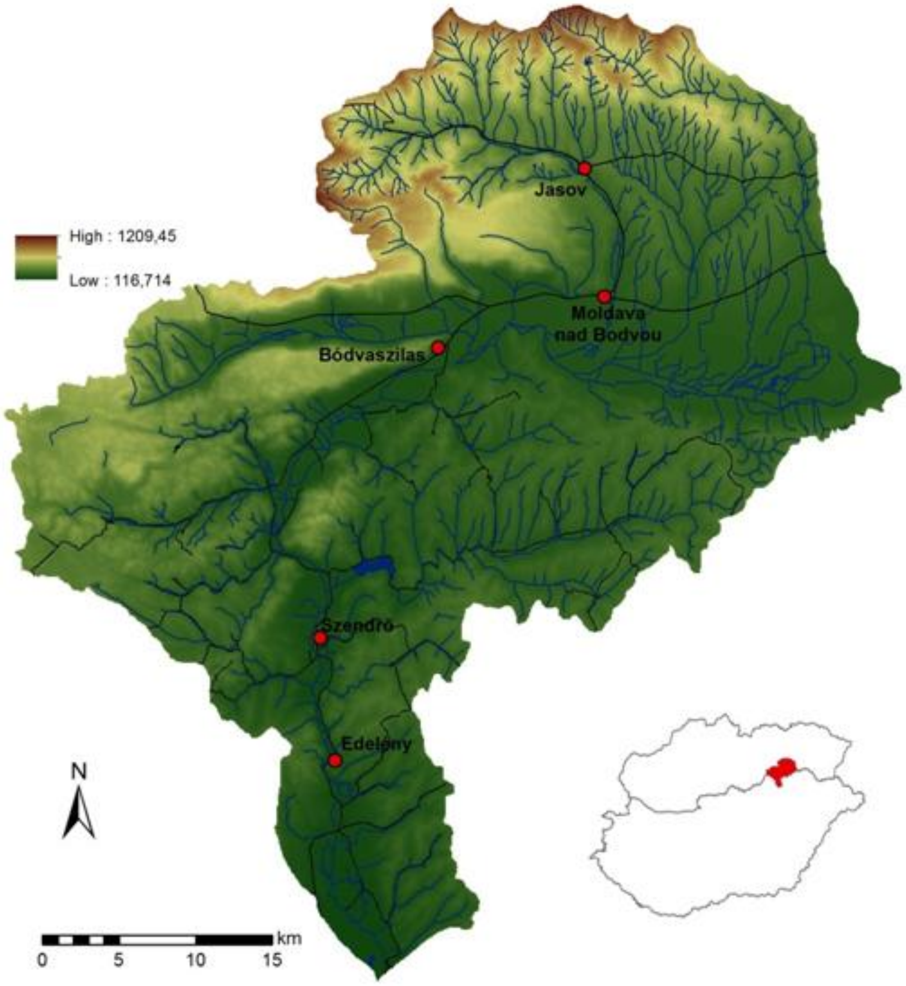

Fig. 1. Bodva watershed.

In general, the area is classified as an underdeveloped region, with inhabitants of low income and living standards. The educational level is generally low; the proportion of the population living on a very low level of living standard is very high compared to the national averages. The regional development plans focus mainly on the agricultural and tourism potential and aim to increase the level of education and life quality through the support of the small and medium enterprises. These SMEs are mainly involved in the agricultural sector and the processing of the local products. This agricultural potential and also the area of the settlements and the human infrastructures are endangered by the flooding and ponding waters. The safety of the agricultural production, the clean environment and the building infrastructure is highly important in a region like this, where the majority of the properties have no insurance. Due to the lack of financial means and savings, any damage occurring in these properties is critical and requires major efforts from the governmental organisations to revitalise the area without any relevant self-contribution to decrease the negative impacts of the natural, flood damages.

Materials and methods

Water resources management is one of the fields in which multicriteria methods have been used extensively. Multicriteria analysis (MCA) has been applied in many flood risk assessment management studies (Scolobig et al., 2008; Boroushaki and Malczewski, 2008; Meyer, 2009; etc.); some of them are already mentioned in the introduction. GIS has been developed and often applied to examine spatial and temporal patterns of flood occurrence with the main aim to find associations among geographical factors causing flood evens (Ramlal and Baban, 2003; Romanescu and Stoleriu, 2014; Diaconu et al., 2017).

We used the multicriteria method – the analytic hierarchy process (AHP) (Saaty, 1980) for determining flood vulnerability. The methodology of flood vulnerability map development is presented in the flowchart in Figure 2.

The analytical hierarchy process is employed for rating a set of alternatives or for the selection of the best of alternatives.

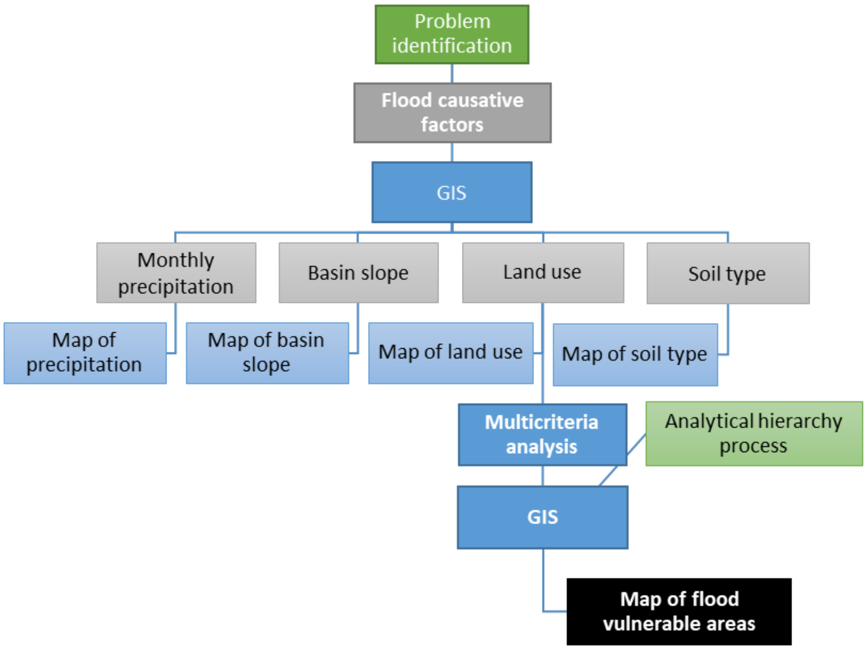

Fig. 2. The methodology of flood vulnerability map development.

The initial data required for this study were acquired from the Atlas of the Slovakian Landscape, and further data were provided by Slovak Water Management Enterprise, s.c. Kosice, Soil Science and Conservation Research Institute, Slovak Hydrometeorological Institute.

Basically, two phases are applied in this study to analyse flood vulnerability: firstly, to identify the effective factors causing floods – the potential natural causes of flooding, and secondly to apply the method of MCA in GIS environment to evaluate the flood vulnerability of the area.

Choosing the risk factors

The first step in assessing the flood vulnerability in the Bodva catchment was the selection of hydrological and geographical factors which can influence the flood occurrence. We have selected: monthly precipitation, soil type, basin slope, land use. The data were obtained from Hydrometeorological Institute (precipitation); Soil Science and Conservation Research Institute (soil type); Digital Terrain Model (basin slope) and Corine Land Cover (land use). The next step was a determination of classes of each factor and importance of factor's class, as shown in Table 1.

Tab. 1. Risk factor's class and his importance.

Risk factors	Risk factor's classes	Importance of factor's class ($RF_{q,t}$)
Monthly precipitation	0 – 54.9 mm	1
	55 – 59.9 mm	2
	60 – 64.9 mm	3
	65 – 69.9 mm	4
	70 mm and more	5
Soil type (content of clay particles)	0 - 10 %	1
	10 -30 %	2
	30 - 45 %	3
	45 - 60 %	4
	60 % and more	5
Basin slope	0 - 15%	1
	15 - 30 %	2
	30 - 45 %	3
	45 - 80 %	4
	80 % and more	5
Land use	forest	1
	pastures and meadows	2
	agricultural land	3
	urbanised area	4
	water area	5

The risk factor´s classes according to Table 1 are presented in the separate factors maps in Fig. 3-6. ArcGIS 9.3 was used for transferring data to the appropriate GIS layers. Maps in Figures 3-6 present the real values of the risk factor in the river basin as well as reclassification according to Table 1.

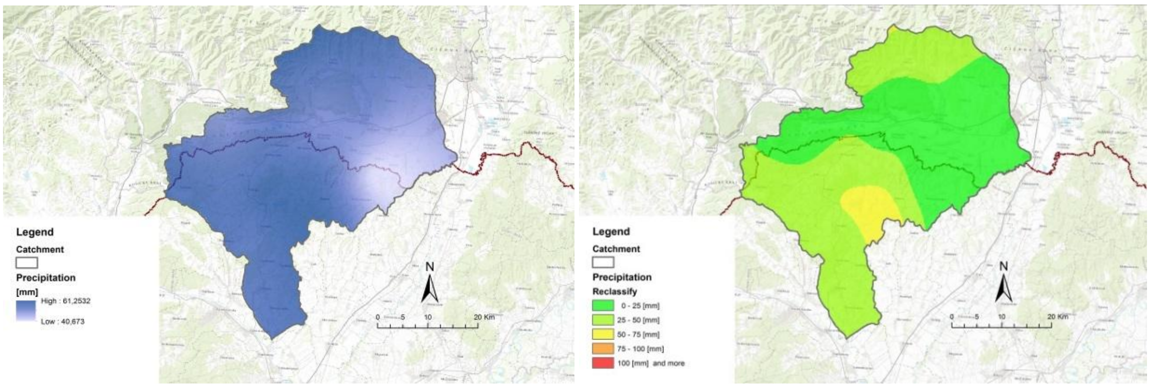

Fig. 3. Map of daily rainfall.

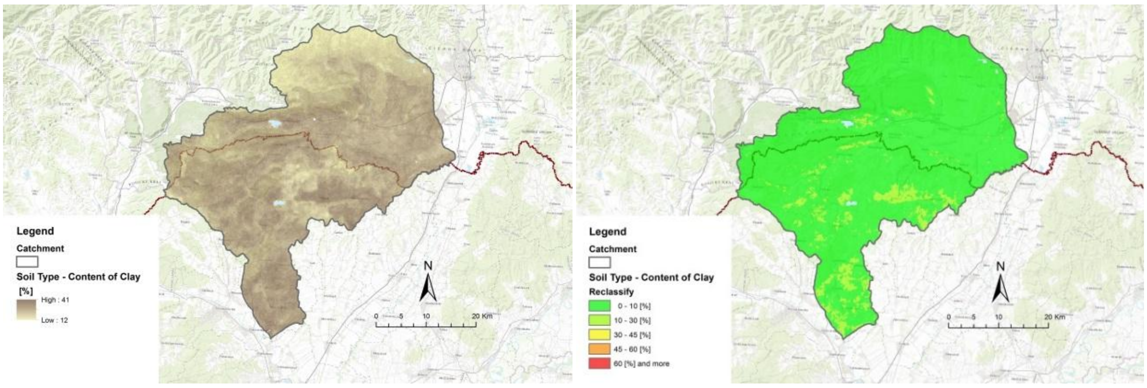

Fig. 4. Map of soil types. Weight-percentage of the particles with diameter <0.01mm.

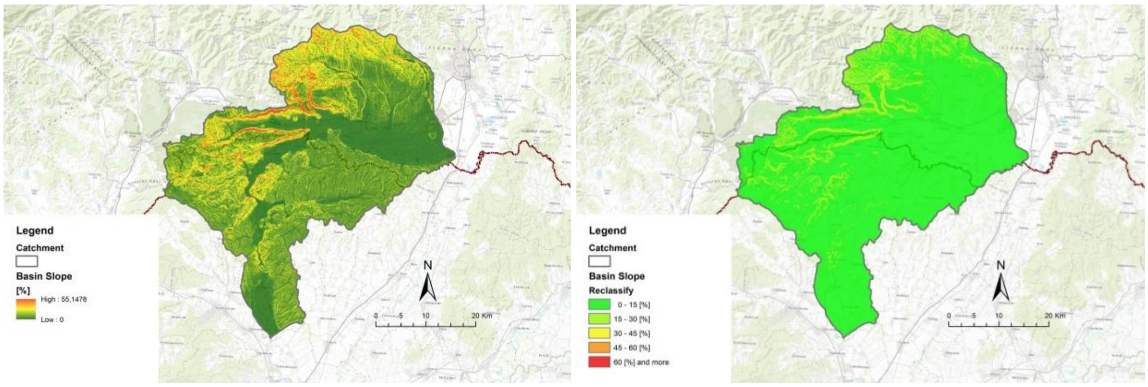

Fig. 5. Map of basin slope.

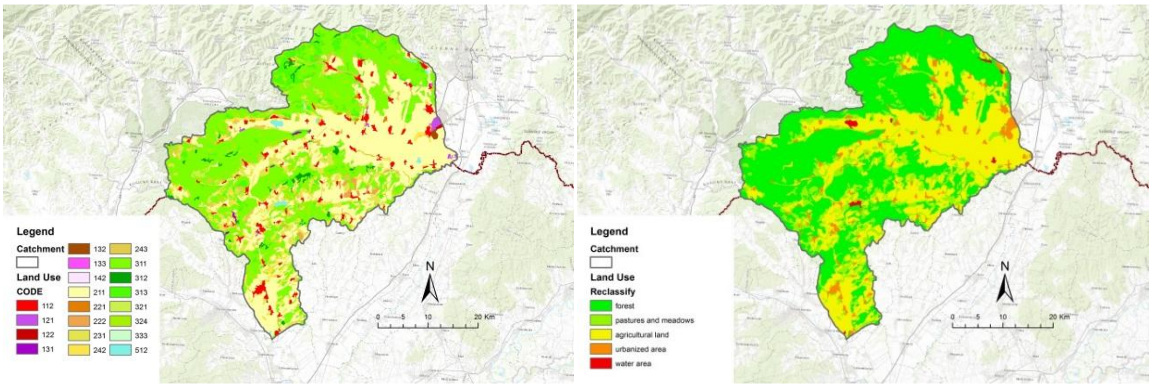

Fig. 6. Map of land use.

MCA method: analytical hierarchy process was used for defining the flood vulnerability in Bodva river basin. The spatial variability of flood vulnerability is an important part of flood risk assessment on the national level, as well as for application of spatially differentiated approaches to flood defence strategy (Solín and Skubinčan, 2013). The multi-criteria analysis ends with a more or less stable ranking of the given alternatives and hence a recommendation as to which alternative(s) should be preferred.

Defining flood vulnerability areas using MCA – AHP

The analytical hierarchy process (AHP) developed by Saaty (1980) was applied for the determination of the importance of selected causal factors. The matrix of pairwise comparison of causative criteria (Table 2) was used to assess the degree of significance of the individual criteria and measures, and to determine how the evaluated variants fulfil the resolution of these criteria. AHP method is a structured mathematical technique for organising and analysing complex decisions. Assessments are based on expert estimates by comparing the mutual influences of two or several causative factors based on the selected scale (Saaty, 1980) in order to obtain the relative importance of selected factors. The relative weight of selected criteria was based on an iterative process and the matrix of pairwise comparison, where the matrix Ā of type p x p (i.e. it has p rows and p columns) was calculated by the normalisation of the columns A (Boroushaki & Malczewski, 2008) according to the relation:

$$\overline{A} = \left[RF^{*}_{qt}\right]_{p \times p} \tag{1}$$

For calculation of the element of the matrix a^{*}_{qt} , the relation applies (2):

$$RF^{*}_{qt} = \frac{RF_{qt}}{\sum_{q}^{p} RF_{qt}} \tag{2}$$

The matrix Ā x Ā was calculated and normalised in $\bar{A}_2$, subsequently $\bar{A}_3$, ..., $\bar{A}_z$ were calculated until all columns of the obtained matrix are identical. The column then gives the vector ω defined by the relation (3):

$$\omega_q = \overline{RF}^{*}_{qt(z)} \tag{3}$$

for all $q = 1, 2, ..., p$

Tab. 2. The matrix of pairwise comparison of causative criteria and calculation of the normalised weight of criteria.

	RF_{MP}	**RF_{ST}**	**RF_{BS}**	**RF_{LU}**	**Weight**
RF_{MP}	1.00	5.00	5.00	7.00	0.49
RF_{ST}	0.20	1.00	3.00	5.00	0.09
RF_{BS}	0.20	0.33	1.00	5.00	0.17
RF_{LU}	0.14	0.20	–	1.00	0.25
Sum	1.54	6.53	9.20	18.00	1.00

The resulting vulnerability was calculated using the following formula (Eq. 4):

$$V = \sum (RF_{1j}W_1 + RF_{2j}W_2 + RF_{3j}W_3 + RF_{4j}W_4) \qquad (4)$$

where: V is a vulnerability, RF_{1j}, RF_{2j}, RF_{3j}, RF_{4j} are the importance of factor's class, and W_1, W_2, W_3, W_4 are the normalised weights for each criterion.

Results and Discussion

The result of our assessment is the categorisation of the flood vulnerability of the Bodva catchment into four flood risk classes. The flood vulnerability was evaluated in four classes – acceptable, moderate, undesirable and unacceptable (Table 3) – arranged according to MILSTD 882D Standard practice for system safety. The results are inevitable for the flood risk management and proposing flood mitigation measures for the most vulnerable territories. Vulnerability´s classes were divided using Box plot method (Tukey, 1977). The obtained results from software ArcGIS 9.3 are presented in Fig. 7.

Tab. 3. Vulnerability acceptability and its significance.

Vulnerability rate / acceptability	The significance of flood vulnerability in the watershed	Scale of vulnerability
1 / acceptable	Vulnerability in watersheds are acceptable – current practice	1 – 1.73
2 / moderate	Vulnerability in watersheds are moderate – the condition of continual monitoring	1.73 – 2.13
3 / undesirable	Vulnerability in watersheds are undesirable – flood protection	2.13 – 2.46
4 / unacceptable	Vulnerability in watersheds are unacceptable – immediate flood protection	2.46 and more

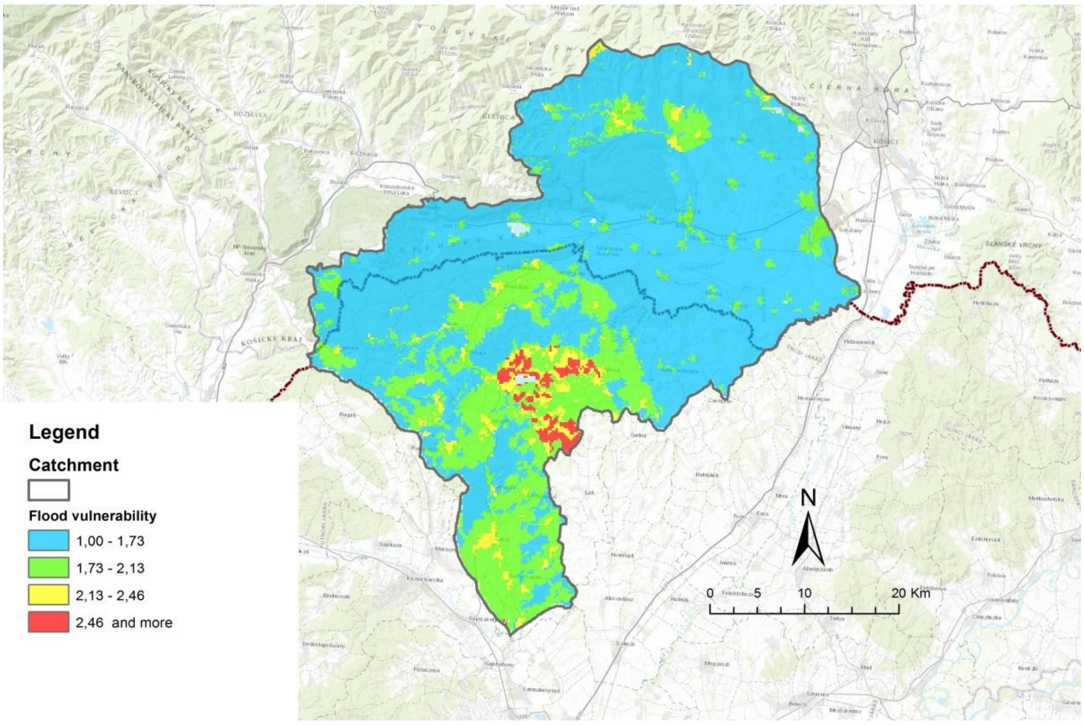

Fig. 7. Map of flood vulnerability in the study area based on the analytic hierarchy process.

The flood vulnerability assessment based on the analytic hierarchy process shows that the Bodva river basin is formed mainly by areas with acceptable and moderate undesirable flood vulnerability. Zones with the undesirable and unacceptable level of flood vulnerability were also identified, but with only relatively small areas. The undesirable and unacceptable zone covers only some part of the hilly Cserehát Region in Hungary and represents 3 % respectively 1 % of the study area. Moderate vulnerability zones in 24 % of the study are also mostly in the Hungarian part of the watershed. Acceptable flood vulnerability is covering 72 % of the assessed area mostly in Slovakia.

Flood vulnerability is a joint effect of two independent mechanisms natural conditions and the human activities in the basin. The primary impulses of floods are usually extremely intense precipitation. The total catchment's hydrological response to intense rainfall is determined by its natural environment, a whole complex of characteristics of the watershed.

The results are mostly coincident with the results from preliminary flood risk assessment which has to be done in the Slovak Republic in 2011 (Zeleňáková and Gaňová, 2011).

It should be noted that AHP method shows suitable results of flood vulnerability assessment as related to the existing floods in the recent years. It is a suitable method for analysing the flood-vulnerable area. The development of this assessment for whole Bodva catchment has the advantage that there is a method which is easy to apply.

As described above, we created multicriteria vulnerability map for Bodva river basin. The results obtained from this assessment indicate the importance of the determination of flood-vulnerable areas for decision makers in water management, especially in the flood risk management.

Conclusion

Rivers act as natural connectors between Slovakia and Hungary due to the geographical and hydrogeological features of these countries. Slovakia and Hungary are concerned mutually in conservation and protection of the rich ecosystem of the related areas and shielding the settlements along the riversides.

This paper presents a work carried out in the Bodva river basin involving the use of GIS tools and multicriteria analysis methods to generate maps of flood vulnerable areas. Basically, two phases are applied in this study to analyse flood vulnerability: firstly, to identify the effective factors causing floods – the potential natural causes of flooding, and secondly to apply methods of MCA in GIS environment to evaluate the flood vulnerability of the area. The level of flood vulnerability was evaluated in four classes (acceptable, moderate, undesirable, and unacceptable). The composite map (Fig. 7) showing the flood vulnerability provides the results based on the use of the multicriteria method in ArcGIS software. A flood vulnerability risk map can be a quick decision support system tool to study the impact of planned human activities on the catchment area.

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Development of GPS and GIS-Based Monitoring System for the Quality of Excavated Coal

***Bayram Ali Mert*[1] and *Ahmet Dag*[2]**

Because of the advancement of geospatial technologies such as GIS and GPS integration, many mining companies have started to use the technology for mine planning, analysis and management. In this context, this study focuses on real-time monitoring of the excavated coal quality using GIS and GPS integration. For this purpose, firstly, digital maps and tabular quality data were created by analysing the drill holes data, and then they were combined under the GIS environment by writing a MapBasic computer application using Visual Basic. The application consists of three sections. A GPS section that awaits the coordinate information that will be received over the GPS and that makes coordinate transformations; a map analysis section that functions in order to view digital maps and track shovel or trucks on the screen and the point-block-quality query section allows flexible data extraction, based on the structured query. Finally, by mounting a GPS receiver on the bucket wheel excavators in exemplary opencast coal mining, the monitoring of the excavation point over the digital maps were enabled , and the monitoring of the stock accounts as a database for the quality data such as the amount, LCV, MC%, and AC%, simultaneously with the coal production were provided.

Key words: *GIS, GPS, Geostatistics, Afsin-Elbistan Coal Basin, Opencast Mining*

Introduction

The mining industry is changing as the industry is becoming increasingly competitive. To keep pricing low, mining companies have been turning to advanced automation technologies to keep up. In this context, beneficiations practices such as selective mining and blending-homogenization processes are increasingly gaining prominence, and this requires both effective production management and planning. As well as the increase in efficiency, companies are also looking to ensure that safety is at the top priority. For this reason, with the increasing popularity and functional development of geospatial technologies such as Geographical Information System (GIS) and Global Positioning System (GPS), many mining companies have started to use the technology as the preferred tool for mine planning, analysis, and management (Zhou et al., 2007; Wang et al., 2011; Craynon et al., 2016).

In general, GIS is a computer system capable of assembling, storing, manipulating, and displaying layers of geographically referenced information, i.e., data identified according to their locations (Carranza, 2008). The system replaced old map-analysis processes, traditional drawing tools, and drafting and database technologies. In GIS, each layer of spatial data is linked to corresponding tabular information (Harris and Barrie, 2006). Each object on the map layers has location-coordinate information in which the objects are defined and expressed on the map (Bonham-Carter, 1994). For the extraction of the location-coordinate information, or the need to access GIS data over the location, data producing devices are quite important and difficult to use. In this respect, the Global Positioning System (GPS) receivers, which can measure at a sensitivity of 1-2 cm, has been used as the most practical alternative to classical data extraction methods (Trimble, 1999; Misra and Enge, 2010). GPS is well known to work independently and provide real-time data for construction equipment (Behzadan et al., 2008). GPS devices are also affordable and easy to install. The data it provides can also be analysed with relatively little computational effort (Pradhananga and Teizer, 2013). The GPS positional accuracy enhances the functioning of GIS by improving the spatial quality of GIS data. The integration of GPS as a spatial data source for GIS makes it possible to successfully combine features accurate geographic coordinates and the corresponding attributes and values of that feature.

A number of GPS and GIS studies on the mining activities are available in the literature. Mainly, Gili et al. (2000) have discussed the applicability of the GPS to the monitoring of landslide surface displacements and achieved high-precision measurement results. Prakash et al. (2004) have designed and installed GIS based system for managing surface and underground fires in coal mining areas; Nieto and Dagdelen (2006) have developed a vehicle proximity warning-collision avoidance system to improve safety of trucks in open pit mines; Gu et al. (2008) have designed and developed an intelligent monitoring and dispatch system of trucks and shovels in an open pit mine; Salap et al. (2009) have developed a GIS-based monitoring and management system for underground mine safety in three levels as constructive safety, surveillance and maintenance, and emergency; Mancini et al. (2009) have monitored the ground subsidence by using GPS in a salt mine, and created a hazard map using the GIS techniques; Enji et al. (2010) have monitored the trucks on 3D maps to reduce mining

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accidents and indicated that 3D assisted driving system has the potential to increase reliability and reduce uncertainty in open pit mining operations by customizing the local 3D digital mining map; Qinghua et al. (2010) have designed and developed a dynamic management system of ore blending in an open pit mine by using GIS and GPS. Briefly, these studies carried out in particular on the subject of monitoring the trucks and shovels and/or increasing the safety in open pit mines. In this study, a system that was not previously in the literature to monitoring quality of the excavated mine was discussed. To this end, Afşin- Elbistan-Turkey opencast coal mine which is equipped with six bucket wheel excavators was selected as an exemplary mining area, and the system approach has been established to monitoring the qualities of the excavated coal.

The study consists of two sections. In the first stage, preparation of GIS database containing the quality data of the opencast coal mine; and in the second stage, development of a monitoring system for the coal qualities, have been discussed.

Preparation of GIS Database

In this section of the study, firstly, all geologic and sampling data such as *x*, *y*, *z* coordinates, dip and azimuth angles of drill holes, lithological definitions of samples taken from drill holes, lower calorific value (LCV), ash content (AC%), moisture content (% MC) on an as-received basis, core recovery area entered and maintained in an electronic database (Fig 1). Then, coal basin was divided into blocks sized 2.5 m x 100 m x 100 m, and average quality values of the blocks were estimated using 3D geostatistical analyses described graphically in Fig. 2. In these analyses, respectively, an appropriate theoretical variogram models were determined, cross-validation methods were performed to the variogram model, and representative estimates and their errors were generated for a volume by kriging interpolation techniques which were further discussed in detail in Mert (2010), Mert and Dag (2015, 2017), Singer and Menzie (2010) and Srivastava (2013).

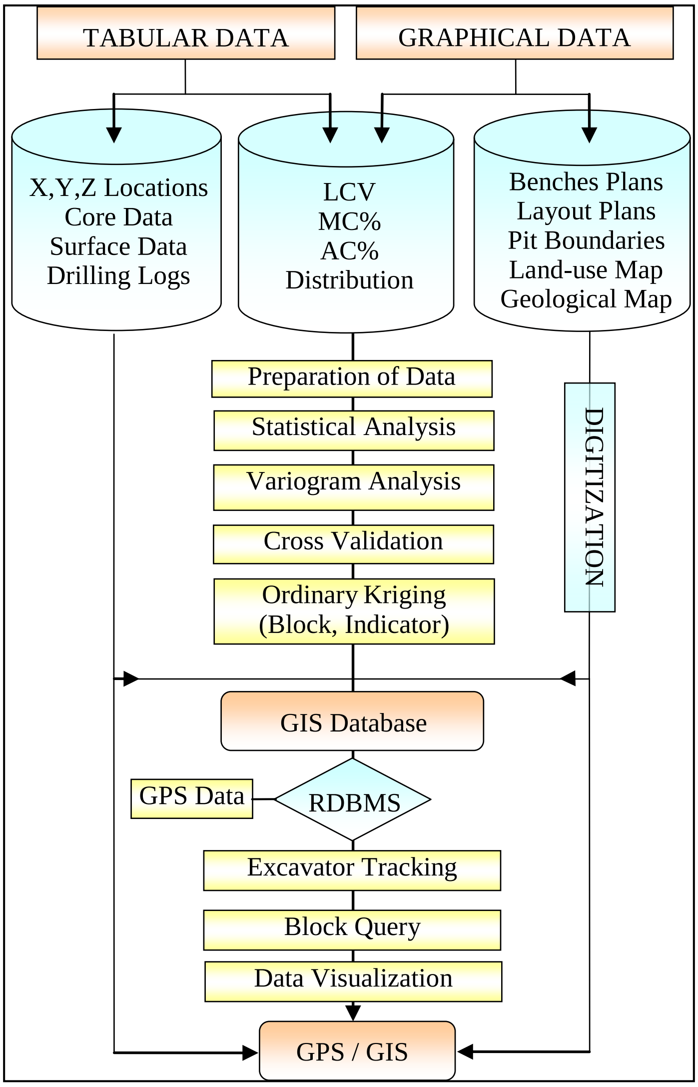


Fig. 1. General flow chart of the study.

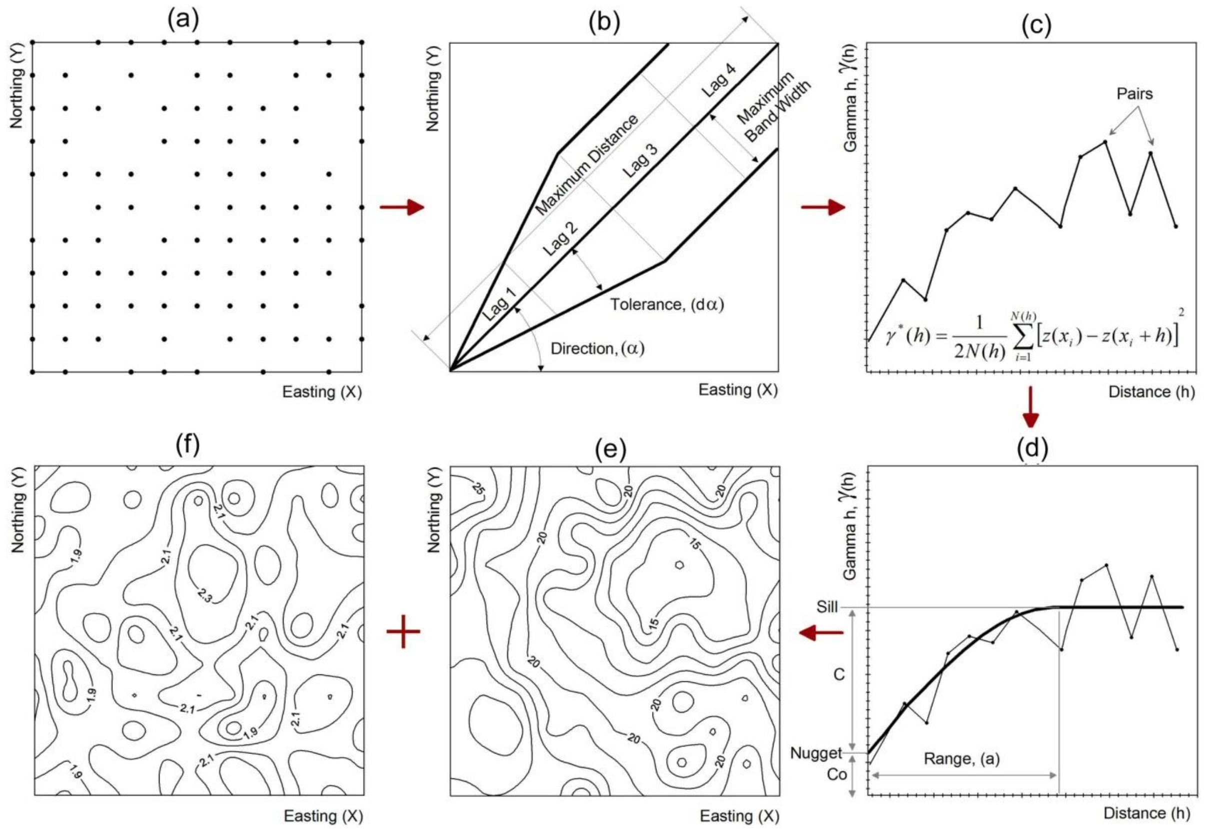


Fig. 2. Graphical representation of geostatistical analysis stages: a) post plot of sample data, b) tolerance angles and distance tolerances, c) experimental semivariogram, d) theoretical semivariogram, e) contouring of kriged values, f) kriging error map.

The final stage of the analyses, all of the kriging estimation results were combined as a spreadsheet format for the following applications in GIS/GPS querying. The created spreadsheet data includes 2.938.880 blocks value such as LCV, AC%, MC%, and geographical coordinates (Tab. 1).

Tab. 1. View of the coal quality from the integrated database.

Block ID	East (X)	North (Y)	Elev (Z)	LCV	LCV Std.Err.	AC%	AC% Std.Err.	MC%	MC% Std.Err.
1	325150	4243650	968.75	1233.00	139.30	12.69	6.49	52.88	7.35
2	325250	4243650	968.75	1233.00	145.04	12.69	7.39	52.88	7.58
3	325350	4243650	968.75	1220.67	142.10	12.31	7.09	50.76	7.20
¦	¦	¦	¦	¦	¦	¦	¦	¦	¦
¦	¦	¦	¦	¦	¦	¦	¦	¦	¦
¦	¦	¦	¦	¦	¦	¦	¦	¦	¦
2938879	332950	4247450	1226.25	903.40	38.50	23.39	4.94	56.89	2.26
2938880	333050	4247450	1226.25	905.73	57.12	23.39	6.04	58.15	3.26

Development of Quality Monitoring System

This section deals with the development stages and qualities of the coal quality monitoring system which can perform location dependent analyses. The primary principle during the development stage of the system was to enable real-time tracking of the incidents and product movements in the opencast mine enterprises.

In the Afsin-Elbistan opencast mine, the overburden and coal excavated by the bucket wheel excavators are sent to dump sites through conveyors (Ural and Onur, 2001; Tutluoglu et al., 2011). According to the design of the thermal power plant, the lower calorific value (LCV) of the demanded coal should be 1050 kcal/kg on average, a minimum of 950 kcal/kg, and a maximum of 1600 kcal/kg; while the 30-day maximum average should be greater than 1000 kcal/kg (Gunalay, 1969). The ash content (AC%) should not exceed

250 g / 1000 kcal, and the moisture content (MC%) should not exceed 64 %. The coal blending and stocking site has a large design with an effective capacity of 660.000 tons and a maximum capacity of 1.000.000 tons. Thus, instant tracking of the quality and amount of coal that is conveyed to the stock area is important for processes such as blending. Based on the tabular data, we combined under the GIS, we had blocks at 112 different depth levels, and at 100x100x2.5 m dimensions, whose LCV, AC%, MC%, and coal boundaries and geographical coordinates were known (Fig. 3). Based on this information, we attempted to answer the following three questions were:

1. On which geographical coordinate does the excavator excavate?
2. Into which block in our tabular data does the coordinate, where the excavation is carried out, fall?
3. What are LCV, AC% and MC% quality values of the block in the coordinate where the excavation is made?

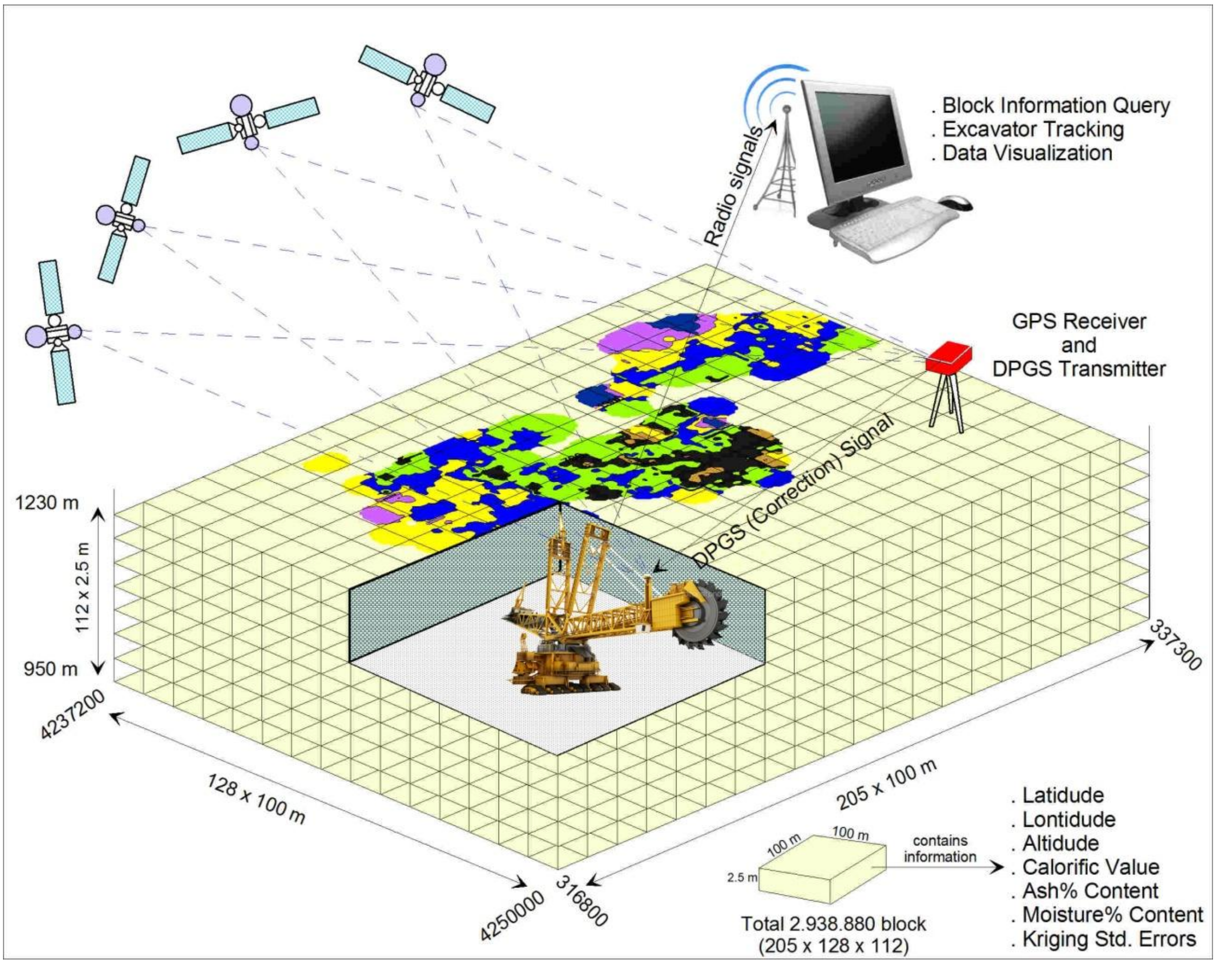


Fig. 3. Working principle of the system.

According to GPS technology, it is possible to reach coordinate information with an error sensitivity of 2-5 cm (Nieto and Dagdelen 2006; Gu et al., 2008; Enji et al., 2010). Thus, it can be concluded that the coordinates where the excavations are carried out can be reached by mounting a GPS receiver onto the excavator and sensors on its boom. Thus, it would be possible to determine on which block the coordinate of the GPS receiver extracts falls, and determine the quality values of the block through the queries to be made in the tabular data. To this end, a computer application with GIS/GPS integration, which can make a point-block query in the tabular data, required needed. An algorithm was developed and written in Visual Basic 6.0 from MapInfo using MapBasic. The Visual Basic application consists of three sections. A GPS section that awaits the coordinate information that will be received over the GPS and that makes coordinate transformations; a map analysis section that functions in order to view digital maps and track heavy construction equipment on the screen and the point-block-quality query section (Fig. 4). In this section, the relational database management system (RDBMS) allows flexible data extraction, called a ‘query’, with a single criterion or multiple criteria, based on structured query language (SQL). The GPS section operates in the background. Every time it receives the coordinate information, it renews the display image in such a way to reflect its new status by sending this information to map the analysis section. In the point-block query section, a user can optionally make location-based quality queries over the database.

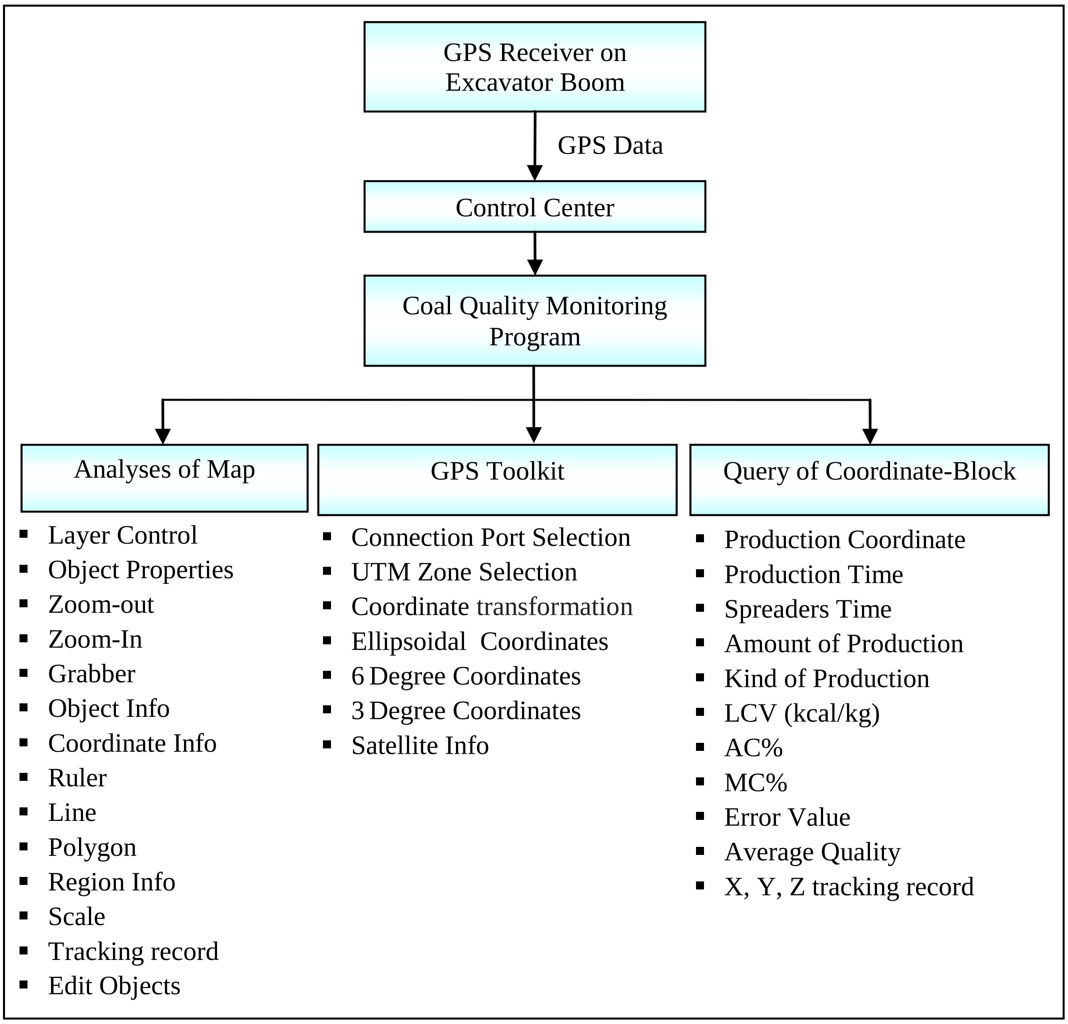


Fig. 4. The general working principle of the coal quality monitoring system.

GPS Section

The Garmin GPS III-Plus used in the applications is a versatile, portable receiver. A connection can be established between the GPS and the computer over the RS-232. When the GPS is connected from the serial communication port using the Visual Basic, the GPS transmits the location data to the computer in the form of NMEA sentences. GLL is the simplest sentence containing the location data. In a sample GLL sentence "$GPGLL, Latitude of position, North or South, Longitude of position, East or West, UTC of position, Status" such as "$GPGLL, 4916.2249, N, 12311.4500, W, 224509, A" the latitude is 49 degrees 16.2249 minutes north; the longitude is 123 degrees 11.45 minutes west, and fix taken at the time 22:45:09, data valid according to Greenwich.

Through the analysis of the GLL sentences, the coordinate data can be digitally processed. In addition, the GPS Toolkit module, which is developed for Visual Basic programming language to reach the entire GPS functions, is available for use free of charge. A variety of data such as the number of satellites connected, the quality of the GPS signals, etc., can be accessed thanks to the module.

In the program, by selecting the port to which the GPS receiver is connected from the opened related boxes in the GPS screen, the user can connect to the GPS and see both the number of satellites connected and the connection qualities, visually on the screen (Fig. 5). Since the location information is presented in the form of ellipsoidal geographical coordinates, they were transformed into a 6^o and 3^o Turkish Coordinate System with the UTM Projection ED-50 datum using the equations given by Grafarend and Krumm (2006). However, the prepared graphical and tabular data was stored in the UTM Projection ED-50 datum coordinates, and these two should be compatible with the queries. For the datum and coordinate transformations, firstly, the central zone meridian of our mining area should be selected over the screen. After the selection of the zone central meridian, the transformed 3^o and 6^o coordinates and the connected GPS satellites are visually presented on the screen.

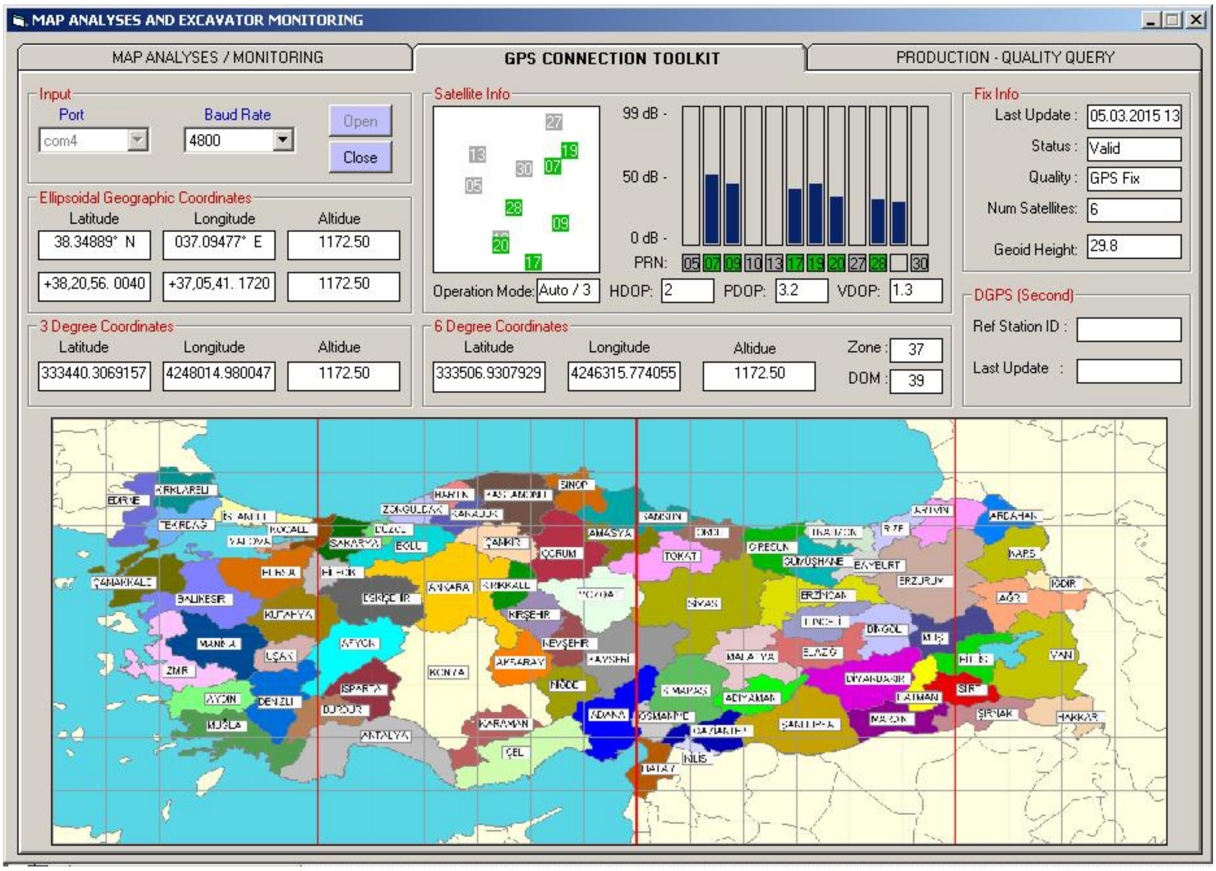


Fig. 5. An image from the GPS connection screen.

Map Analysis Section

The graphical data that is created on this screen of the section can be viewed as digital maps. The viewing of these maps requires various operations in terms of computer programming. First, the layers that constitute the map and geographical objects that form each layer are stored in the memory by processing the files that constitute the map to be imaged. The viewing takes place by drawing each graphical layer processed from the file over each other in the specified order. The coordinates of the geographical objects forming the drawn layer should be recalculated according to the coordinate systems of the screen during the drawing process. An important aspect in the viewing of digital maps is that the screen and the map have different coordinate systems and units. The origin is located in the upper left-hand corner of the screen coordinate system. The X-axis is towards the right, while the Y-axis is downwards. The unit of the coordinate system of the screen is a pixel. In this case, unexpectedly, the viewed part of the map is upside down, and these types of problems can be eliminated by a series of software techniques. Another issue is that the coordinate system is re-scaled according to the required magnification level, and the map should be able to be scrolled down in order to view different parts. All the coordinates that define the geographical objects that are needed to be viewed on the screen should be transformed into the new coordinate system before the viewing operation. This operation requires the application of a series of mathematical operations to all the coordinates. Considering that map operations are continuously performed, such a solution slows software viewing operating down. While performing operations such as viewing maps, updating the images, and answering user requests, by awaiting the location information to be received, incoming coordinates should be transformed into a suitable projection format. Since awaiting location information requires the constant operation of codes, it interrupts the operation of other parts of the software and makes it impossible to respond to user requests. This problem could be overcome by applying certain software techniques.

In this context, using the OLE support of the Visual Basic programming language in the map viewing section, applications integrated with powerful GIS abilities of the MapInfo were developed, and thus the map viewing operations were accelerated. In this section, a user can upload a map in*.dxf, *.dwg, *.mif, *.mid, *. dgn, *.e00, *.shp vector formats onto the screen by converting them to a MapInfo *.tab format and can view it at the requested magnification levels. The magnification level refers to the horizontal distance of the area viewed in the map in units of the distance unit of the map. The magnification level determines the number of details to be viewed on the map; the smaller the levels, the more detail one can see on the map (Fig. 6).

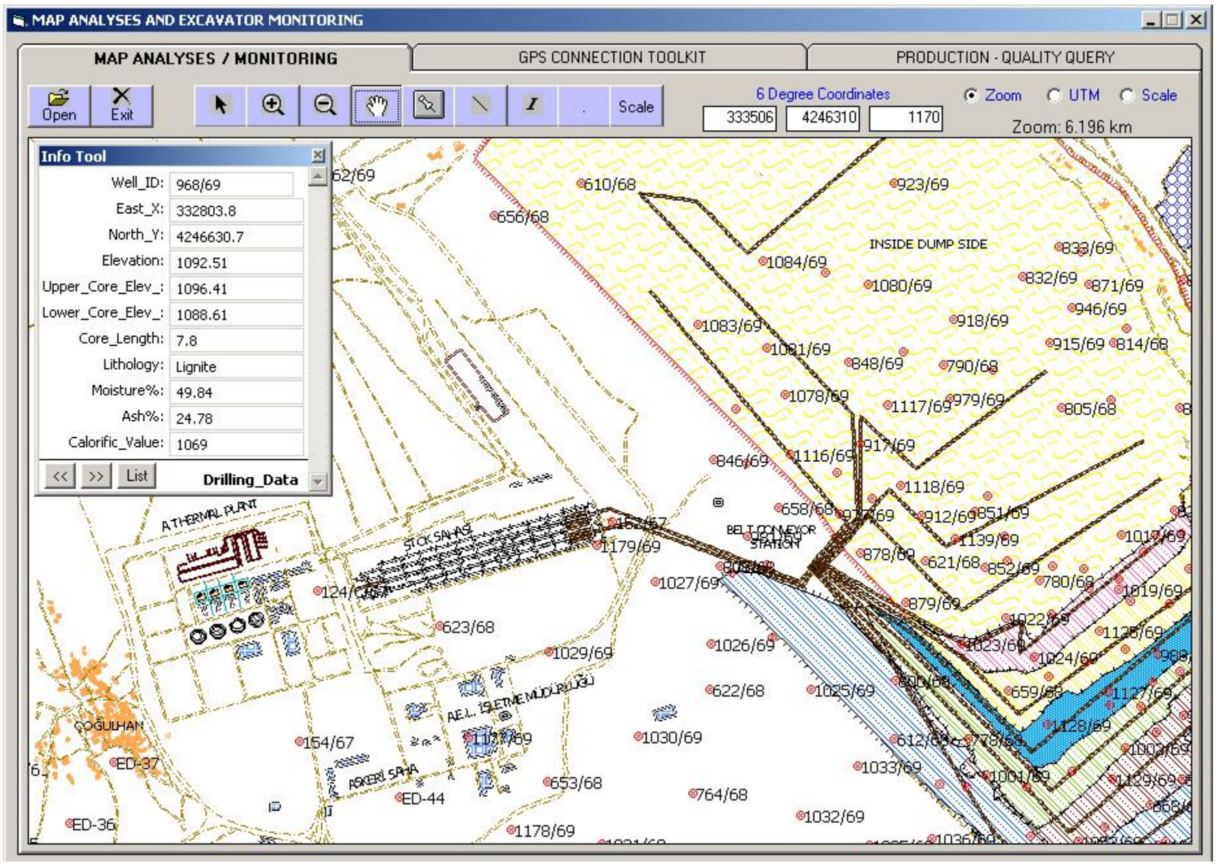


Fig. 6. Digital map analyses and excavator tracking screen.

Furthermore, the user can also view different sections of the map. This operation takes place by scrolling the map down to the desired amount to different directions. The user can reach the digital value of a point if they wish. For example, they can access the log data of a drill hole over a drill hole point.

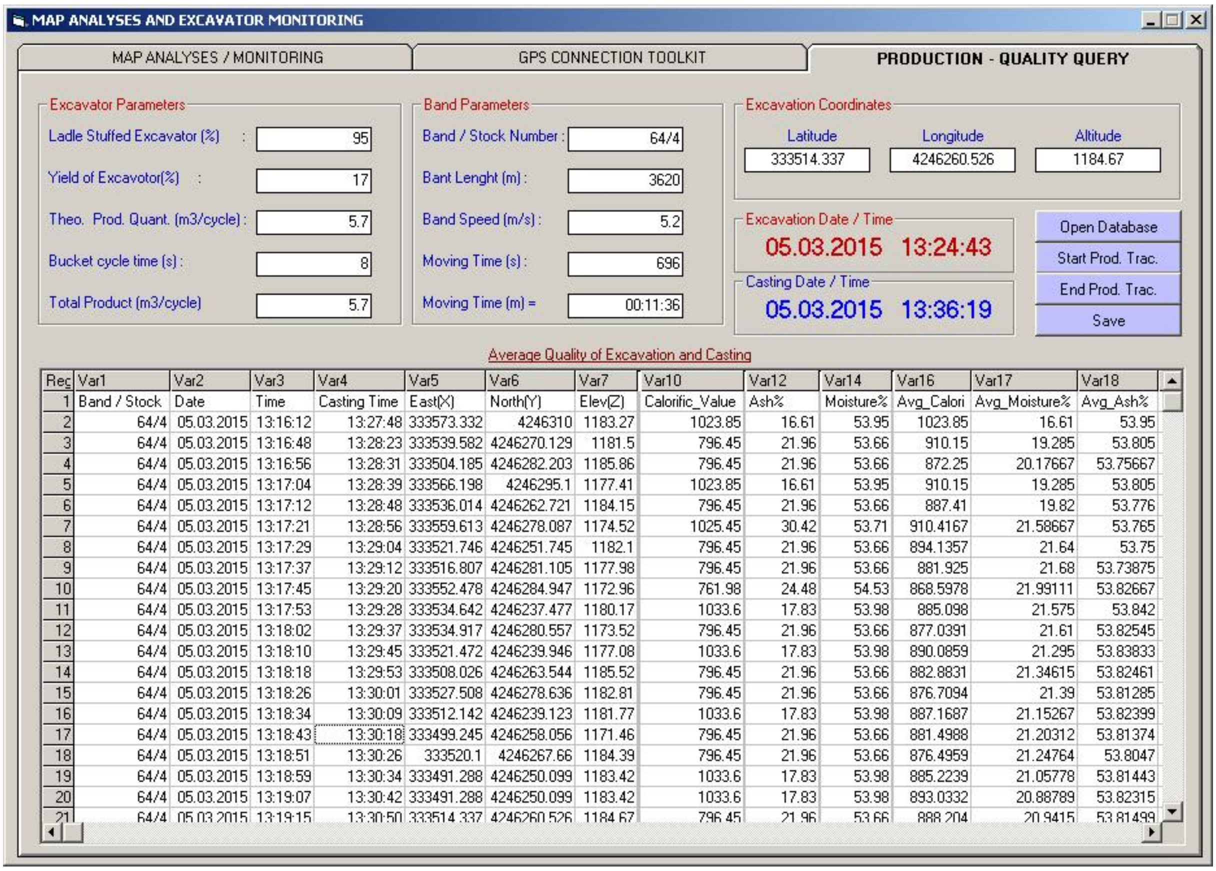
It is the duty of the MapInfo OLE inspection to perform all these requests for the user (MapInfo, 2004). In case of such a request, the MapInfo readjusts coordinate system of the screen transforms geographical objects according to this new screen coordinate system and renews the image. Moreover, the developed GPS section of the program awaits location information that will appear by operating in the background. The map analysis section renews the display image by processing the new location information it has obtained on the map that is being viewed. Thus, any mobile vehicle such as an excavator or truck bearing a GPS is tracked in real-time over the digital maps on the computer screen.

Production - Quality Querying Section

In this section, location data and GIS database are matched to determine excavated blocks and quality values in real time. In the matching process, the approach where the coordinate acquired by the GPS receiver falls into the nearest block among in our GIS database was adopted.

In the point-block query, the approach where the coordinate extracted by the GPS receiver falls into the nearest block among those with the known coordinates in our database was adopted. As block-distance calculations would be time-consuming at each received coordinate, the distances between all the blocks were calculated once only, and the nearest twenty blocks were taken to the buffer memory as a separate database. As the relocation was larger than the radius of the sphere covered by the twenty blocks we had, query operations were accelerated by taking the second twenty blocks to the buffer storage with the same variable identifications.

The quality values such as LCV, AC%, and the MC% of the block in the coordinate where the excavation is made are kept on the same line as the block number in our tabular data. The identification number, which is known as "ID" is the same in all the features for the identified block (Fig. 7). The quality values of the block where the excavation is made such as the number, the coordinate, the LCV, the LCV estimation error, the AC% estimation, the AC% estimation error, the MC% estimation, and the MC% estimation error, were determined and included in the database that was presented as output.



Rec	Var1	Var2	Var3	Var4	Var5	Var6	Var7	Var10	Var12	Var14	Var16	Var17	Var18
1	Band / Stock	Date	Time	Casting Time	East(X)	North(Y)	Elev(Z)	Calorific_Value	Ash%	Moisture%	Avg_Calori	Avg_Moisture%	Avg_Ash%
2	64/4	05.03.2015	13:16:12	13:27:48	333573.332	4246310	1183.27	1023.85	16.61	53.95	1023.85	16.61	53.95
3	64/4	05.03.2015	13:16:48	13:28:23	333539.582	4246270.129	1181.5	796.45	21.96	53.66	910.15	19.285	53.805
4	64/4	05.03.2015	13:16:56	13:28:31	333504.185	4246282.203	1185.86	796.45	21.96	53.66	872.25	20.17667	53.75667
5	64/4	05.03.2015	13:17:04	13:28:39	333566.198	4246295.1	1177.41	1023.85	16.61	53.95	910.15	19.285	53.805
6	64/4	05.03.2015	13:17:12	13:28:48	333536.014	4246262.721	1184.15	796.45	21.96	53.66	887.41	19.82	53.776
7	64/4	05.03.2015	13:17:21	13:28:56	333559.613	4246278.087	1174.52	1025.45	30.42	53.71	910.4167	21.58667	53.765
8	64/4	05.03.2015	13:17:29	13:29:04	333521.746	4246251.745	1182.1	796.45	21.96	53.66	894.1357	21.64	53.75
9	64/4	05.03.2015	13:17:37	13:29:12	333516.807	4246281.105	1177.98	796.45	21.96	53.66	881.925	21.68	53.73875
10	64/4	05.03.2015	13:17:45	13:29:20	333552.478	4246284.947	1172.96	761.98	24.48	54.53	868.5978	21.99111	53.82667
11	64/4	05.03.2015	13:17:53	13:29:28	333534.642	4246237.477	1180.17	1033.6	17.83	53.98	885.098	21.575	53.842
12	64/4	05.03.2015	13:18:02	13:29:37	333534.917	4246280.557	1173.52	796.45	21.96	53.66	877.0391	21.61	53.82545
13	64/4	05.03.2015	13:18:10	13:29:45	333521.472	4246239.946	1177.08	1033.6	17.83	53.98	890.0859	21.295	53.83833
14	64/4	05.03.2015	13:18:18	13:29:53	333508.026	4246263.544	1185.52	796.45	21.96	53.66	882.8831	21.34615	53.82461
15	64/4	05.03.2015	13:18:26	13:30:01	333527.508	4246278.636	1182.81	796.45	21.96	53.66	876.7094	21.39	53.81285
16	64/4	05.03.2015	13:18:34	13:30:09	333512.142	4246239.123	1181.77	1033.6	17.83	53.98	887.1687	21.15267	53.82399
17	64/4	05.03.2015	13:18:43	13:30:18	333499.245	4246258.056	1171.46	796.45	21.96	53.66	881.4988	21.20312	53.81374
18	64/4	05.03.2015	13:18:51	13:30:26	333520.1	4246267.66	1184.39	796.45	21.96	53.66	876.4959	21.24764	53.8047
19	64/4	05.03.2015	13:18:59	13:30:34	333491.288	4246250.099	1183.42	1033.6	17.83	53.98	885.2239	21.05778	53.81443
20	64/4	05.03.2015	13:19:07	13:30:42	333491.288	4246250.099	1183.42	1033.6	17.83	53.98	893.0332	20.88789	53.82315
21	64/4	05.03.2015	13:19:15	13:30:50	333514.337	4246260.526	1184.67	796.45	21.96	53.66	888.204	20.9415	53.81499

Fig. 7. On-screen monitoring of the quality of the excavated coal

The total production amount, depending on the theoretical production amount, performed within the cycle time determined by the user and the mean quality and error values calculated according to the total production are presented in the output. The stock records can also be viewed in the data by entering the stock number of the coal fed into the stocks, the band length, and the band speed data of the conveyor from the screen. Furthermore, all the defined features can be presented as output while preparing the tabular data such as the date, hour, etc., of the excavation.

Conclusions

The GPS was mounted on a joint on the bucket of a bucket wheel excavator by an application carried out in the Afsin-Elbistan coal opencast mine, and three different types of quality data were recorded with a relocation of almost twice the block sizes (100x100x2.5 m) in our data in measurements that took one and half hours. The analysis of the screen image on the tables in Fig. 7 shows that the production amounts were summed up on a continuous basis depending on the time and the total production amount, and the mean quality values were presented in the related digits. Thus, the engineer who is responsible for production can have information on temporal quality and the amount of coal that is conveyed to the stocks. Considering that the production quality is envisaged to be equal to the quality values of the core samples obtained from the nearest drill hole to the excavation point, there is no doubt that more accurate results can be achieved in digital decision making with an approach in which the production is estimated by various drill holes and functional relationships between them. As mining progress, the GIS database should be updated by importing new experimental results to the data set used in kriging estimates. In this view, the accuracy of kriging estimates will increase, and more realistic results will be obtained.

Considering other bucket wheel excavators, excavating coal at different levels and thus, different qualities in the opencast coal enterprise, knowing the average quality of the coal in the stocks will throw light on the blending process. Furthermore, the three-dimensional extractions of the coordinates where the excavations are made enable updating all the changes and measurements regarding the mine in a short time in the computer media, which enables the preparation of the production maps instantly or for a desired period. Further studies can be carried out on the preparation of excavation maps simultaneously with excavation using GPS/GIS techniques.

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Abbreviations

The following abbreviations are used in this manuscript:
AC: Ash Content
MC: Moisture Content
LCV: Lower Calorific Value

Appendix A

The MapBasic computer application and source codes are available from: http://www.jeostat.com/MEC.zip

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Risk Management in Coal-Mines – Methodical Proposal for Polish and Czech Hard Coal Mining Industry

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Effective risk management in coal mining companies may be achieved by adopting an integrated approach, i.e. IERM, which allows them to manage their risk exposure in a complete and complementary way. Risk needs to be properly identified, before it may be estimated, and later responded to adequately. This is a prerequisite for effective risk management in coal mining companies conducting their activities in Poland and the Czech Republic, as well as other countries all over the world. In both countries, i.e. Poland and the Czech Republic, coal mines operate within the Upper Silesian Coal Basin, which means that their operating conditions are almost identical. It may then be possible to standardise risk management procedures and implement them in companies' operations. This may be ensured by using the integrated risk management formula, outlined in this paper. Therefore, the paper aims to give an overview of the risk management problems experienced by coal mines, with the focus on the integrated enterprise risk management (IERM) concept, as well as proposing that the concept should be implemented in coal mines operating in Poland and the Czech Republic. In particular, it proposes that the traditional approach to the risk management process, i.e. Enterprise Risk Management (ERM) should be modified and transformed into an integrated process. The paper uses the method of synthesis. It also contains a review of scientific literature on the subject.

Keywords: *hard coal mining industry, risk management, financial risk, measurement and risk evaluation, enterprise risk management*

Introduction

Risk management in the coal mining sector is an area of a wide range of scholarly discussions (Schneider and Spinel, 2002; Karbownik and Tchórzewski, 2004; Wodarski, 2009; Tchórzewski and Tworek, 2011; Badri et al., 2011; Vaněk et al., 2013; Galvin, 2017; Shuwei et al., 2017). At the same time, it shows high practical applicability, as adverse risk consequences may be successfully reduced in coal mine operations, although the specific character of the risks faced in this sector makes it impossible to predict all the hazards fully and thus manage the risks in their entire range. In particular, this refers to force majeure events, also known as acts of god, as it is not possible to predict all rock bursts or methane outflows, etc. In addition, coal mining is perceived as one of the most dangerous and most risky industries all over the world. A coal miner's profession (vocational risk) involves continuing hazards and safety threats, which are common not only in Poland and the Czech Republic, where the accident rates, including the number of fatal accidents, are still relatively low when compared to such countries as China (Wang et al., 2008). Irrespective of the types of hazards in coal mining activities, however, risks should always be managed effectively and efficiently. This will allow coal mining companies to limit potential losses, which tend to be enormous in case of such occurrences.

Risk in the hard coal industry in Poland and the Czech Republic is managed in a very similar manner. The industries in the two countries are largely comparable; due to the geographical proximity of the coal mine deposits they exploit (the Upper Silesian Coal Basin). In both countries, coal mining enterprises operate in almost identical industrial and macroeconomic conditions (Maruszewska et al., 2014), as the profitability of the mining sector is highly affected by coal prices on the global markets. These are macroeconomic risk factors, which remain beyond the control of coal mines. Apart from these factors, there are also microeconomic risk factors and the literature on the subject also refers to the division into endogenous and exogenous risk factors, as well as the ones which are case-specific (Tchórzewski and Tworek, 2011). The identification of risk sources for a given coal mining company is, therefore, a necessity for effective and efficient risk management. It should also be noted that if risk is to be appropriately managed, i.e. well defined first and then accurately estimated, providing the basis for appropriate risk responses, adequate knowledge of risk management process and methods as well as an ability to put this knowledge into practice, are necessary.

Currently, Polish and Czech coal mines are striving to manage their risks but they are not using any integrated formula for this purpose. Therefore, the paper aims to present the problems of risk management in coal mines, with the focus on the concept of integrated risk management (IERM), proposing, at the same time, that the formula should be implemented in business activities of coal mines operating in the two countries. This proposal may also be considered by coal mining enterprises in other counties worldwide, due to the universal

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character of the recommended formula. In particular, the concept refers to the modification of the traditional risk management formula – Enterprise Risk Management (ERM) (Tworek, 2013) – and its transformation into Integrated Enterprise Risk Management (IERM), taking into account the specific nature of the coal mining sector. The authors' objectives also include the identification of risk categories, and the description of specific risks coal mines are exposed to in their operations. The nature of risk in the coal mining sector necessitates a different approach to risk management, when compared to companies operating in other industries. The paper, apart from theoretical and conceptual deliberations, presents the findings of the empirical research conducted in this respect in some Polish coal mining enterprises. In addition to induction, deduction and synthesis, the paper also provides a review of the literature on the subject and contains a comparative analysis. The authors draw on the knowledge and the experience they have gained from the scientific research – spanning over a number of years – into financial challenges faced by companies, including coal mines, as well as risk management processes and methods in finance, economics, management and technical sciences. They also use the expertise acquired in course of their professional careers, including the assignments they have worked on for mining enterprises. Some source materials (specialised reports) on the companies surveyed come from online resources. Risk is a cross-disciplinary category and risk management can be examined across many dimensions and in various areas, therefore the paper is written by an interdisciplinary team of authors.

Risk Categories in the Coal Mining Sector – an Attempt at a Synthetic Presentation of the Problem

Risk in the coal mining industry has its own unique profile, determined, first of all, by the type of operations carried out directly in coal that is located deep beneath the earth surface, which in turn leads to extraordinary hazards, such as rock bursts, coal dust explosions, methane outflows, life-threatening cave-ins, flooding of excavations etc. These are environmental risks and, as such, are not always possible to foresee. In particular, specific coal mining conditions are caused, first of all, by a limitation of the excavation environment, secondly, the prevailing geo-mechanical impact of rock mass on the environment and, thirdly, the intensification of technical equipment in the excavation area and, fourthly, limited forced ventilation of coal mines (Kapiesz, 2004). These are the basic determinants of risks which are specific to coal mining operations. Nevertheless, when identifying the risks facing the coal mining industry, one should not forget about a mechanism of risk, which is universal. Every coal mining risk has its own cause, i.e. a source of risk, leading to the occurrence of risk and, as a result, risk consequences. Negligence in relation to methane concentration measurement in coal mines, for example, and human errors are frequent causes of methane explosions, which may lead to fatalities. Therefore, management of safety hazards has become a priority, not only in Poland and the Czech Republic (Kapiesz, 2004), but also in the coal mining industries worldwide (Saleh and Cummings, 2011). Addressing this priority, OKD a. s. – the only coal mining company in the Czech Republic – has implemented a number of technical safeguards, such as continuous modernisation of communication devices, motion detection systems in excavations which are vulnerable to rock burst damage, state-of-the-art methane concentration measuring systems etc. (Czechy, 2017). Similar measures have been implemented by Polish coal mining enterprises, such as Jastrzębska Spółka Węglowa S.A. (JSW S.A.), Polska Grupa Górnicza z o.o. (PGG Sp. z o.o.), Kompania Węglowa S.A. (currently PGG Sp. z o.o.) and Katowicki Holding Węglowy S.A. (currently PGG Sp. z o.o.), and contributed to a significant improvement in accident rates. For instance, looking at the statistics as of 18 May 2015, the number of fatal accidents in the Polish coal mining industry was as low as 6 (Polska, 2017). Nevertheless, this industry is still perceived as a particularly hazardous sector, when it comes to a risk of accidents and resulting disabilities, and is often referred to as a risky industry. Therefore, the environmental risks combined with the safety hazards should be seen as the key risk categories in the coal mining industry. Apart from the two categories, which show the overall picture of industry risks (coal mining risks), attention should also be drawn to the risks related to mining processes, i.e. operational risks. The risks are connected with engineering and coal mining technologies (technical risk) deployed under the ground. These are the three key components of global risk in the coal mining industry. In their publications numerous authors share this idea, adding an investment risk, which should not be neglected as every new excavation site requires a significant amount of funds to be spent by a coal mine, and such investment always carries the risk of failure. The exploitation of a new deposit has to be economically effective. That is why, as a rule, investment processes in the coal mining sector involve the calculation of return on investment, on one hand, and an investment risk, on the other hand. A wide range of methods may be used to this end, such as return on investment accounting and risk management techniques, including risk simulation and real options (Hall and Nicholls, 2007). A particularly important method, which should be used in coal mining, is the method that takes into account the Risk-Adjusted Discount Rate (RADR), where a discount rate is adopted as a calculation rate in the Net Present Value (NPV) approach (Marcinek et al., 2010). The advantage it offers is the fact that project risk is also covered. The estimation is based on the general concept of a risk premium expected by an investor (in this case, a coal mining company) and a risk-free rate. When modified to be tailored it to the needs of investment activities carried out by coal mining companies, it may be assumed that – apart from a risk-free rate which expresses the value of money over time and a rate which indicates an average premium for a risk of operations (assets involved) conducted by a coal mining undertaking the project – the calculation of the RADR needs to take into account another rate which represents an additional risk factor, which may be positive, negative or zero-value, and which expresses the difference between the risk taken up by the coal mining company in their business activities and the risk of the investment project in question (Marcinek et al., 2010). As a result, the RADR may be widely applicable in coal mining industries in Poland, the Czech Republic and other countries, as investment projects are inherently risky and the traditional formula of NPV clearly needs to be modified, i.e. by replacing the traditional discount rate calculated according to the Weighted Average Cost of Capital (WACC) method or the Capital Asset Pricing Model (CAPM), in form of NPV_{RADR}. Such an approach takes into account the dependency between the risk the coal mining company experiences in its operations as a whole and the risk of the given investment project. It can then be assumed that the RADR stands for the discount rate for which the NPV of the project undertaken by the coal mining enterprise equals 0, which should be seen as another dependency in this respect. Under this concept, the more risky the project, the higher value of the calculation (discount) rate should be accepted in calculations and vice versa. In general, the project should help the company to maximise its value. In Poland, such an approach is followed by, for example, Kombinat Górniczo-Hutniczy Miedzi (KGHM Polska Miedź S.A.) (KGHM, 2017). However, no matter how risk is adopted in investment activities and, further on, in operational or financial activities conducted by coal mining enterprises, risk is a common and dynamic phenomenon in the coal mining sector, which is likely to bring about losses and tends to cause pervasive and wide-ranging effects over time (Tworek, 2013). Besides, this definition of risk in the coal mining sector may also be completed by adding a political risk. The Polish coal mining industry is a very demanding sector in this respect. For illustrative purposes – at the turn of 2014/2015 in Poland a wave of protests swept through Upper Silesia die to a decision made by management boards of former KW S.A. (currently PGG Sp. z o.o.) and JSW S.A on restructuring processes to be launched in these companies (e.g. a closure of 4 coal mines belonging to KW S.A. 4 was planned, which would lead to around 20,000 workers being made redundant) (Polska, 2017). However, due to these social protests and the political pressure the decision was abandoned. Similar problems were encountered in 2016 and may be predicted to recur in the future. The situation in the Czech Republic is slightly different as trade unions in the Czech coal mining sector are much less privileged.

The major sources of risks in coal mining projects are presented in Fig. 1.

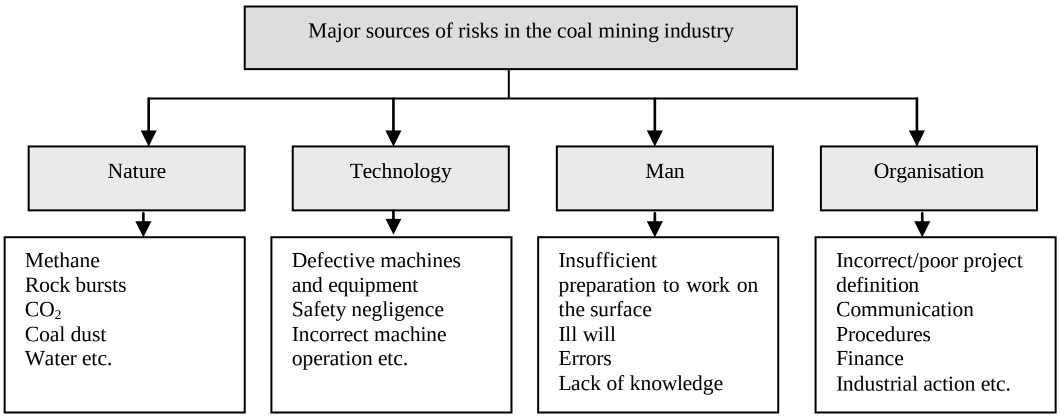

Fig. 1. Sources of risks in projects carried out in the hard coal industry (Karbownik and Tchórzewski, 2004; Wodarski, 2009).

Fig. 1 summarises and gives an overview of the key issues related to the specific character of risks in the hard coal industry. As can be seen in Fig. 1, there are a number of fractional reasons which may cause risks in the operations carried out by a coal mining enterprise. In particular, the organisational risk may be related to the workers' resistance against a decision about the coal mine closure, on one hand, and the social resistance against a radical restructuring programme, to be implemented in the coal mining sector, on the other hand (Karbownik, 2005). The risk factors listed in Fig. 1 can be divided into endogenous and exogenous ones, where an unpredictable exogenous risk means a lack of political will to carry out the consistent restructuring of coal mines (Poland), while a predictable exogenous risk means insufficient government funds for the coal mining restructuring programme, on one hand, and a fall in revenues generated by the coal mining companies, on the other hand (Karbownik, 2005). The general economic situation of the Polish coal mining industry is best reflected by the current financial standing of PGG Sp. z o.o., i.e. the largest mining group in Europe and, at the same time, the leading producer of hard coal in the European Union, which replaced troubled KW S.A. (insolvency risk) in 2016 (PGG, 2017). In the Czech coal mining sector, the situation looks much less disadvantageous due to higher effectiveness of management in OKD, a. s. and, generally, better developed organisational culture. The years 2017 and 2018 are expected to see similar trends both in the Polish and in the Czech hard coal industries. The key reasons behind this are low coal prices at the world commodity exchanges, which reflect the unfavourable developments in the ARA (Amsterdam-Rotterdam-Antwerp) coal price index. Unlike Poland, the Czech Republic harnesses some other sources of energy (nuclear energy). In Poland, due to the political reasons, as well as some social resistance (the memories of the Chernobyl nuclear plant disaster in 1986 are still vivid), a nuclear plant has not been constructed yet. Coal mining is the main source of energy in Poland for the needs of heavy industry (iron and steel industry, metallurgy, electricity generation etc.).

The problem of risk in the operations of the Polish coal mining enterprises may be illustrated by the results of the empirical research conducted in the coal mines belonging to such groups as JSW S.A., PGG Sp. z o.o. (former KW S.A. and KHW S.A.). The key aim of the research was to identify the most frequent risk factors which occur in projects carried out in the coal mining sector. In course of the research, twenty-eight projects implemented in the coal mines of the companies listed above were thoroughly analysed. The projects surveyed were broken down into four groups: firstly, underground coal mining projects (infrastructure), which comprise the activities related to the components of infrastructure and are aimed at ensuring the smooth operation of the underground part of a coal mine, for example, construction or removal of a mining level, drainage, methane extraction, etc.; secondly, underground coal mining projects (production), which comprise the activities directly related to the mining capacity of the coal mine, such as wall reinforcement or closure; thirdly, on-the-surface projects (infrastructure), which comprise the activities related to the components of infrastructure and are aimed at ensuring the smooth operation of the on-the-surface part of the coal mine, for example, construction of a coalbed methane extraction station; and fourthly, on-the-surface projects (other), which comprise the activities related to the operation of the coal mine, focusing on supporting processes such as information sharing, sales network development etc. (Tchórzewski and Tworek, 2011). The research shows that the biggest group among all the projects surveyed and conducted by coal mines are underground coal mining ones (infrastructure) – 39 %, followed by underground coal mining projects (production) – 29 % (Tchórzewski and Tworek, 2011). This may come as no surprise as this is typical for the coal mining industry and geology, i.e. coal mining operations are linked to underground engineering projects (Badri et al., 2011). The projects are likely to be exposed to environmental risks (acts of god), which are mostly due to changeable geological conditions, insufficient investigation of the structure and load-bearing properties of rocks and soils (Schneider and Spinel, 2002). In as many as 14 projects, the coal mining environment (natural hazards) was indicated as a key risk factor in the operations of the coal mines under research, and this risk was experienced in case of every project under review (Tchórzewski and Tworek, 2011). Therefore, in the light of these results, it may be concluded that an unfavourable natural environment is a major risk factor in projects carried out by coal mines in Poland. As this risk is inherent in all coal mining projects, which has to be clearly emphasised, it can be presumed that it occurs in the Czech Republic in a similar way. In addition, the key risk factors include delays in project completion stages, a lack of appropriate project management experience, errors in technical documentation, as well as problems with the funding for the project. A detailed analysis shows that over 250 various risks were identified for the 28 projects surveyed and 35 of these risks could be classified as having at least significant impact on the project (Tchórzewski and Tworek, 2011). In particular, the most important observations made when reviewing the research findings include the following: first of all, the group of risk factors having at least significant impact on the project comprises 10 elements, which are indicated more than 5 times (such factors can be regarded as commonly present in projects); secondly, at the same time, it can be noticed that the factors placed under the umbrella term of „delays" are the most popular ones – 33 occurrences (the most frequently indicated reaction (risk response) to these risks is making allowances, when designing a project schedule, for possible delays; this means being aware that the schedule is too tight but also forced by external conditions not too leave much space for any adjustments in the action plan); thirdly, the risk factor number five is a lack of project management experience and competence on the part of Project Manager and the Project Team' (such a high position in the ranking means that managers working for coal mines are increasingly aware of project requirements and needs as well as the necessity to continue the development of their competence as well as the competence of their co-workers); fourthly, since coal mines work on a number of projects at the same time, they seem to be concerned about their access to funds for the projects, even the ones which can be regarded as strategic from the point of view of the company's operations (Tchórzewski and Tworek, 2011). It was also observed that there was a clear lack of any homogeneous system for risk analysis and evaluation, for the needs of similar projects implemented in the various coal mines surveyed. This has led to the fundamental conclusion that coal mines in Poland lack an integrated risk management system. An analysis of the operations and the organisational structure of the Czech company of OKD a.s. has led to the same conclusion.

The Concept of Integrated Risk Management in a Coal Mining Enterprise – Proposed Methodology

The implementation of the integrated risk management concept in Polish and Czech coal mining enterprises is bound to bring a number of advantages. Contrary to the traditional risk management concept of ERM

(Tworek, 2013), the integrated approach to risk management (IERM) – will enable coal mining companies to manage their risks in a comprehensive way and standardise risk management policies in all coal mines belonging to the coal mining groups. The ERM formula is applied in many industries all over the world, including Poland. The example given above, i.e. KGHM Polska Miedź S.A., one of the leading world producers of copper and refined silver, could be referred to again, where a common framework was implemented for risk management across the organisation, with the related principles outlined, in particular, in a document approved by the company's management board in 2013 – Corporate Risk Management Policy at KGHM Polska Miedź S.A. Capital Group (KGHM, 2017). It sets out the guidelines for risk management in the company and the goals defined in this area, such as: first of all, to ensure that shareholder value is created and protected by establishing a coherent approach to risk identification, evaluation and analysis and by implementing responses to key risks; secondly, to protect employees' lives and health, the natural environment and the reputation of the company's brand; thirdly, to support the achievement of business objectives by introducing tools for early warning of opportunities and threats; fourthly, to ensure strong support for decision-making at all levels across the organisation; fifthly, to build an organisation which is aware of risk to be taken and aims at continuous improvement (KGHM, 2017). However, the detailed analysis of the risk management policy and activities of KGHM Polska Miedź S.A. may lead to a critical opinion about the manner in which risks are handled by this company. First of all, risk management is not carried out as an integrated process. The company also fails to employ all the accessible risk management methods completely.

Due to the specific character of operations, the company size, the multitude of processes which are carried out in the coal mining sector and, first of all, the risks which such companies as JSW S.A., PGG Sp. z o.o., (former KW S.A. and KHW S.A.) and OKD a. s. face in their operations, an integrated risk management system (IERM) should be introduced at the central level in all these enterprises, based on an independent managerial function – a risk manager. The concept is presented in Fig. 2.

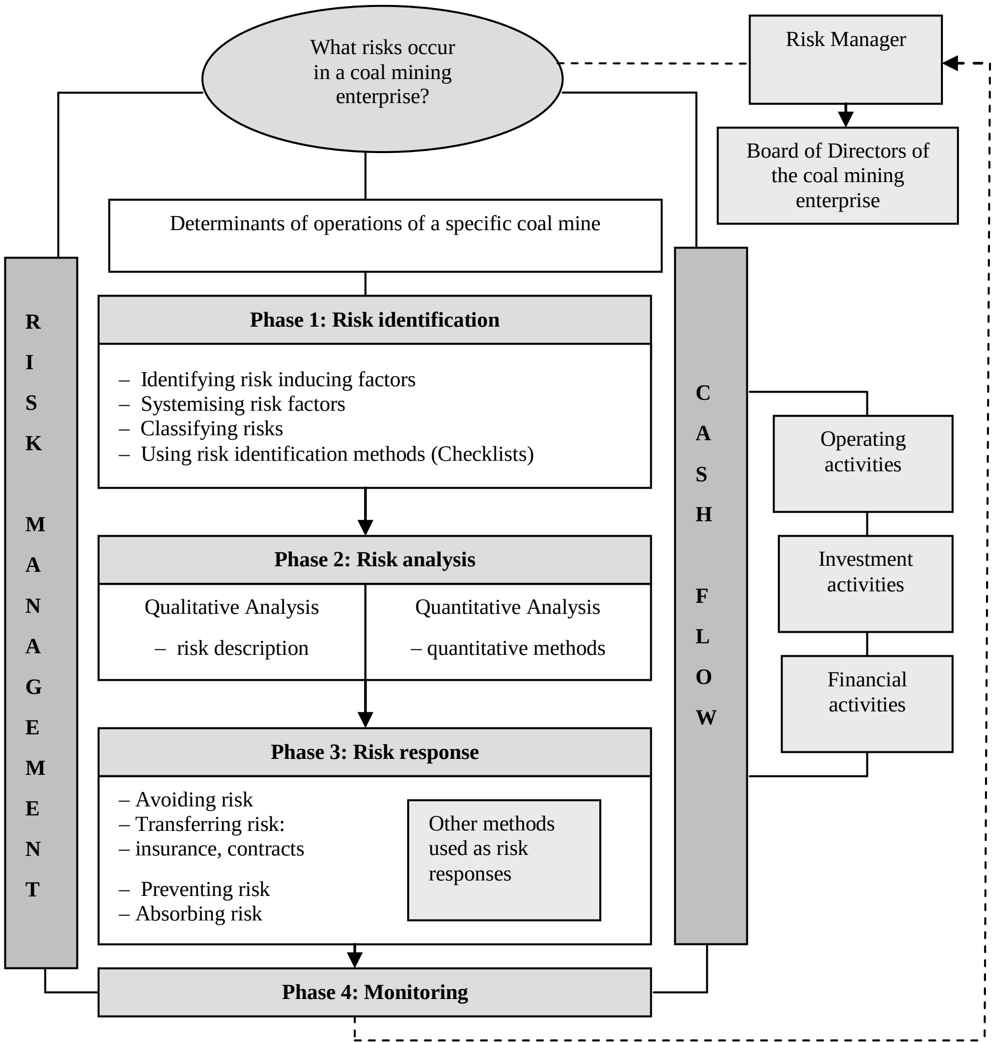

Fig. 2. An idea diagram of an integrated risk management system in a coal mining enterprise (Tworek, 2013).

Fig. 2 presents a four-phase process of risk management in a coal mining enterprise. In particular, phase 1 of the risk management process involves risk identification, with the use of appropriate methods, techniques and tools, in order to define the factors, which may lead to risks in a coal mine, and their division into specific risk categories (Fig. 1). It is recommended here that checklists should be widely used, as they are a fairly common tool in activities conducted by companies with different business profiles (Tworek, 2013). In practical terms, checklists are based on answers given to pre-agreed questions, i.e. specific types of risks are assigned to previously identified risk areas in a given coal mine, and then checklist questions are formulated, to be responded to by a risk manager (Tworek, 2013). This method is best suited for risk identification due to its strengths, and, first of all, the fact that – unlike probabilistic methods – it does not require any complicated computer software and, consequently, tends to be quite affordable. Its main advantage is high simplicity and ease of application in practice. The use of the method is recommended in international risk management standards, such as ERM standards, with ISO 31000:2009 (AS/NZS ISO, 2009) as the standard with the highest applicability (Tworek, 2010). In addition, ISO/IEC 31010:2009 standard shows the methods which should be employed in a risk estimation process (ISO/IEC, 2009). Taking into account the specific character of coal mining operations, the application of some methods indicated in the ISO standard, especially simulation ones, may prove to be particularly useful. The ISO/IEC 31010 standard makes reference to as many as 31 methods (ISO/IEC, 2009), among which special attention should be drawn to a stochastic simulation method of Monte Carlo, where risk is described by the distribution of probability (Rogowski, 2016), in line with the general definition of risk in science. However, this does not mean that other methods, indicated in the standard, cannot be used in coal mining enterprises. This refers, in particular, to other risk identification methods (phase 1), such as brainstorming, which is very popular and should be used in a complementary way, remembering, though, that industry-specific conditions tend to play an important role when identifying risk (Tworek and Valouch, 2011). When looking at the entire risk management process in a coal mining enterprise, risk identification appears to be of key importance as it provides the basis for risk analysis and evaluation (phase 2), utilising appropriate quantitative and qualitative methods (Fig. 2). Risk quantification is the most challenging stage in the risk management process, and this is particularly true when it comes to probabilistic methods. Currently, however, coal mining enterprises all over the world have a wide array of options here. The Monte Carlo method, for instance, when applied in the practical business context, can prevent numerous companies from making wrong investment decisions. This method has some advantages, which are highlighted by many authors in their publications on the topic including its applicability to the coal mining sector (Marcinek et al., 2010). This method may prove to be markedly useful when evaluating risk of projects conducted by coal mining enterprises, as the analysis of target variable distribution (investment profitability level) generated in the simulation allows us to look at specific parameters of the distribution in a detailed way and calculate the probability of an investment project being unfeasible, i.e. NPV < 0, meaning that the investment under consideration is bound to bear high risk (Rogowski, 2016). In order for the Monte Carlo simulation method to be used to analyse risk of a specific project, selected input data needs to be defined in a deterministic financial model, the aim of which is to calculate the NPV for the project, as referred to above (Rogowski, 2016). The literature points out to the fact that computer programs (Crystal Ball or @RISK) designed for Monte Carlo analysis enable the generation of thousands of cash flow alternatives (i.e. thousands of scenarios) and, as a result, thousands of project NPVs (Marcinek et al., 2010). Monte Carlo simulation provides data on numerous attributes, i.e. maximum loss, maximum and expected profit, although the distributions of possible NPVs as such do not show which project should be chosen, i.e. the investor has to know how to interpret the results (Marcinek et al., 2010). Every type of distribution which is adjusted to the given data may be used in probabilistic simulation, for example, preliminary metallurgical tests in a potential coal mine may show that the processing output could be expressed as normal distribution with the average value of 85 % and a standard deviation of 5 % (Marcinek et al., 2010). Also, a wide range of other probabilistic and statistical measurements proposed by science may be taken advantage of in risk simulation carried out for coal mining companies (Hall and Nicholls, 2007), which is referred to indirectly in ISO/IEC 31010 standard. At the same time, the standard focuses on quality analysis methods such as risk matrix, where specific types of risk are assigned specific likelihood of occurrence and, in addition to that, risk may be graded, ranging from very low, through low, moderate, high and very high (PMBOK, 2009). This may lead to better understanding of risk mechanism in the coal mining sector and, first of all, help to complete quantitative methods to make the results more reliable. The strengths offered by the method include, first of all, the fact that it enables a company to prioritise different project-related risks for further analysis or for coming up with adequate risk responses (phase 3) and secondly, it reflects the level of risk tolerance accepted by the coal mining company (ISO/IEC, 2009). Other methods indicated in ISO/IEC 31010 standard, such as sensitivity analysis, decision trees, HAZOP, FMEA etc., also demonstrate their applicability, although they can only be labelled as simple methods here (compared to simulation methods), with inflexibility being the main argument raised against their suitability. This deficiency, which may also be attributed to the discount method of NPV, is making them increasingly unpopular in the coal mining sector, to the advantage of dynamic methods (risk simulation, real options), though they continue to be applied in business practice.

As presented in Fig. 2, the risk, once estimated, needs to be evaluated and responded to in the right way (phase 3). The most effective method in this respect seems to be insurance, which may be perceived as a separate method of risk financing in coal mining operations (Wang et al., 2008; Galvin, 2017). This method allows risk consequences to be transferred to an insurer. This is highlighted by ISO 31000 standard (AS/NZS ISO, 2009). In practical terms, Polish and Czech coal mines, as well as coal mining companies located in other countries all over the world, should opt for all risks insurance, to ensure comprehensive protection for their business, which is particularly relevant when dealing with investment processes in the coal mining sector. Currently, this appears to be the most effective financial instrument (Valouch et al., 2009) for preventing a coal mining company and a project undertaken by it from negative risk effects. The only downside here seems to be the high cost of insurance policies. All these actions, tasks and efforts, related to management, are subject to control and monitoring (phase 4) by a risk manager, who is then expected to report the status of risk management in their coal mining enterprise to the board of directors. This manager is required, in particular, to manage risks at the corporate level. It does not mean, however, that a risk management team – consisting of various subject matter experts and specialists, including engineers, lawyers, economists etc. – may not be appointed. In line with this concept, the appointed risk management team would have a separate scope of tasks and responsibilities, and would be responsible, first of all, for defining the scope of tasks and responsibilities related to their activities, in cooperation with the director/top level management of the coal mine; and secondly, for simplifying and reviewing risk management initiatives at the operational and strategic levels; thirdly, for reporting risk management initiatives and activities and their results; fourthly, for communicating the risk management issues; and fifthly, for reviewing the company's risk management policies on an annual basis, against the types of risks that need to be addressed (Ministry of RP, 2004). This team could be led by one person – the risk manager, who would bear overall responsibility for risk management in the enterprise, in front of the board of directors (Fig. 2).

The main advantage of the integrated risk management concept, as illustrated in Fig. 2, is its applicability in operations of all coal mines belonging to a mining enterprise. This will allow integrating risk management in all coal mines separately and then creating one integrated risk management system at the central corporate level. An essential part of the concept, however, is finding one common denominator for the coal mining enterprise, i.e. the value around which risks could be estimated. Net cash flows may be regarded as such a value, as every economic event, including the ones which are risk consequences, is reflected in the financial reporting of a coal mining enterprise (Tworek, 2013). The financial reporting data enable the identification of all the risky events which have occurred in the company's activities. After that, in order to estimate risk, two methods can be used complementarily. The first and most important one is Cash-Flow-at-Risk (*CFaR*) method, which shows risky cash flows in the coal mining company. Its formula is following:

$$P(CF \leq CF_0 - CFaR) = \alpha \tag{1}$$

where *CF* is a cash flow in a specific period, which is a random variable, *CFaR* is a risky cash flow, CF_0 means the planned cash flow in the analysed period, and α is the tolerance level (Jajuga, 2007). The second method – Earnings-at-Risk (*EaR*) – shows profits at risk in a company and can be described with the following formula:

$$P(E \leq E_0 - EaR) = \alpha, \tag{2}$$

where E means a net profit in the analysed period, which is a random variable, *EaR* is a net profit at risk, E_0 is the planned net profit in the analysed period, and α is the tolerance level (Jajuga, 2007). The methods are simply the expansion and modification of the Value-at-Risk (*VaR*) concept and their choice in order to estimate risk, as suggested in the paper, seems reasonable from the point of view of the subject matter and the methodology. This is also due to the fact that in science risk is perceived as a strictly quantitative category, which should be emphasised again (Knight, 1921).

Conclusion

Risk management in coal mining companies requires a systemic approach. Risks which are taken in the coal mining sector, including risk factors (Fig. 1), justify such an approach. What seems particularly important here are risk consequences, which may be painfully disastrous in this sector. To give some examples, in 2006 in Poland a methane explosion in Halemba coal mine caused the deaths of 26 miners. Also, 20 miners were killed and 35 injured in Wujek coal mine in 2009. These accidents belong to the most tragic disasters in the history of the Polish coal mining industry in the last 10 years.

Risk management in coal mining enterprises should not, therefore, be limited to the general concept of ERM, but it needs an integrated formula (Fig. 2). Integrated risk management means a holistic approach to risk management, with the risk manager taking advantage of a full range of methods available in this respect (AS/NZS ISO, 2009). The methods used to identify and quantify risks, as well as the ones designed for risk management processes, should be applied in a complete and complementary way. Besides, a coal mining enterprise needs to find the common denominator around which risk should be estimated. The paper recommends that net cash flows may be used as such value (Tworek, 2013), since – according to the general concept of risk in science – all risk consequences have their financial implications (Valouch et al., 2009), i.e. losses incurred by coal mining enterprises. Summing up, it may be concluded that integrated risk management in a big coal mining enterprise with a modern management style means the following:

1. the enterprise has clearly identified who is to handle and bear the responsibility for risk management;
2. the risk management is carried out in all the dimensions in which the enterprise operates and applies to all the coal mines included in this group;
3. a complete range of methods are used to manage risks, with the focus on the CFaR method proposed in the paper;
4. the risk management supports the overall risk management process in the coal mining enterprise;
5. the risk management carried out by risk managers also refers to competitors (other coal mining enterprises) and, in particular, takes into consideration the macroeconomic, systemic and industry-specific determinants;
6. the risk management is carried out in an on-going and reliable way, and it is analysed as a process;
7. an effective risk management process mitigates the risk experienced by the entity in its operational and strategic activities, i.e. contributes to the creation of its value (Tworek, 2013).

Only such a formula will allow the achievement of risk management goals, which include, on one hand, maximisation of the enterprise value and, on the other hand, mitigation of losses that are now incurred by Polish and Czech enterprises due to risks. This conclusion is equally pertinent to coal mining enterprises worldwide, keeping it in mind that methodical aspects are of key importance, since incorrect selection of risk identification methods, coupled with insufficient knowledge of their applications, may lead to wrong evaluation (quantification) of risk and the failure to take into account all the risk factors a given coal mining enterprise is exposed to. Consequently, inadequate risk responses may be chosen. Another vital issue is the knowledge of strengths and weaknesses presented by specific risk management methods. Here, the attention should be drawn to the relevance of some solutions offered in the risk management standards mentioned in the paper, such as, in particular, ISO/IEC 31010 standard, which is highly applicable and is especially recommended to production companies. When using the solutions outlined in the paper, note should be taken of the fact that the concept illustrated in Fig. 2, has a prominent advantage i.e. high flexibility of application. One has also to remember that every coal mining company all over the world is different in some respects and, as a result, risk management processes will naturally vary from case to case. Therefore, the method ought to be tailored to the needs of the coal mining company where it is going to be employed. The implementation of the solutions suggested in the paper is bound to bring tangible benefits to numerous coal mining enterprises in Poland, the Czech Republic and other countries, such as, for example, the generation of additional savings for a corporate group as insurers tend to reduce insurance premiums for production companies that have put in place an integrated risk management (IERM) system in their operations.

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Waste Cutters Utilization in Underground Coal Mining

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With increasing depth of underground mining and complexity of mining and geological conditions, the number of wasted cutting tools increases. Increased rock hardness in coal-, ore-, salt-, gypsum and other mines leads to an increased number of cutters worn out during the operation of shearers and road headers. A lot of wasted cutters are piled up in mines. Research has shown that mainly a cutter head is worn, and up to 70-80% of the tool retains its shape almost unchanged. Reusability of a significant part of wasted cutters is proved. Design of a composite cutter providing its multiple uses and reducing wastes in underground coal mining is presented. An engineering solution on remanufacturing and reusing wasted cutters piled up in mines is suggested. This requires pre-sorting of waste and selection of suitable cutters to repair. Then, a deformed head of each worn cutter is removed, and an axial bore is drilled in the cutter tail. A replaceable cutting head is turned from a metal bar and is equipped with a carbide tip. The operating head is secured into the holder made of the worn-out tool. A shape and a mechanism of the operating head attachment ensuring the reliability of the connection are designed. Such cutter is reusable and can be mounted on combines. Industrial tests of the composite cutter in mines showed good results: one holder served as the basis for the operation of nine operating heads, and it was not required to purchase nine traditional full-size cutters. The solution reduces metal consumption by five times and ensures a significant reduction in purchase costs (up to 1.5-1.7 times), thus improving the resource efficiency of coal mining.

Key words: *mine, combine, cutter, waste, operating head, utilisation, resource efficiency*

Introduction

Mining industry belongs to the most resource-intensive industries in the world. As the depth of mining operations increases and the geological conditions become more complex, the problem of resource-efficient mining technologies and processes becomes increasingly important (Umnov, 1995; Miroshina, 2002; Komarov et al., 2007; Troubetzkoy, 2011).

Road heading and extraction of minerals from salt, gypsum, coal, and other mines are currently carried out mechanically by means of tunnelling and mining combines. Actuating devices of these machines have the form of crowns, bars and screws equipped with tangential rotary cutters (TRC) (Fig. 1). Tangential rotary cutters have replaced radial cutters due to some advantages, such as self-sharpening and relatively longer life, lower energy intensity of failure, easy installation and operation. Further improvement of actuating devices and cutting tools is a subject of many research works all over the world. There are studies on the effect of cutters' inclination on their penetration into the rock mass (Jonker et al., 2014; Fu et al., 2015). Dewangad and Chattopadhyaya (2015) studied how the amount of the broken coal and cutter temperature correlate with penetration depth. Works by Dewangad et al. (2015) and David (2014) are devoted to the influence of the elemental composition of the tip material on its durability in rock and coal breaking, as well as to the mechanism of degradation of tungsten-cobalt alloy in contact with the rock. The research of Bolobov has shown that the mining tool wear rate is influenced by the hardness of rocks, their abrasivity and the structure of mineral grains (Bolobov et al., 2015).

Chinakhov et al. (2011) and Prokopenko et al. (2016a) propose to prolong the tool life by strengthening cutter heads with extra armouring and hard-facing steel bodies. Technical solutions changing the geometry and the shape of cutter heads to increase their breaking capacity are presented in a number of proceedings (Fader and Lammer, 2011; Greenspan et al.,. 2014; Sarwary and Hagan, 2015). Papers by Tompson and Tank (1990) and Liu et al. (2015) study an impact of water supply in the breaking area on the efficiency of rock breaking.

Researches by Khoreshok et al. (2012), Bolobov et al. (2012), Kolesnichenko et al. (2012) present test results of tangential rotary cutters operating on mining machines in the Kuzbass mines (Russia) and recommendations to improve their design. Advanced designs of cutters with replaceable reinforcing tips, removable heads, secured shanks, etc., are offered by the following scientists in scholarly proceedings (Bell, 2013; Bookhamer and Chad, 2014; Monyaket al., 2104; Parrott, 2014; Prokopenko et al., 2015, 2016b, 2017). The use of ellipsoid cutter tips instead of conical ones is discussed in the work Khoreshok et al. (2013).

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A considerable disadvantage of the TRC is that they are not reusable. Nevertheless, effective solutions on the further use of worn out cutters have not yet been proposed. As a result, after some (often inconsiderable) wear of the body, a tool falls into the category of waste products. Such cutters are either thrown away straight in the face or lifted up to the surface, where they are stored in open mine warehouses for a long time rusting and depreciating in large quantities. At best, they are sold to metallurgical plants as scrap to be melted. These facts stipulate low resource and cost efficiency of rock-breaking tools in mines.

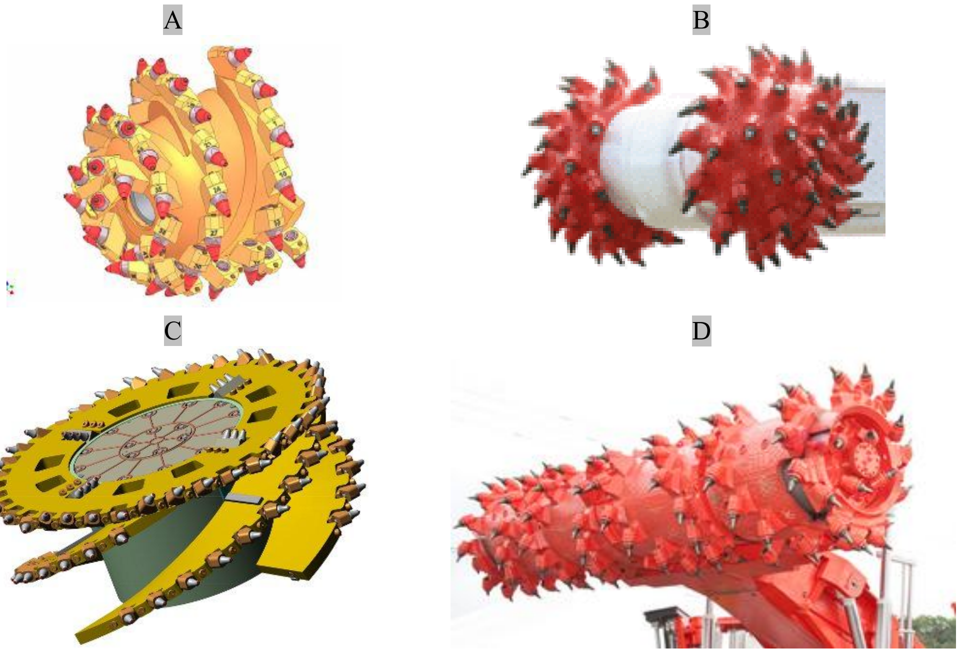

Fig. 1. Actuating devices of mining combines:
A – Direct-axis crown; B - Cross-axis crown; C - screw; D – bar.

Materials and methods

Cutters mounted on tunnelling and mining combines in the Kuzbass coal mines were used as the object of the research. Surveys were carried out in mines of the northern, central and southern parts of the coalfield with different mining and development conditions. Structurally a tangential rotary cutter is a metal holder with a cylindrical shank and a conical head with high-strength wear-resistant alloy cutting tool which is fixed to the edge. The holder shank is mounted in the cutter holder of the actuating device and fixed firmly to prevent spontaneous loss of the tool. Special metal locks or plastic half-rings mounted on the shank groove are used as clamps.

Actuating devices usually have 28-56 cutters or more, and combines have as many as a hundred and fifty cutters. In general, all currently used cutters for tunnelling and mining combines are similar in design. They differ only in size and shape of heads and shanks (Fig. 2).

Fig. 2. Model range of cutters for various combines.

Rock-breaking is accompanied by a gradual abrasion of the tool reinforcing element. The tool life is determined by several factors, the main ones being the hardness of the rock broken, strength and quality of the tool metal, operational condition of the tool holder, fastening security, a driver's qualification. In the Kuzbass mine, cutters serve from a few weeks (for coal) to several hours (for durable sandstone). The average consumption rate of cutters for one combine is 200-300 units per month, rising up to 150-250 pieces per day when breaking a layer of hard and abrasive rock. One 1 kg cutter costs 800-1,000 rubles that is comparable with the cost of 1 ton of coal mined.

According to the service instructions, a cutter with a worn out carbide tip cannot be used any more as it is not able to break the rock, and it should be replaced with a new one. Fig. 3 shows worn out cutters demounted from various combines in different mines.

Fig. 3. Wasted mining cutters after rock breaking in the Kuzbass mines.

Wasted cutters from seven Kuzbass mines were surveyed. Their size was measured after the operation; their shape and wear pattern were assessed. In total, about five hundred cutters were surveyed.

For justification of the proposed tool dimensions, the finite element method was applied to make computations in SolidWorks Simulations software which is used to analyse the stress-strain state of structures, including mining machinery (Buyalich et al., 2016; Khoreshok et al., 2016).

The results of computation were verified in the course of industrial tests in "Pervomaiskaya" coal mine (RF, Kemerovo region) on road-header КСП-35 while driving a roadway of 16.5 m^2 cross-section, along stratum No24 with depth of 1.03 m and average rock hardness f = 4-6 (8) on the Protodyakonov scale.

Results and Discussion

The analysis of wasted cutters size and shape indicates that up to 70-80 % of the holder often remains practically unchanged. Only the front part of cutters is subjected to abrasion. However, further use of cutters without the carbide element is prohibited due to a sharp increase in cutting force, intense frictional sparking, and increased loads on the combine transmission. Demounted and wasted cutters are often worn out no more than 10-15 %. In this case, up to 85-90 % of the cutting tool made of high-strength and expensive steel goes to waste. The mass of a new tool is 1,050g, and 890-945g of it is wasted.

Remanufacture of wasted cutters for further use can help to improve the resource efficiency of mines. Studies of the pattern and extent of cutters wear as well as of their design features make it possible to recover a significant part of cutters wasted during coal mining. For that purpose, it is proposed to sort the wasted cutters and select those with wear degree which does not exceed 50 % of the initial length of the head. According to expert estimations, the share of "recyclable" cutters can be up to 70-80 % or more of the total amount of waste. After that, it is required to remove the front deformed part of the cutter leaving 50-70 % of the initial length of the head intact. In the remained part of the head, a slot should be drilled along the axis, its length l and diameter d corresponding to the cutter size (Fig. 4).

After that, an operating head to the holder which follows the shape of the initial head is turned out of a metal rod. It is tipped with carbide and subjected to thermal treatment. The operating head length and shape must restore the original settings of the head. The operating head should have a shank to be placed in the holder slot. An expanding half-ring is fixed in the groove of the shank. It arches into the slot groove and fixes the operating head on the holding head without preventing their mutual rotation. Such cutter can be reused several times, which is an important advantage alongside its low cost. For reuse, a worn-out head can be easily replaced with

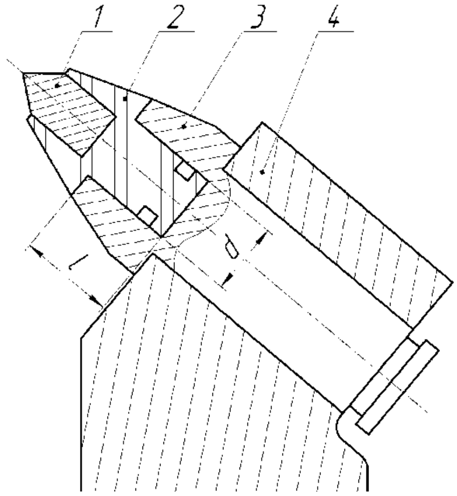

Fig. 4. Construction of composite cutter:
1 – hard-alloy tip; 2 - operating head; 3 - holding head; 4 - cutter support.

a new one. Besides, an extra rotary group (in addition to the cutter holder shank) facilitates rotation of the cutter and ensures even wear, which increases its service life.

Designing a composite cutter structure required verification of operating head key design parameters, namely diameter **d** and length **l** of the shank. The construction of cutter РГП 33-87-70/16М mounted on road-header КСП-35 was chosen for verification of operating head shank (OHS) parameters. These combines are widely used in the Kuzbass coal mines for the road heading in rocks of medium and high hardness. The actual cutter dimensions were used to make a geometric model and perform strength computations using the finite element method in SolidWorksSimulations software.

The aim was to compute diameter **d** and length **l** of the operating head, which would provide maximum structural strength during operation of cutters. A series of computations were performed to analyse how the dimensions effect on the stress-strain state of the structure. During analysis, the shank diameter **d** was varied in the range of 16 to 34 mm in increments of 2 mm; shank length **l** was varied in the range of 17 to 29 mm in increments of 2 mm.

Reduction of maximum stresses in the capacity size of the operating head and the holding head was taken as a criterion for selection of optimum dimensions. "Fixed" fastening of the lower edge of the support was assumed as the kinematic boundary condition. This type of fastening limits linear displacements along three coordinate axes, taking them equal zero (Fig. 5).

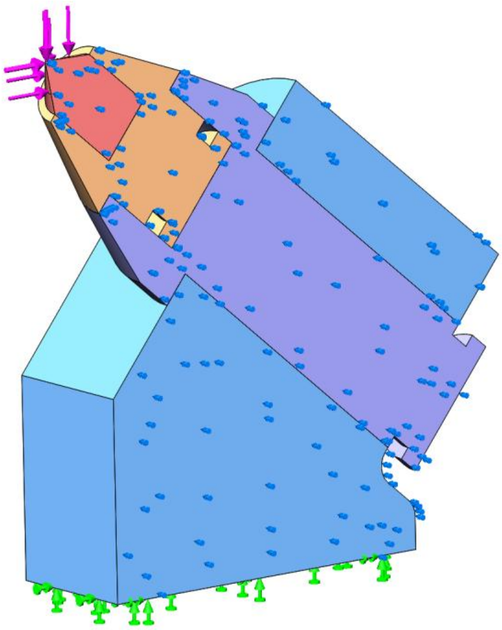

Fig. 5. Design model of the composite cutter with applied loads and fastening types.

Since it was a geometrical model, boundary condition "Symmetry" was assumed due to properties of detail materials and loads and fastening types being symmetric relative to the vertical plane. The geometric model was dissected by a plane of symmetry; the kinematic boundary condition prohibiting displacement along the normal to the cutting plane was assumed for the cross-section surfaces. It reduced the size of the problem and removed irrelevant degrees of freedom of the components, whereby the density of the finite element mesh and the computational accuracy were improved.

The hard tip operating surface was loaded with cutting force Pz = 10,476 H and Py = 2931 H, which corresponds to the conditions of cutting rocks of hardness f = 5 units on the Protodjakonov scale (Aksenov et al., 2013). Since the computation was performed for the composite unit, contact interaction conditions for contacting detail faces were described. Contact condition "Related" simulating solder connection was assumed for hard tip surfaces. Interaction of other details was described with "No penetration" contact condition, excluding occurrence of component interference, but conceding backlashes. Contact condition was used with option "surface to surface". This type of contact facilitates maximum accuracy when solving a contact problem with interacting smooth curved edges, but it requires the greatest computing resources.

A mesh with parabolic finite elements (FE) in the form of tetrahedrons was used when sampling the geometric model. The parabolic FE provided a better description of the model geometry and increased the accuracy of computations due to more points if compared with the linear FE. Mesh settings: FE size - from 1 to 5 mm; element size increase ratio - 1.6; automatic condensation of the mesh was not used. FE size was chosen in such a way that further mesh condensation would have no significant effect on computation results.

For computations, "FFEPlus" solver was applied, which uses advanced matrix reordering, being more efficient for large problems. As a part of the study, various computations with changing OHS diameter and length were analysed. Computations show that geometric parameters d and l affect the distribution of equivalent stresses by Mises criterion in the cutter elements under operating loads. Fig. 6 shows a diagram of stresses for a structure with d = 28 mm l = 23 mm. It shows the distribution of stress magnitudes over the support body, holding head and shank, as well as over the removable head with the hard tip in the range of 0-100 MPa. The greatest stresses occur at the cutting face of the tip (up to 100 MPa), the smallest - in the support (5-35 MPa). A high-stress zone (60-80 MPa) appears where a removable head is fixed in the retaining head and opposite to the direction of the cutting tool motion.

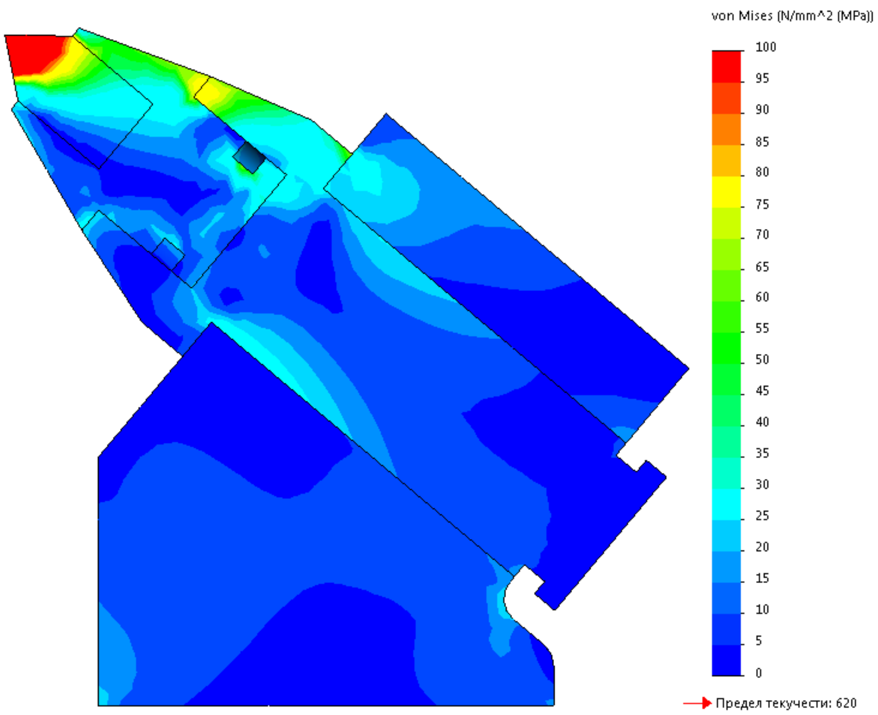

Fig. 6. Distribution of equivalent stresses by Mises criterion in composite cutter elements.

The results of computations for 70 variants of the original data are presented in graphs (Figs. 7 and 8). Ratios of holding head maximum stresses to shank diameters for its various lengths are analogous to minimum stresses of the shank with diameters ranging from 18 mm to 22 mm. Outside of the specified range, an increase of maximum stresses is observed. Minimum stress is 68 MPa for shank diameter d = 22 mm and shank length l = 29 mm (Fig. 7).

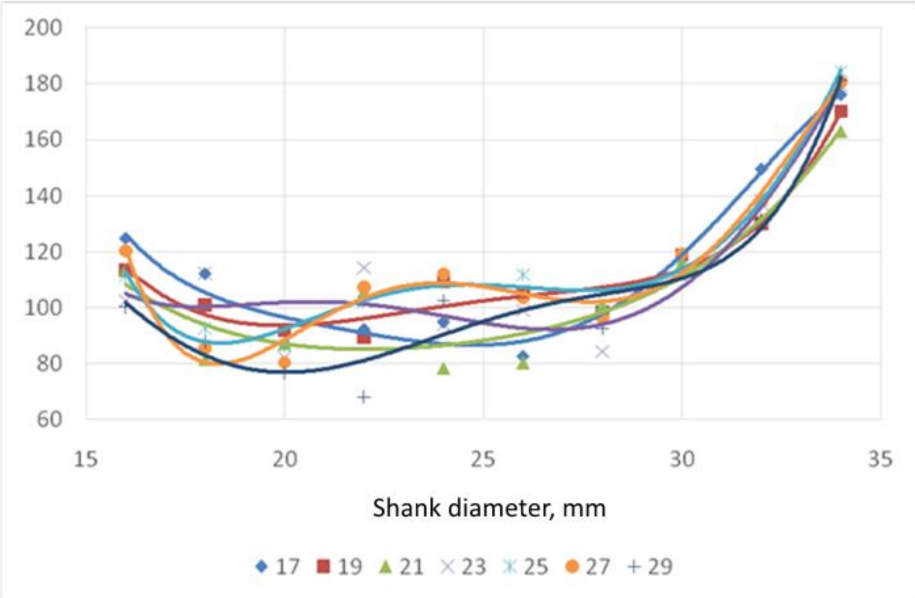

Fig. 7. The relationship between holding head maximum stresses (MPa) and shank diameter d if l=17, 19, 21, 23, 25, 27, 29 mm.

Fig. 8 shows similar curves for the maximum stresses in the operating head. Although relationships have more complex and heterogeneous nature, there is a common minimum for all lengths in the range of shank diameters from 28 to 32 mm. The minimum stress is equal to 75 MPa for diameter d = 28 mm if shank length l = 17 mm.

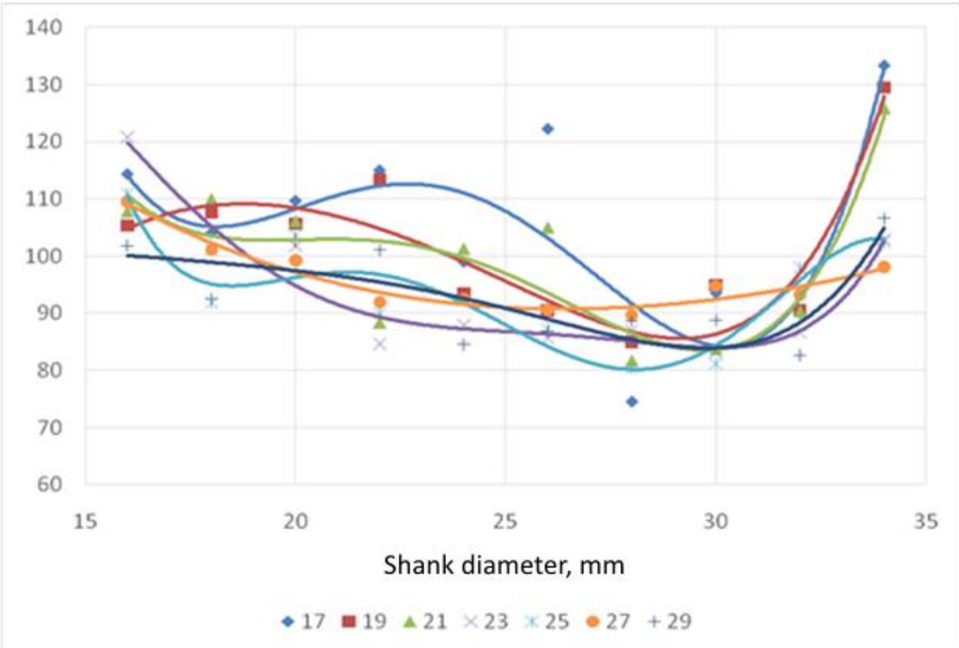

Fig. 8. Relationship between operating head maximum stresses (MPa) and shank diameter d if l =17, 19, 21, 23, 25, 27, 29 mm.

Since the areas of minimum stresses for the holding head and the operating head do not coincide, a graph of arithmetical averages between corresponding points of two previous graphs (Fig. 9) is proposed for more comprehensive evaluation. The graph identified the minimum value corresponding to all size variations, namely, d = 28 mm l = 23 mm.

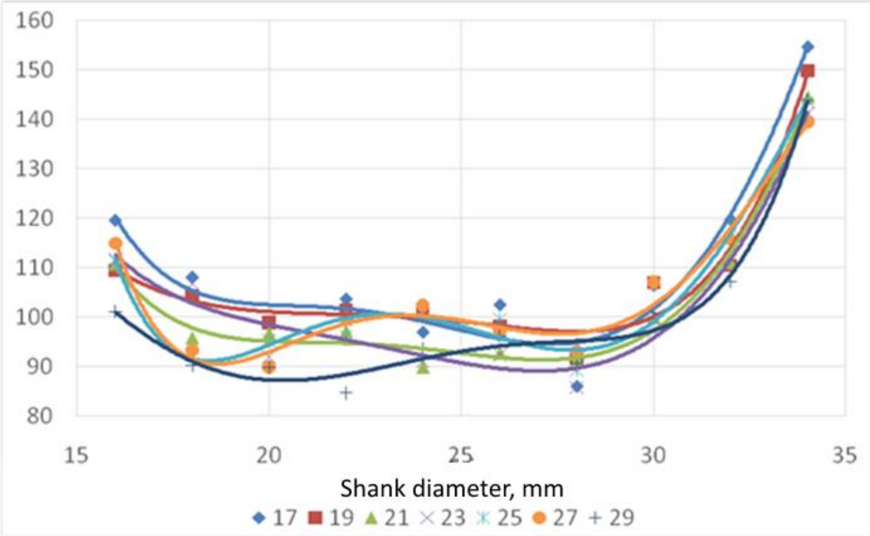

Fig. 9. Relationship between stress arithmetical averages (MPa) and shank diameter d if l =17, 19, 21, 23, 25, 27, 29 mm.

Composite cutters with the optimal settings were manufactured in accordance with the results of the computation. Fig. 10 shows the holder of a worn-out cutter and the process of installing a new operating head into it.

A **B**

Fig. 10. Composite cutter remanufactured from a worn-out one
A – holder made of waste; B – installing a new operating head into it.

The operating head shanks were 28 mm in diameter and 23 mm in length. Sample cutters manufactured in accordance with the recommendations were tested at KSP-35 road-header in "Pervomaiskaya" coal mine in 2014. Two composite cutters were installed in the second row of the crown-type actuating device. The operating heads were replaced on reaching wear limit. In total, 18 operating heads were tested. Wear was even, without breakdowns. Heads lifetime was 3-4 weeks; that corresponded to the road heading 60-90 m long.

Industrial tests of the remanufactured cutters in the mine showed good results: one holder was used as the support for 9 cutting heads, having replaced 9 conventional tools. Calculations show that 9 operating heads require 1,935 g of metal and replace 9 conventional cutters of 9,600 g. Thus, metal consumption is reduced up to 5 times. Purchase costs are reduced 1.5-1.7 times. The current annual consumption of combine cutters in the mines of Kemerovo region is about 200-300 thousand pieces (200-300 tons), the utilization of waste reduces the need for metal up to 40-60 tons per year and save up to 75-113 mln rubles per year.

Conclusion

As a result of the research, the organisational and technical solution to improve the resource efficiency of cutting tools for mining combines is suggested. It is proposed to remanufacture waste combine cutters by means of reconstructing and equipping them with changeable operating heads. A composite cutter using a holder from a wasted cutter as the support and a new cutting head is designed. A shape and a mechanism of the operating head attachment ensuring the reliability of the connection are designed.

Computer modelling in SolidWorks Simulation software sets optimal values of OHS diameter and length, which provide the highest strength characteristics of the cutter body during operation in rocks of hardness f=6-8 on the Protodyakonov scale. The lowest stresses are observed in the body of cutter РГП 33-87-70/16М if OHS diameter is 28 mm and the length is 23 mm. The operating heads with the specified parameters were tested on cutters of КСП-35 road-header operating in the mine. The test results proved the validity of the specified parameters. The heads operated without any damage until worn-out evenly. The tests show that the holder can serve as a basis for the operation of nine operating heads replaced subsequently.

Thus, the holder made of waste can be used multiple times. It ensures a significant reduction in purchase costs (up to 1.5-1.7 times) and metal consumption up to 5 times, as well as increases resource efficiency of coal mining.

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Availability of Suitable Raw Materials Determining the Prospect for Energy Storage Systems Based on Redox Flow Batteries

Petr Vanýsek[1] and ***Vítězslav Novák***[2]

Successful large-scale deployment and manufacturing of newly designed products depends on the availability of raw materials and therefore even fundamental research on electrochemical energy sources cannot ignore the need to secure enough construction and active mass materials. Increasing use of renewable energy sources (for example, wind and solar) require some means of energy storage to balance fundamentally periodic or irregular energy supply. This storage can be electrochemical. One of the most interesting types of electrochemical cells suitable for energy storage are the so-called redox flow batteries (RFB) that store energy in reservoirs. Unlike in conventional cells and batteries, where the amount of stored energy directly depends on the size or volume of the battery electrodes, in the flow cells the advantage is that their energy capacity can be adjusted by refilling the connected containers. The paper describes the basic principles, design and types of flow systems, as well as interesting modern developmental trends related, among other things, to the availability, supplies, mining and market prices of raw materials used in these storage devices. The present concept of RFB is based on utilisation of various oxidation forms of vanadium. However, since the world supplies of vanadium are limited and unsuitable to meet the whole theoretical demand for energy storage, other concepts, based on more common metals (zinc, lead) or organic redox systems, are being discussed.

Key words: *global ore resources, redox reactions, energy storage, flow cells, RFB, accumulators, raw material market*

Introduction

Unlike the fundamental limits of electrochemical power sources, which are based on thermodynamic data and are well understood, prediction of the viability of mass production of a battery with particular chemistry requires sufficient supplies of chemical and raw materials that may not be known with high certainty. While data on available minerals exist, they have a large uncertainty error bar, and the availability is also driven by demands. If the demand for a particular material increase, the willingness to pay a premium for extraction may bring to market resources previously thought non-viable (Fletcher, 2011; Takaya et al., 2018). For example, lithium metal availability and its perceived shortage or abundance have been a study of a number comparisons, for example, (Gruber et al., 2011) and current news economy considerations (Patterson and Gold, 2018). In a rare case, as happened with mercury (Vanýsek, 2015), the demand may also decrease. Here we will look at a type of a battery that relies on utilising reduction and oxidation of metal salts, for example, vanadium. Hence, its commercial success depends on the ability to produce enough vanadium salts, presumably by tapping the materials available in the Earth crust.

The energy of chemical bonds is a very advantageous way of storing energy. Combustion is historically (and even prehistorically) the most significant way of releasing energy in the form of heat. However, thermal energy is less advantageous for energy supply than electrical energy. For this reason, it would be better to convert the chemical energy of bonds directly into electrical energy. This is possible in electrochemical sources, both in the primary cells, that are discarded after use, and secondary ones, which can be recharged after use, and in particular in fuel cells, which are electrochemical sources whose own active substance is not the part of the conversion cell, but is stored in external containers. The active substances and their choice in the flow cells are significantly and actively influenced by the raw materials used as the basis of the redox pairs.

With increasing efforts to use renewable sources as a source of energy, there is a new practical complication, especially for solar cells and wind generators, namely that these energy sources are working intermittently and to some extent unpredictably (Tauš et al., 2015). It is therefore preferable, on a global scale, that electricity should be stored at times when it is overproduced and then made available at times when the demands for energy is higher than the supply from these sources. So far the most efficient storage systems are mechanical, of which the most advantageous are both pumping hydroelectric power plants and compressed air storage (Vanýsek et al., 2015). However, these systems are only effective if they are designed for high performance, requiring substantial initial investment, and physically cannot be placed everywhere. On the other hand, retention of energy in electrochemical cells of the second type (rechargeable batteries) is an obvious choice, and from the point of view of known technologies, it is quite possibly even the most practical method. The task of science and research is to find batteries that will be reliable and generally financially and practically

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available with good technical parameters. This article discusses one type of an electric accumulator, the so-called redox flow battery.

The principle of the redox flow battery

The expression "redox" is derived from joining two words, reduction and oxidation, implying the simultaneous occurrence of both of these processes, oxidation, loss of electrons and reduction, the gain of electrons. From the general electrochemical point of view, where the overall charge balance is thermodynamically required, any electrochemical system will be a "redox" system. However, in the vernacular of electrochemical power sources, the redox flow battery was adopted for a particular concept of electrochemical energy storage.

A redox flow battery (often abbreviated RFB) describes a power source that uses for energy generation two solutions, one in an oxidised form, the other in a reduced form. During the release of energy the solutions react on electrodes, the first is reduced, and the other is oxidised and on the outside connected the circuit between the two electrodes flows electric current. During the process of charging the function of oxidation and reduction is reversed and the system is charged from an external energy source.

The principle of the flow redox cells is the same as the principle of any galvanic cell. Oxidation and reduction, occurring simultaneously, but in separate half-cells, cause the flow of an electric current, carried by ion flow in the electrolyte of the electrochemical cell and by electrons in the external electric circuit. This electric current is then the source of energy where it is needed. Compounds that undergo oxidation or reduction are sources of chemical energy. When these substances are reacted, the electrochemical cell is discharged. For rechargeable (secondary) cells, the discharge process can be reversed, and the cell again recharged via an external power source. Reactive substances pass into their original form during charging. However, the redox flow cells differ from the conventional electrochemical cells by the fact that the reacting material is not part of the construction of the cell, but it is supplied from external storage tanks in the form of electrolytes which, during cycling, pass from the charged to the discharged state. The total energy capacity of the system is proportional to the amount of electrolytes in the external reservoirs, while the output power is dependent on the electrode arrangement (the surface of the electrode system). In a sense, the behaviour of the flow cell, when delivering energy, is identical to the fuel cell operating principle. However, the fuel cell is not expected or designed to reverse the current flow and recharge the system again. The diagram of the redox flow cell showing its principle is given in Fig. 1 and a real commercial cell is depicted in Fig. 2.

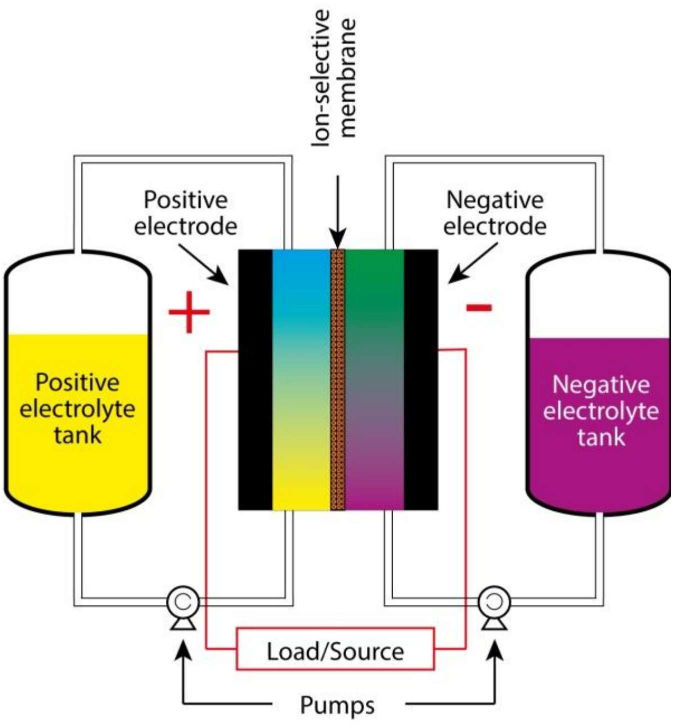


Fig. 1. A diagram of a redox flow battery.

Fig. 2. An actual commercial vanadium flow cell. The left and right upper containers in the transport cages hold the respective vanadium solutions. The middle is the armature of the electrochemical cell. The containers and the cell are placed over the blue reservoirs intended to capture any spill in case of an accident. For sizing an Estwing 22, a 13" geological hammer, is leaning against the middle retention reservoir.

Advantages and disadvantages of the redox flow batteries

The greatest advantage of redox flow cells is that the parts defining the power and energy parameters are physically separated from one another. Their design can then be very variable depending on the needs and applications. A need to increase the cell capacity can be solved by increasing the volume of electrolyte storage tanks. Alternatively, by supplying a new electrolyte, the cell can be quickly "charged." If less power is sufficient, smaller cell size can be constructed. Then, for greater performance, it is possible to design larger cells or use several smaller modules. Since the cell electrodes do not change chemically during charging and discharging (at least in theory), the number of possible operating cycles is theoretically endless. Other benefits include the ability to respond quickly to network requirements, minimal maintenance, or zero emissions. These cells are also characterised by short-term overloading tolerance or the possibility of replenishment of energy by exchanging the storage containers.

Compared with other common types of batteries (for example, Li-ion), the RFB power and energy density are very low. This makes the cells unsuitable for mobile and traction applications. Accordingly, for larger nominal currents, the active surface of the electrodes must increase. This results in a high concentration gradient of electrolyte flowing through the cell, resulting in the reduction of an average current density. Compared with conventional batteries, flow cells are more complicated and require additional support devices such as mechanical pumps, sensors, control units, additional tanks, and the like.

Early beginning. The idea of a flow-cell battery was first mentioned in 1933 in P. A. Pissoort's patent, which also described the use of a vanadium redox pair (Pissoort, 1933). On the basis of US patent (Thaller, 1976) research was carried out in the 1970s by NASA regarding such cells. At first, the systems of redox pairs of Fe-Cr (Ponce de León et al., 2006) and Fe-Ti (Savinell et al., 1979) (soluble salts of Fe, Cr, and Ti in aqueous HCl) were studied. The reactions for the first system can be described as follows:

Positive electrode $$Fe^{2+} \underset{\text{Discharging}}{\overset{\text{Charging}}{\rightleftharpoons}} Fe^{3+} + e^- \quad (1)$$

Negative electrode $$Cr^{3+} + e^- \underset{\text{Discharging}}{\overset{\text{Charging}}{\rightleftharpoons}} Cr^{2+} \quad (2)$$

The open circuit potential of this cell (OCV) was about 1.18 V.

The reactions of the second mentioned couple were:

Positive electrode $$Fe^{2+} \underset{Discharging}{\overset{Charging}{\rightleftarrows}} Fe^{3+} + e^{-} \tag{3}$$

Negative electrode $$Ti^{4+} + e^{-} \underset{Discharging}{\overset{Charging}{\rightleftarrows}} Ti^{3+} \tag{4}$$

This system exhibited somewhat higher open circuit potential (1.19 V) than the Fe-Cr scheme. However, the current density was low, only about 14 $mA \cdot cm^{-2}$, compared to 20 $mA \cdot cm^{-2}$ of the first system. This type of a cell was using the solution of 1.0 $mol \cdot dm^{-3}$ $TiCl_3$ in 3.5 $mol \cdot dm^{-3}$ HCl on the negative side and 1.0 $mol \cdot dm^{-3}$ $FeCl_3$ in 3.0 $mol \cdot dm^{-3}$ HCl on the positive side.

Practical system - a system with vanadium salts. In 1978, A. Pellegri and P. M. Spaziante filed a patent application in which they introduced the idea of using vanadium (Pellegri and Spaziante, 1983). However, they did not become involved in another major development. The first known and commercially successful demonstration of the vanadium cell was presented in 1986 by a group of Australian scientists led by M. Skyllas-Kazacos of the University of New South Wales (Skyllas-Kazacos et al., 1986). This success awakened a Japanese interest in flow systems. In 1989, the development of vanadium redox batteries intensified, utilising the experience gained in developing Fe-Cr systems. In 1996-2000, testing systems emerged, and the first commercial installation was launched in 2001.

The vanadium redox batteries (VRB) concept is particularly interesting because it is based on the use of two different salts of vanadium dissolved in an acidic environment. Vanadium exists in several valences, and the two electrochemical half-cells forming the resulting cell are based on the use of different valence state compounds of the same element. The added advantage of this concept is that in the event of accidental mixing of both solutions no irreversible depreciation of the stock solutions will happen. The negative side is using the redox reaction of vanadium V^{2+}/V^{3+}, and the positive side is the reaction V^{5+}/V^{4+}. The typical solutions of vanadium salts are 1.6 - 2.0 $mol \cdot dm^{-3}$ in 2.0 $mol \cdot dm^{-3}$ H_2SO_4. The reactions during charging and discharging on the two electrodes follow the scheme:

Positive electrode $$VO^{2+} + H_2O \underset{Discharging}{\overset{Charging}{\rightleftarrows}} VO_2^{+} + 2H^{+} + e^{-} \tag{5}$$

Negative electrode $$V^{3+} + e^{-} \underset{Discharging}{\overset{Charging}{\rightleftarrows}} V^{2+} \tag{6}$$

If the two electrolytes were mixed together, they would react, releasing energy, but in the form of heat. Therefore, to obtain electrical energy instead of heat, the two electrode chambers are separated by a membrane, which allows passage of only one kind of ions. In the case of VRB, it allows transport of hydronium ions H^+ (or, more correctly H_3O^+), which travel between the chambers of the positive and the negative electrode. The presently used membrane is NAFION manufactured by DuPont. Considering the cost of the fluorosulfonate polymer NAFION, a VRB large-scale deployment is debatable. Therefore, one of the aims of the battery research is finding more economical membrane separators. The potential of a fully charged cell without load (OCV - Open Circuit Potential or Voltage) is about 1.6 V for the system of half-cells based on vanadium (II) and (V), each with vanadium concentration of 2.0 $mol \cdot dm^{-3}$ in 2.0 $mol \cdot dm^{-3}$ H_2SO_4 (Skyllas-Kazacos et al., 1986). The energy density of the 2.0 $mol \cdot dm^{-3}$ vanadium electrolytes is around 25 $Wh \cdot kg^{-1}$ (Skyllas-Kazacos et al., 2011), the current density can reach 10 to 130 $mA \cdot cm^{-2}$ depending on the system configuration, which can operate in the temperature range 10-40 °C (Skyllas-Kazacos et al., 1999). Any of these parameters should be regarded as approximate. The so-called standard potential available form tables is an equilibrium value at standard conditions, which are a defined temperature and pressure, but most importantly, also unit activities of all the participating reactants, which are not just the redox pairs, but in the case when protons enter the reaction, even the activity of the acid enters into the play. For example, Alotto (Alotto et al., 2014) gives as the standard VRB potential $E^o = 1.26$ V at 25 °C, but the practical equilibrium (pseudo) standard potential is $E^o = 1.4$ V, which confirms, for example, Buckley (Buckley, 2016). The concentrations in practical cells must be as high as possible (higher energy density). For the thermodynamic calculation, the activities would have to be unity and the same for the cathodic and anodic half-cell, which is the situation for a half-charged cell. Therefore, the charged cells will have higher potentials than the standard values; the discharged cells will have, of course, lower potentials.

One advantage of the vanadium cell is also the fact that the colours of the various oxidation states in a sulfuric acid solution of vanadium are very distinct, yellow for VO_2^+, pale blue for VO^{2+}, green for V^{3+} and purple for V^{2+}. This can be used for example in assessing spectrometrically the state of charge of the VRB (Buckley et al., 2014).

The energy density of the system with vanadium salts on both sides of the electrochemical cell is relatively low. Therefore, research has focused on modifying these systems to increase the density and, above all, to find an alternative to poorly available vanadium. Therefore, systems are developed where the vanadium salt is replaced by another variant of the positive half-cell chemistry. These are, for example, V-Br, V-Mn, V-Ce systems, V-glyoxal (O_2), V-polyhalide and others. At present, the best parameters are still available with vanadium salts on both sides, followed by the vanadium-bromine system. However, it is assumed that further development of suitable electrodes, membranes and electrolytes will improve the parameters of alternative vanadium-based systems. In the event of higher energy efficiency, higher energy density, lower prices, or a larger range of working temperatures, future deployment of these systems as energy storage could be considered.

An interesting variant of a vanadium flow cell is the so-called vanadium-oxygen redox fuel cell (VOFC) (Menictas and Skyllas-Kazacos, 2011). Here is even the description "fuel cell" in the name. In this system, the positive half-cell consists of a gas diffusion electrode using oxygen from the air. This saves weight and volume of the system, one electrolyte tank and half of the support technologies. On the other hand, a relatively large amount of platinum-based catalysts is required for the construction of the gas diffusion electrode. The chemical reactions are as follows:

Positive electrode $$2H_2O \underset{Discharge}{\overset{Charging}{\rightleftarrows}} 4H^+ + O_2 + 4e^- \quad (7)$$

Negative electrode $$4V^{3+} + 4e^- \underset{Discharge}{\overset{Charging}{\rightleftarrows}} 4V^{2+} \quad (8)$$

and the OCV of the cell is E_o = 1.0 V. Due to the absence of the entire single electrolyte subsystem, the energy density of this solution is substantially increased. It is to be noted, however, that in the systems using oxygen (air) it is tacitly assumed an unlimited source of air is available, which in some cases (for example on submarines) may not be true.

Practical applications of the vanadium systems exist, and the total installed capacity of the VRB in the world is 18 MW in 24 different locations. The largest storage site is currently located in Japan in Osaka, which has 3 MW output power at 16 minutes of discharge.

Modern systems and future development

Vanadium salts are relatively expensive, not available on a large-scale, and relatively rare, considering that the primary use is of vanadium metal (92 % of total production) in steel manufacturing (Kudelas et al., 2014). The mining is heavily centred on the Asian countries, as shown in Fig. 3.

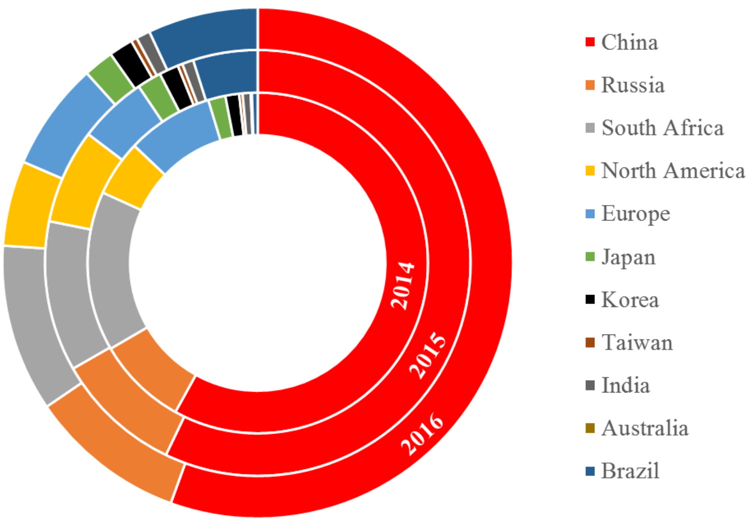
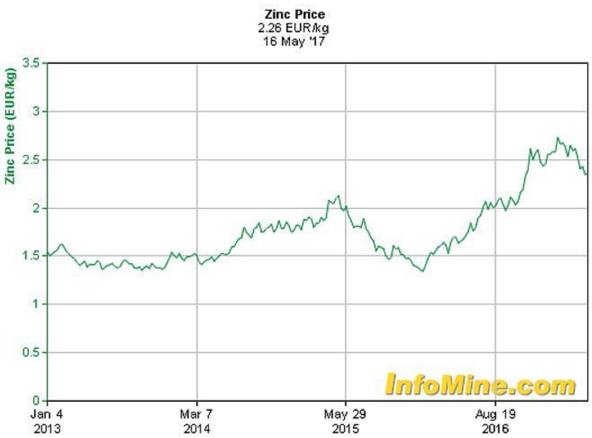


Fig. 3. Production of vanadium (USGS, 2017).

Given this, the current development is focused on the search for other attractive redox cell systems utilising more readily available raw materials with lower cost and high solubility in aqueous solutions. A detailed overview of modern trends is, for example, presented by Skyllas-Kazacos and her colleagues (Skyllas-Kazacos et al., 2011) in a review from 2011 and the newest results are summarised in a review from 2016 (Ulaganathan et al., 2016). Another fundamental shortcoming of the vanadium cells lies in the corrosive nature of the necessary sulfuric acid electrolyte. While the vanadium cells were those first studied and put into operation, there are other promising chemical principles that represent the most modern approaches, possibly with a high risk of failure but also with a high potential reward.

System Zn-Br. One such modern cell uses zinc and bromine chemistry, which gives the cells higher energy density (mainly due to a solid zinc phase) than the vanadium-based system has. It is a so-called hybrid system that differs from conventional flow batteries in that at least one of the redox pairs is not fully soluble. The electrolyte on the anode side is aqueous, and the electrolyte on the cathode side also contains an organic amine, which contributes to greater solubility of bromine. During charging, solid metal zinc is deposited on the anode, while the bromide ions are oxidised to *liquid* bromine, which forms on the opposite electrode. The concept of such a battery was described more than a hundred years ago (Bradley, 1885), nevertheless not until 1970-1980 Exxon a Gould suggested a practical use (Butler et al., 2000; Putt and Attia, 1982). Demonstration hybrid systems exist in the size of 50 to 400 kWh, which can supply energy for 2-10 hours with the efficiency of 70 % and more (Linden, 1995; Butler et al., 2000). The energy density is about 65–75 $Wh \cdot kg^{-1}$ (Linden, 1995). An even more recent concept was designed in the Pacific Northwest National Laboratory (PNNL) by a team led by Wei Wang (Li et al., 2015; Wei et al., 2015). This concept is based on zinc and polyiodide. Some of the problems of the bromine-zinc battery are the cost of electrodes, material corrosion, the formation of metal dendrites during the deposition of zinc during charging, which may lead to a cell short-circuit, significant self-discharge, unsatisfactory energy efficiency, relatively short service life (Ponce de León et al., 2006) and not the least that bromine, if released into environment, can be hazardous. The cells with metal deposition also have in general lower number of useful cycles.

The undeniable advantage of zinc over vanadium is, however, its price, which is steadily on the average only 10 % of the price of vanadium (Fig. 4) (USGS, 2017).



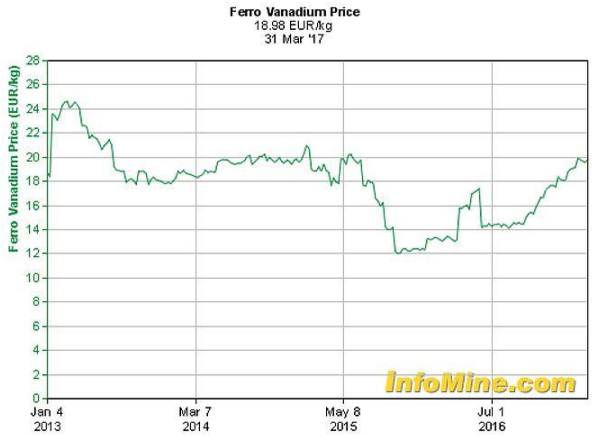


Fig. 4. Comparison of prices of zinc and vanadium (Infomine, 2017).

An obstacle to overcome is that in zinc cells, the amount of zinc deposited on the surface of the negative electrode grows over time through the diaphragm or membrane separator, thereby reducing the efficiency of the battery.

Flow-through cells with organic electrolytes. In the paper (Janoschka et al., 2015) is described a redox flow-through cell which is based on such materials as the ion-radical TEMPO (2,2,6,6-tetramethyl-piperidin-1yl)oxyl or viologen. The advantage of such an arrangement is that no corrosive solvents are used, and therefore cheaper membranes can be used in the construction of the cells. The proposed organic materials are synthetic and, in principle, should the proper technology be developed, they could be produced in considerable quantities. Due to the novelty of this cell, its shortcomings or possible problems are still unknown. Generally, the biggest problem with non-aqueous redox cells will be the availability of the solvents that promote high stability of the active material. The capacity of the cell is directly proportional to the solubility of the active material. Aziz and co-workers (Huskinson et al., 2014) described a new concept of the flow cell based on organic molecules quinones. Abruña et al. (Potash et al., 2016) came with an idea how to use in a flow cell a single kind of organic molecule, but one that exists in both the oxidised and reduced form. An example can be diaminoanthraquinone. An advantage of such an arrangement is that it is possible to design a membrane-free system relying only on laminar flow which does not allow spontaneous mixing of the two electrolytes in contact.

Flow-through lead battery. Another interesting concept of the flow-cell battery is the so-called lead-acid battery (Nandanwar and Kumar, 2014; Hazza et al., 2004; Pletcher and Wills, 2004). The schematic representation is shown in Figure 5. Unlike the conventional lead-acid battery (lead and sulfuric acid solution), it uses the highly soluble form of divalent lead Pb(II), which is supplied in the form of an electrolyte for both half-cells, for example as lead methanesulfonate in concentration up to 2.5 mol·dm^{-3}. During charging, lead is deposited from this electrolyte on the negative electrode and lead oxide on the positive electrode. Electrode reactions occur according to the scheme:

Positive electrode: $$Pb^{2+} + 2H_2O \underset{Discharging}{\overset{Charging}{\rightleftarrows}} PbO_2 + 4H^+ + 2e^- \quad (9)$$

Negative electrode $$Pb^{2+} + 2e^- \underset{Dicharging}{\overset{Charging}{\rightleftarrows}} Pb \quad (10)$$

The OCV cell is approximately 1.62 V. Several systems, such as perchloric acid, hydrochloric acid, hexafluorosilicic acid or tetrafluoroboric acid, have been studied as a suitable electrolyte that dissolves the lead salts. At present, a methanesulfonic acid is used, which ensures good solubility of divalent lead and sufficient stability of the deposited solid lead and lead oxide.

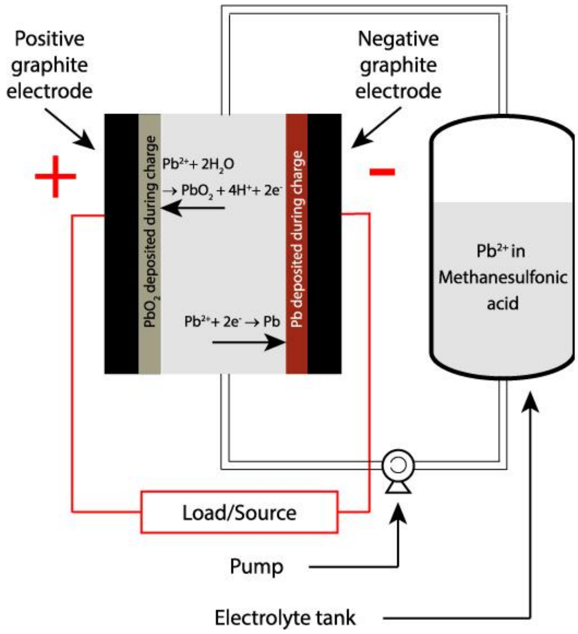


Fig. 5. Schematic depiction of the lead flow battery.

Because the electrolyte solution is the same for both half-cells, it is not necessary to use an ion exchange membrane and, at the same time, the concept requires only a single electrolyte reservoir. This greatly reduces the cost and structural complexity of the cell. Problems encountered in this type of a cell are closely related to phase changes on the electrodes during cycling and are typical of systems where metal deposition occurs. While the anodic deposition of PbO_2 layers takes place relatively simply, the lead deposition to form a compact layer leads to a formation of dendrites around the edges of the negative electrode, which can cause the cell to short. Problems are also related to poor adhesion of the PbO_2 layer to the support collector. These problems could be addressed by the addition of suitable additives, which is the subject of current research in this field (Collins et al., 2010; Chen and Chang, 2015).

Chemically regenerated redox fuel cells. A chemically regenerated redox fuel cell is a type of fuel cell that uses a redox pair solution as an electron mediator for fuel and oxidant reaction. Thus, the chemically regenerated redox fuel cell is also a kind of flow electrochemical cell because it has two redox pair solutions flowing along the electrodes. Following a subsequent electrochemical reaction on the electrodes, these solutions are taken to regeneration reactors where they are re-reduced or oxidised by a reducing or oxidising agent. After regeneration, the solutions circulate again along the electrodes, and the cycle continues. Compared to the flow cells described here in the previous chapters, however, charging or regeneration takes place outside of its own central electrochemical cell. The first results on redox fuel cells were written by Kummer and Oei (Kummer and Oei, 1982; Oei, 1982; Kummer and Oei, 1985), whose work has shown both advantages and limitations of the redox fuel cell. The main attraction of this concept is to avoid catalysts on the surface of electrodes and the use of simple (cheap) electrode materials. Hydrogen gas can be used to reduce the need for regeneration (charge). However, the main disadvantage of using hydrogen to regenerate the negative half-cell is a relatively high potential for the reversible redox pair of hydrogen, which limits the choice of redox pairs that would be suitable for the negative half-cell. Oxidation regeneration should be possible with air oxygen. Unfortunately, even here in further studies, it was shown that the oxidative regeneration of the positive half-cell is kinetically slow and requires relatively expensive catalysts, which negates the main purpose of this approach. Kummer and Oei were looking for a suitable approach for electric cars (Kummer and Oei, 1982; Kummer and Oei, 1985). Other researchers (Ferrigno et al., 2002) evaluated various alternative membranes for these cells. Recent work has been devoted to research into a cell in which methanol is used as fuel (Ilicic et al., 2010; Moraw et al., 2007).

The aspect of global resources is constructing redox flow cells. The path from laboratory design to a useful mature product is described by the technology readiness level (TRL), from Level 1 (Basic Principles observed and reported) to Level 9 (Actual application in its final form). While many of the battery technologies are or will be proven through successful operations, it does not mean the batteries would be suitable for truly large-scale production relevant for energy production and storage.

The primary power demand on Earth has been in 2015 18 TW (BP, 2016), with 78 % produced from the fossil fuels. As the focus on renewables grows, so does demand on new technology, but power generation (e.g., wind, solar) and energy storage. Deployment of these new technologies will require a shift towards new materials and unprecedented demand for mineral resources.

While the elemental abundance of elements in Earth crust may provide some guidance to mineral availability, it is rather skewed guidance. From the planning point of view, the elements that tend to concentrate into ores with sufficiently high concentration to allow mining are those that will be promising for large-scale technology.

Due to fluctuations of power supplied by solar and wind energy, some of it needs to be stored. If we assume that today's energy production is 10 % derived from wind and solar and it would be desirable to store 20 % of that, it would represent 0.36 TW of power, and assuming a 24-hour cycle; it would correspond to storage of $3x10^{16}$ J of energy. Since a lead–acid battery has energy density about 140 $kJ \cdot kg^{-1}$, if the above storage were solely depended on lead, then the amount of lead required would be about $2.1x10^{11}$ kg. Considering that present yearly production of lead is about $4x10^{9}$ kg, the needed amount of lead corresponds to about 50 years of production. For a vanadium redox flow, with the density about 54 $kJ \cdot kg^{-1}$, about $5.6x10^{11}$ kg of vanadium would be needed. This brings up to the forefront the issue of a mass-specific problem. In this scenario, the amount of vanadium corresponds to about 8800 years of present yearly production (Vesborg and Jaramillo, 2012).

Conclusion

Considering that many commercial vanadium and other redox cells already exist and there is no doubt that there is a need to store excess electricity and that there is a lack of suitable energy storage alternatives (pumping hydroelectric power plants and compressed air storage), the development of VRB is timely. Future electrochemical storage of energy has already almost achieved success as commercial systems are available for purchase. Ultimate success will depend on which technology or concept will be chosen as the most advantageous, and this choice may not even be the same in all geographic and economic areas. Since the first models of industrial flow cells are already installed, there is no doubt that there will be future demand for such systems. Current cells based on vanadium cannot singularly meet this demand, as the fundamental redox material is not sufficiently common and would not be affordable even on a large-scale. This will require shifting to other materials. If such cells are developed, it is almost guaranteed that they will be profitable and economically successful.

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Exploring the Oil Supply-Demand Shocks and Stock market Stabilities: Experience from OECD Countries

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This paper explores the interactive relationships between oil price shocks and the stock market in 11 OECD countries using traditional cointegration test and look at the rolling window Granger causality effects with various predictive power contents running between the variables. Taking into account both world oil production and world oil prices in order to supervise for oil supply and oil demand shocks, strong evidence of the sensitivity of stock market returns to the oil price shock specifications is found in several sub-periods. As for rolling window causality tests, it is found that the impact of oil price shocks substantially differs along the different countries and that the results also differ among the various oil shock specifications. The overall finding suggests that oil supply shocks have a negative effect on stock market returns in the net oil importing OECD countries. Indeed, the stock market returns are negatively impacted by oil demand shocks in the oil importing OECD countries and positively impacted by the oil exporting OECD countries. Furthermore, these results will give a dimension for future undertaking studies with varying empirical findings.

Key words: *oil supply-demand shocks, rolling window, stock market returns*

Introduction

The oil price has experienced a series of shocks for more than fifteen years, and these shocks are not without impact on the industrial sector and therefore on economic growth and financial stock market development. More specifically stock market returns are highly sensitive to the oil price shocks. This sensitivity of stock prices to oil price shocks have been the subject of many works such as those of Jones and Kaul (1996), Sadorsky (1999), Huang et al. (1996), El-Sharif et al. (2005), Naifar and Al Dohaiman (2013), Chang and Yu (2013), Mohanty et al. (2011), and Nguyen and Bhatti (2012). While, Huang et al. (1996) results indicate non-significant sensitivity of stock returns to oil price shocks for some specific markets such as that of the S&P 500 stock market, several studies such as those of Nandha and Faff (2008), Sadorsky (1999), and Issac and Ratti (2009) shows a negative connection between stock returns and oil price increases. Among others, oil production is introduced as an explanatory variable by Kilian (2009), Kilian and Park (2009) and Güntner (2014). Bernanke et al. (1997) and Lee et al. (2012) introduced the short-term interest rate. Park and Ratti (2008) and; Cũnado and Perez de Gracia (2003; 2005; 2014) has developed models that associate the stock returns to the different macroeconomic variables.

Several studies have focused on the nature of the relationship between oil price changes and stock market returns. Bernanke (1983) and Pindyck (1991) argued that a higher change in energy prices creates uncertainty about future energy price and incites, consequently, firms to postpone irreversible investment decisions in reaction to the profit prospects. Ciner (2001) has introduced nonlinear effects and confirms the same results according to which there is a significant negative connection between oil price shocks and real stock returns. According to Basher and Sadorsky (2006), a rise in oil prices acts as inflation tax and increases risk and uncertainty, which lead to reduce wealth and affect the stock price seriously. While Jones and Kaul (1996) found a serious reaction of stock prices to oil price shocks in the US and Canada. Chen et al. (1986) found that the returns generated by oil futures are without significant impact on stock market indices such as S&P 500, and there is no gain in considering the risk caused by the excessive volatility of oil prices on stock markets. In the same line, Apergis and Miller (2009) obtained results that do not support a large effect of structural oil market shocks on stock price in eight developed countries. This result is in line with Park and Ratti (2008) findings, where oil price shocks exert a statistically significant impact on real stock returns.

Lee et al. (2017) has analysed the nexus between oil price shocks and country risks using Structural VAR (SVAR) estimates for oil importing and exporting countries and found that oil exporting country, such as Canada, indicates significant impact with economic and political risks on the supply-side, while the US with a

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specific demand shock as an oil-importing country. Reboredo and Rivera-Castro (2014) examined the connection between oil prices and stock market returns and the results of the wavelet multi-resolution analysis show that oil price changes have no much effect on stock market returns in the pre-crisis period at either the aggregate as well as the sectoral level. Bastianin and Manera (2017) found the dynamic response of oil price shocks with the aggregate oil-specific demand, along with supply-side shocks for the US. The finding also in line with Morana (2017) recent finding, where also reveals the same condition for Middle East countries. Naifar and Al-Dohaiman (2013) have investigated the impact of both change and volatility of oil price variables of stock market returns under regime shifts in the case of the Gulf Cooperation Council (GCC) countries. Their results show evidence supporting a regime dependent relationship between GCC stock market returns and OPEC oil market volatility with exception to the case of Oman. Aloui and Jammazi (2009) have developed a two-regime Markov-switching EGARCH model to examine the interdependence between crude oil shocks and stock returns. The main result of their study supports that net oil prices play a pivotal role in determining firstly the volatility of real returns and secondly the probability of transition across regimes. Hong et al. (2002) also confirm the significant negative connections between the lagged petroleum industry returns and the US stock market. Similarly, Issac and Ratti (2009) results confirm a clear long-run connection between oil price and real stock market returns supporting the negative reaction of real stock prices to the increase in oil prices.

The remainders of this paper proceed as follows. Section 2 is focused on the data and empirical analysis. In this section, we present the variable definitions and the modelling approaches. The discussion of empirical findings is the subject of Section 3, and finally, Section 4 concludes.

Data and Empirical Strategies

We collect data for real stock prices, real industrial production, nominal interest rates and oil prices over the period from January 1990 to December 2013. The countries included in our analysis are Canada, Czech Republic, Denmark, Hungary, Korea, Mexico, Norway, Poland, Sweden, UK and US. All data used in this article are monthly. Thus, the starting date of the sample period is determined by the availability of monthly data serving to compute our variables for each country. Other papers that also use monthly data are those of Sadorsky (1999), Park and Ratti (2008), Driesprong et al. (2008) and Lee et al. (2012). The real stock returns in each market, denoted R_t, are computed using the following equation: $R_t = \left(ln(P_t) - ln(P_{t-1})\right) \times 100$, where P_t represents the real stock market index at the time t. To avoid the impact of the inflation rate we use approximately the real stock returns instead of the returns calculated for each market. We also use the real national price for each country as a proxy for the oil price. The UK Brent nominal price is used as a proxy for the nominal oil price. This proxy is commonly used by several authors such as Cũnado and Perez de Gracia (2005) and Engemann et al. (2011) in order to investigate the type of interconnections between oil shocks and macroeconomic variables.

The data for the oil price and the oil production are obtained from the Energy Information Administration (EIA) Database and the International Financial Statistics from the International Monetary Fund. Finally, the data for the macroeconomic data (industrial production, producer price index, consumer price index, short-term interest rates and exchange rate) are compiled from the OECD database and the Global Financial Data (GFD). This relation specifies the oil price variations defined as the first log difference of real oil prices. The oil supply shocks (oss_t) and oil demand shocks (ods_t) will be computed respectively as follows.

$$\begin{cases} Oss_t & = \Delta wop_t, \quad if \ \ sign(\Delta op_t) \neq \ sign(\Delta yOil_t), \\ & = \ 0, \qquad\qquad\qquad otherwise \end{cases} \tag{1}$$

$$\begin{cases} Ods_t & = \Delta wop_t, \quad if \ \ sign(\Delta op_t) = \ sign(\Delta yOil_t), \\ & = \ 0, \qquad\qquad\qquad otherwise \end{cases} \tag{2}$$

In the first step, we use the conventional unit root tests of Dickey and Fuller (ADF), Phillips and Perron (PP) and Kwiatkowski et al. (KPSS) tests to verify the stationarity of all variables. In a second time, we apply the endogenous breaks LM unit root test of Lee and Strazicich (2003) to avoid spurious rejections from the conventional unit root tests. For each of the variables contains a unit root, we proceed with the second step to determine the lag length of the VAR version using the Akaike Information Criterion (AIC). Then, we apply the Johansen's cointegration test to determine the number of cointegrating vectors using two different likelihood ratio statistics (LR). First, we will look at the trace and the maximum eigenvalue statistics. In the second step, the Granger causality tests are performed. Finally, we analyse the impact of oil price changes on stock markets by examining the Granger causality tests obtained by estimating the rolling window parameters.

The likelihood ratio (LR) and the Lagrange Multiplier (LM) are commonly used in testing the Granger causality seems to have non-standard asymptotic properties once the variables used in the VAR equation system are integrated or cointegrated (Balcilar et al., 2010). A point of view commonly shared in this vein is that the modified Wald test based on a bootstrap distribution has better properties. To illustrate the bootstrap LR Granger causality let's consider the following bivariate VAR(p) specification

$$Y_t = \lambda_0 + \lambda_1 Y_{t-1} + \cdots + \lambda_p Y_{t-p} + u_t, with: t = 1, 2, \cdots, T \quad (3)$$

where, $u_t = (u_{1t}, u_{2t})$ corresponds to a zero-mean independent white noise process having a non-singular covariance matrix. P is a known lag length order determined based on the AIC. A simplified specification of the bivariate VAR(p) illustrated in eq. (4) process considering two variables $y_1$as dependent variable and y_2 as an independent variable can be presented as follows:

$$\begin{bmatrix} y_{1t} \\ y_{2t} \end{bmatrix} = \begin{bmatrix} \lambda_{10} \\ \lambda_{20} \end{bmatrix} + \begin{bmatrix} \lambda_{11}(L) & \lambda_{12}(L) \\ \lambda_{21}(L) & \lambda_{12}(L) \end{bmatrix} \begin{bmatrix} y_{1t} \\ y_{2t} \end{bmatrix} + \begin{bmatrix} u_{1t} \\ u_{2t} \end{bmatrix} \quad (4)$$

where, $\lambda_{ij}(L) = \sum_{k=1}^{p} \lambda_{ij,k} L^k$, ij = 1, 2 and L is the lag operator defined as $L^k x_t = x_{t-k}$. Based on eq. (2), we can test the null hypothesis that the independent variable does not Granger cause the dependent variable by imposing the restriction of $\lambda_{12,i} = 0$, for I = 1, 2, ….., p. In the same way, we impose the restriction $\lambda_{21,i} = 0$ for I = 1, 2, ….., p. to test the null hypothesis that the dependent variable does not Granger cause the independent variable. As regards the rolling window based causality technique the tests proceed as follows. As a first step sets a rolling window of size T and we estimate than the Modified Wald (MWALD) causality test for the beginning sub-sample of T observations. In the next step, the first observation is removed from the sub-sample, and a new observation are included the estimation is performed once again. The same procedure continues subsequently by removing one observation from the beginning and including one new observation. The last step consists to normalise the generated χ^2-statistics by a certain level of significant level, and the null hypothesis is rejected if the normalized statistic is above one.

Empirical Results

For the 11 OECD countries, the outcome of ADF, Phillips-Perron and KPSS unit root tests in level and the first difference of the real stock prices, short-term interest rate, real industrial production and real oil (national and world) prices are presented in Table 1. The illustrated results in Table 1 show that about all variables are integrated of order one except the real oil price which seems, in a first look, to be trend stationary in level for Canada, Korea, Mexico, Poland and Sweden. However, this result can be carefully taken into account. In fact, the plot of real national oil price time series shows, for each country that the series are not really trending stationary in level. The history of the real national oil prices shown in Figure 1 until 11, which indicates a presence of breaks in all oil price series. The conventional unit root tests fail to reject the null hypothesis when structural breaks are present. These tests drive their critical values assuming no breaks under the null hypothesis. Consequently, in the presence of a unit root with a break, they tend to reject the null hypothesis suggesting that time series is stationary around trend when it is non-stationary with a break.

To avoid this problem and to examine the potential presence of breaks, we use the endogenous two-break LM unit root tests proposed by Lee and Strazicich (2003) This later seems to be unaffected by breaks under the null hypothesis. We find as anticipated significant structural breaks of real national oil prices of Canada, Korea, Poland and Sweden but not for Mexico (see Table 2). Meanwhile, for this last country, the time series of real national oil price seems to be a linear trend stationary potentially because of the shortness of data. Regarding the ADF, PP, KPSS and LM unit root tests, the results conclude in favour of unit root for all level series.

Assuming that all variables contain a unit root, we test them for cointegration in each VECM using both the trace and the maximum Eigenvalue tests. The results of applying the Johansen and Juselius (1990) approach are shown in Table 3. The Table includes the ranks given in the first line, the number of cointegration vectors in line 2 and eigenvalues and trace statistics for each selected country. The critical value is mentioned using asterisks, and the null hypothesis is that the number of cointegrating relationships is equal to r, which is given in the maximum rank observed in the first line of Table 3. The alternative is that there are more than the rank cointegrating relationships. We reject the null if the trace statistic is greater than the critical value. The existing of one or more cointegration vectors explains that the variables have a long run relationship. The results displayed in the first part (world oil prices) of Table 3 show that there is at least one cointegration vector with an intercept and/or trend in all countries except for the UK for which we find one cointegration vector without constant. Consequently, we can conclude that there is at least one cointegration vector for all selected countries. In the second part (national oil prices) of Table 3, the null hypothesis of no cointegration is not rejected only for the UK. Looking at the Johansen cointegration test results, we conclude that the VECM can be applied to all countries except for the UK (r=0) under the 'all shock' specification of world oil prices. To assess the effect of oil price shocks on stock returns for USA, UK, Canada, Czech Republic, Denmark, Hungary, Korea, Mexico, Norway, Poland and Sweden, we have estimated four different VECM processes for each of the selected OECD countries. As explained above and following Sadorsky (1999) and, Park and Ratti (2008), each process contains the variable stock prices, real industrial production indexes, short-term interest rates, and different specification for oil price shocks: (i) national real oil price; (ii) national oil price as defined in (1) and (2); (iii) world real oil price; (iv) world oil price as defined in (1) and (2). Using the above-estimated models, we continue by performing a Granger causality test as well as a rolling window approach for the full sample. Table 4 summarises the results of the Granger causality test to examine the linkages between oil supply and demand shocks and stock price considering both national and world oil prices.

We tested for the null hypothesis that oil price, as it is shown in Table 4. The results, for the national oil prices specification, seem to be classified into 5 categories. As regards the first class including Canada, Mexico, Norway, and Sweden, we find results confirming the rejection of the null hypothesis according to which oil price does not Granger cause stock price and this for the three specifications of oil price including op, oss and osd. Thus, results from sample bootstrap Granger causality tests indicate that oil price with its three specifications seems to have predictive power for stock price for each of these countries. For the second class, including Denmark, Hungary, Poland, and the UK, the results show the rejection of the null hypothesis for the oil supply and oil demand shocks. For the oil price, we cannot reject the null. This indicates that oil supply and demand shocks have predictive power for the stock price, whereas there is no predictive power between global oil price shocks and stock price. As regards the US case the results indicate that the null hypothesis is not rejected for the oil supply shocks, which appear without predictive power for the stock price. Oppositely, we reject the null hypothesis for both oil price and demand shocks. These two oil prices specifications seem to have significant predictive power. For the case of Korea, the oil supply shocks seem to be without significant predictive power for the stock price, whereas, oil price as well oil demand shocks appear as having significant predictive power. For the last class regroups the Czech Republic, only demand shocks do Granger cause the stock price. Neither oil price nor oil supply shocks have predictive power.

The results using world oil prices specification differ considerably to those discussed above. World oil price with its different specification appears as without predictive power in the cases of Hungary, Poland and UK. For all the rest of selected countries (except for Norway), the global oil price seems Granger cause stock price. As regards, oil price shocks, the results show that while oil supply shocks have a great predictive power for the stock price in only the case of Korea, the null hypothesis seems to be rejected in the cases of Czech Republic, Denmark, Norway, and the US. We notice here that the previous major studies on the linkages between oil price shocks and stock price used various approaches to supervise for autoregressive autocorrelation, long and short run among others. However, although the important results they found, they never examined the stability of the estimates. Structure changes induce changes in the parameters, and consequently, the pattern of the causal connection may vary in its turn over time. If the parameter constancy of the estimated model is violated, therefore the Granger causality tests will show sensitivity to both or each of sample period used and to the lag order of the selected model such as VAR or cointegration model.

Tab. 1. Conventional unit root tests.

	Stock prices			Real industrial productions			Short-term interest rates			Oil real prices		
	ADF	PP	KPSS	ADF	PP	KPSS	ADF	PP	KPSS	ADF	PP	KPSS
At level												
Canada	-1.417	-1.419	1.652***	-1.861	-1.834	0.603**	-3.729***	-2.619*	1.462***	-5.107***	-4.358***	1.924***
Czech Rep	-3.383*	-2.144	0.519**	-3.001**	-2.880*	0.148	-0.770	-1.324	1.521***	-1.605	-1.738	1.415***
Denmark	-2.572	-2.795	1.783***	-2.715	-2.404	0.756***	-1.681	-2.960	1.438***	-3.482**	-3.242*	1.760***
Hungary	-3.093**	-2.838*	1.575***	-3.369*	-3.264*	1.667***	-2.591	-2.616	1.484***	-2.965	-3.109	1.832***
Korea	-3.341*	-2.863	1.541***	-3.509**	-2.672	1.960***	-3.580**	-1.770	1.745***	-4.864***	-4.215***	1.950***
Mexico	-0.535	-0.522	1.735***	-2.785	-2.621	1.327***	-2.754	-1.980	1.310***	-3.514**	-3.658**	1.730***
Norway	-0.584	-0.679	1.799***	-2.268	-2.375	0.448***	-3.681**	-2.175	1.270***	-3.197*	-3.278*	1.847***
Poland	-2.891	-2.569	1.541***	-3.106	-3.110	1.973***	-2.384	-2.417	1.814***	-4.118***	-3.496**	1.960***
Sweden	-1.246	-1.059	1.644***	-1.690	-1.720	1.643***	-2.990	-2.807	1.621***	-4.089***	-3.501**	1.921***
UK	-1.440	-1.465	1.480***	-2.032	-2.181	0.379*	-2.684*	-2.613*	1.473***	-2.692	-2.809	1.738***
US	-2.769	-1.390	1.762***	-1.473	-1.482	0.416***	-1.683	-1.770	1.161***	-3.321*	-2.993	1.823***
World										-3.383*	-3.124	1.663***
At first differences												
Canada	-16.261***	-16.273***	0.132	-14.552***	-14.846***	0.445*	-4.514***		0.311		-13.301***	0.037
Czech Rep.	-11.238***	-11.366***	0.173	-18.147***	-18.139***	0.054	-10.872***		0.088		-13.513	0.033
Denmark	-12.691***	-13.106***	0.043	-19.815***	-22.422***	0.264	-10.604***		0.079		-13.394***	0.078
Hungary	-11.017***	-10.846***	0.398*	-17.810***	-17.844***	0.251	-13.144***		0.130		-14.277***	0.048
Korea	-11.540***	-10.874***	0.087	-12.750***	-14.456***	0.230	-10.512***		0.037		-12.726***	0.046
Mexico	-11.067***	-11.082***	0.114	-12.401	-12.422	0.065*	-11.040***		0.064		-12.942***	0.077
Norway	-13.995***	-14.094***	0.050	-16.445***	-22.631***	0.419*	-7.506***		0.075		-13.585***	0.082
Poland	-12.632***	-12.593***	0.059	-15.898***	-15.896***	0.031	-5.379***		0.265		-13.422***	0.029
Sweden	-11.331***	-11.309***	0.080	-18.927***	-18.850***	0.315	-18.089***		0.113		-13.131***	0.060
UK	-12.822***	-14.817***	0.071	-15.465***	-15.439***	0.060	-10.147***	-9.703***	0.198		-14.459***	0.133
US	-12.554***	-12.527***	0.061	-11.303***	-11.463***	0.135	-11.167***	11.677***	0.067		-11.926***	0.062
World											-12.566***	0.0915

*Note: ADF denotes Augmented Dickey-Fuller unit root tests, PP refers to the Phillips-Perron unit root tests, KPSS denotes Kwiatkowski–Phillips–Schmidt–Shin tests. *, ** and *** denote rejection of the null hypothesis at the 10, 5 and 1% levels of significance, respectively. The lag length in all the tests has been selected based on the Akaike Information Criteria (AIC).*

Tab. 2. Lee-Strazicich double breaks unit root tests.

	Single break				Double breaks					
	Model A		Model B		Model A			Model B		
	t-stat	Break	t-stat	Break	t-stat	Breaks		t-stat	Breaks	
National oil prices										
Canada	-5.456***	2000M4	-5.763***	1999M07	-5.785***	2000M04	2004M04	-6.559***	1997M10	1999M10
Czech Republic	-3.397*	1999M01	-3.489	2008M08	-3.617*	2000M04	2001M09	-4.031	1999M04	2001M08
Denmark	-2.606	2004M12	-4.631**	1999M05	-3.129	1993M11	2000M07	-5.290*	1998M04	1999M09
Hungary	-3.290*	2002M10	-3.748	2001M09	-3.553*	2001M09	2009M06	-4.058	2001M04	2005M03
Korea	-3.344*	1997M11	-6.163***	1995M09	-3.735*	1997M11	2008M04	-6.868***	1993M09	2007M12
Mexico	-1.990	1998M10	-3.930	2004M05	-2.146	1998M10	2004M04	-4.252	1999M08	2004M02
Norway	-2.853	2004M12	-3.938	1999M07	-3.771*	2000M07	2004M12	-5.534*	1999M05	2001M09
Poland	-4.422***	1999M10	-4.457**	1999M06	-4.644***	1998M05	1999M03	-5.113	1997M10	1999M06
Sweden	-2.831	1999M03	-5.193***	1999M07	-3.238	1999M03	2004M12	-5.631*	1999M10	2004M12
UK	-2.436	2004M12	-4.599**	1999M04	-2.614	2004M09	2004M12	-5.349*	1996M11	1999M04
US	-3.624**	2004M09	-5.851***	1999M05	-3.892**	2004M09	2005M02	-7.846***	1995M06	1997M03
World Oil Price	-2.567	2005M02	-4.939**	1999M05	-3.283	2004M09	2005M02	-5.639*	1997M12	2005M02

*Note: *, ** and *** denote rejection of the null hypothesis at the 10, 5 and 1 % levels of significance, respectively. Model A: change in the intercept. Model B: change in the intercept and trend. The critical values for the LS unit-root test with one break are tabulated in Lee and Strazicich (2004, Table 1). The critical values for the LS unit-root test with two breaks, tabulated in Lee and Strazicich (2003, Tab. 2), depending upon the location of the breaks. For $\lambda_1 = 0.4$ and $\lambda_2 = 0.6$, the critical values equal, respectively, -6.45 (1 % level), -5.67 (5 % level), and -5.31 (10 % level).*

Tab. 3. Johansen and Juselius cointegration test results.

	Statistics	$r = 0$		$r \leq 1$		$r \leq 2$		$r \leq 3$	
		(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
World oil prices									
Canada	Trace	49.614**	77.273***	23.530	43.710**	8.765	20.071	1.345	7.189
	Max-Eigen	26.084*	33.564**	14.765	23.639*	7.420	12.882	1.345	7.189
Czech Republic	Trace	45.787*	71.521***	27.333*	37.413	13.825*	19.596	2.228	7.543
	Max-Eigen	18.454	34.107**	13.508	17.818	11.597	12.053	2.228	7.543
Denmark	Trace	33.859	64.216**	19.041	33.486	8.097	18.868	0.000	8.030
	Max-Eigen	14.818	30.730*	10.945	14.619	8.096	10.837	0.000	8.030
Hungary	Trace	60.680***	71.223**	24,127	31.378	9.047	15.147	3.407	5.390
	Max-Eigen	36.553***	39.846***	15.080	16.230	5.641	9.757	3.407	5.390
Korea	Trace	64.941***	86.466***	22.755	32.775	10.436	17.878	2.789*	6.162
	Max-Eigen	42.186***	53.691***	12.318	14.898	7.647	11.715	2.789*	6.162
Mexico	Trace	48.829**	58.350	26.996	33.222	9.606	15.409	0.552	4.665
	Max-Eigen	21.833	25.128	17.390	17.813	9.054	10.744	0.552	4.665
Norway	Trace	60.686***	81.607***	30.416**	47.678**	9.220	23.332	0.198	8.798
	Max-Eigen	30.270**	33.929**	21.196**	24.346*	9.022	14.535	0.198	8.798
Poland	Trace	80.367***	95.461***	28.592*	38.655	9.751	19.163	3.709*	5.435
	Max-Eigen	51.775***	56.806***	18.841	19.493	6.043	13.728	3.709*	5.435
Sweden	Trace	42.604	66.744**	18.920	28.698	7.651	15.226	3.262*	4.368

	Max-Eigen	23.685	38.046***	11.269	13.472	4.389	10.858	3.262*	4.368
UK	Trace	32.586	49.473	17.323	24.870	6.897	12.910	1.868	3.671
	Max-Eigen	15.263	24.602	10.426	11.960	5.029	9.239	1.868	3.671
US	Trace	132.660***	149.850***	14.126	30.741	4.051	11.866	1.332	2.340
	Max-Eigen	118.540***	119.110***	10.075	18.875	2.719	9.524	1.332	2.340
National oil prices									
Canada	Trace	53.797**	83.459***	23.798	49.341**	9.047	20.626	1.094	7.556
	Max-Eigen	29.999**	34.118**	14.751	28.715**	7.953	13070	1.094	7.556
Czech Republic	Trace	46.456*	62.588*	25.536	30.349	10.713	15.440	2.819*	6.259
	Max-Eigen	20.920	32.239**	14.823	14.909	7.894	9.181	2.819*	6.259
Denmark	Trace	35.288	68.175**	19.982	35.213	7.688	19.945	0.035	7.653
	Max-Eigen	15.306	32.962**	12.294	15.268	7.653	12.292	0.035	7.653
Hungary	Trace	60.786***	70.783**	25.746	34.437	8.988	16.178	3.303*	5.308
	Max-Eigen	35.039***	36.345**	16.759	18.260	5.685	10.870	3.303*	5.308
Korea	Trace	62.243***	75.461***	23.093	30.184	11.429	18.333	2.962*	7.085
	Max-Eigen	39.149***	45.277***	11.665	11.851	8.467	11.248	2.962*	7.085
Mexico	Trace	50.686**	57.911	25.328	32.171	8.199	15.012	0.460	4.721
	Max-Eigen	25.360*	25.740	17.129	17.159	7.739	10.291	0.460	4.721
Norway	Trace	54.396***	77.325***	23.448	39.459	8.551	19.152	0.026	8.464
	Max-Eigen	30.949**	37.866***	14.896	20.307	8.526	10.688	0.026	8.464
Poland	Trace	52.029**	72.239***	23.549	43.475**	11.726	18.515	4.341**	6.701
	Max-Eigen	28.480**	28.763	11.822	24.959*	7.385	11.814	4.341**	6.701
Sweden	Trace	44.153	69.033**	18.860	31.685	6.970	16.576	2.238	4.687
	Max-Eigen	25.294	37.349**	11.890	15.108	4.732	11.889	2.238	4.687
UK	Trace	33.329	44.476	13.391	23.345	4.923	13.048	0.183	4.736
	Max-Eigen	19.938	21.131	8.468	10.297	4.740	8.312	0.183	4.736
US	Trace	98.789***	119.500***	14.654	33.663	4.517	12.502	1.083	2.998
	Max-Eigen	84.135***	85.835***	10.137	21.162	3.434	9.504	1.083	2.998

*Notes. (1) Model with an intercept. (2): Model with an intercept and a linear trend. and r represents the number of cointegrating vectors. *, ** and *** denote rejection of the null hypothesis at the 10, 5 and 1% levels of significance, respectively. In column 3 (r=0) we test the null hypothesis of no cointegration against the alternative of cointegration. In column 4 we test the null hypothesis of 0 or 1 cointegrating vector against the alternative of r=2. The lag length in all the tests has been selected according to the AIC, although a robustness analysis suggests that the results of these tests are robust to the chosen* lag length.

Tab. 4. Full sample bootstrap Granger causality test between oil price and real stock price series

Countries/	National oil price		World oil price	
Causality directions	LR-statistic	Bootstrap *p*-value	LR-statistic	Bootstrap *p*-value
Canada				
op −/→ rsp	8.654*	0.060	8.777*	0.060
osd −/→ rsp	60.210***	0.000	1.339	0.480
oss −/→ rsp	43.318***	0.000	1.682	0.270
Czech Republic				
op −/→ rsp	1.782	0.300	7.677**	0.020
osd −/→ rsp	0.154**	0.040	6.776**	0.020
oss −/→ rsp	0.154	0.750	0.013	0.940
Denmark				
op −/→ rsp	9.304	0.040	8.032*	0.050
osd −/→ rsp	10.726**	0.010	10.343**	0.020
oss −/→ rsp	17.515**	0.010	1.905	0.360
Hungary				
op −/→ rsp	3.762	0.270	4.505	0.240
osd −/→ rsp	6.827**	0.020	2.702	0.310
oss −/→ rsp	9.199**	0.020	1.293	0.430
Korea				
op −/→ rsp	8.226**	0.020	13.250***	0.000
osd −/→ rsp	2.160	0.300	1.729	0.500
oss −/→ rsp	11.023***	0.010	4.515*	0.080
Mexico				
op −/→ rsp	14.450***	0.000	12.139***	0.000
osd −/→ rsp	37.284***	0.000	0.694	0.710
oss −/→ rsp	44.770***	0.000	3.410	0.320
Norway				
op −/→ rsp	11.141***	0.000	8.514	0.110
osd −/→ rsp	43.096***	0.000	6.627*	0.080
oss −/→ rsp	57.284***	0.000	2.050	0.280
Poland				
op −/→ rsp	3.064	0.230	5.293	0.150
osd −/→ rsp	27.585***	0.000	1.854	0.490
oss −/→ rsp	25.314***	0.000	0.618	0.780
Sweden				
op −/→ rsp	8.740**	0.040	6.961*	0.090
osd −/→ rsp	45.978***	0.000	2.755	0.340
oss −/→ rsp	51.004***	0.000	2.458	0.360
United Kingdom				
op −/→ rsp	3.053	0.300	3.456	0.330
osd −/→ rsp	23.031***	0.000	1.695	0.450
oss −/→ rsp	10.983**	0.010	0.906	0.470
United States				
op −/→ rsp	25.43**	0.010	10.823***	0.000
osd −/→ rsp	3.733***	0.000	8.674**	0.020
oss −/→ rsp	3.733	0.150	1.446	0.460

*Note: *, **, and *** denote significance at 10, 5, and 1%, respectively. The p-values are obtained through 2000 Monte Carlo simulations.*

Since one of the main objectives of this study is to examine the stability of the oil price shocks, stock price causality test across the analysis period, we used a rolling window regression technique. This estimate approach is based on a changing sub-sample of fixed length that moves sequentially over the whole sample period. The results of rolling window estimates are illustrated in Figures 1 to 11. For each country, the rolling window results show for each of the oil price shock specifications the plots of the bootstrap p-values of the rolling test statistics as well as the magnitude of the effect between the series. For each oil prices specification, panel A and B show the bootstrap p-values of the rolling test statistics, which test the null hypothesis according to which the oil price does not Granger cause the stock price. Panel C and D show the bootstrap p-values of the rolling test statistics, testing the null hypothesis that the oil demand shocks do not Granger cause the stock price taking into account national and world specification, respectively. Finally, Panel E to F shows the bootstrap p-values of the rolling window null hypothesis that the oil supply shocks do not Granger cause the stock price taking into account national and world specification, respectively.

Fig. 1 indicates for Canada that the oil price (national, as well as world) have significant predictive power to stock prices over the sub-period from August 1995 to November 1996 and about over all the sub-period from June 2005 to December 2013. The sign of the impact of national oil price is positive for the period from August 1995 to November 1996 and negative in the other period. While the world oil price has positive predictive power for the stock price during the three sub-periods above. The national oil demand shocks impact negatively to stock price over the period from March 2010 to December 2013 and positively over the sub-periods from August 1998 to July 1999, from January 2001 to April 2002, From January 2005 to September 2009. The national oil supply shocks seem to impact the stock price negatively from August 2008 to October 2010 and a positive impact from this date to December 2013. As regards the world supply shocks the impact is significantly positive from April 2003 to August 2005 to become negative from this date to December 2013.

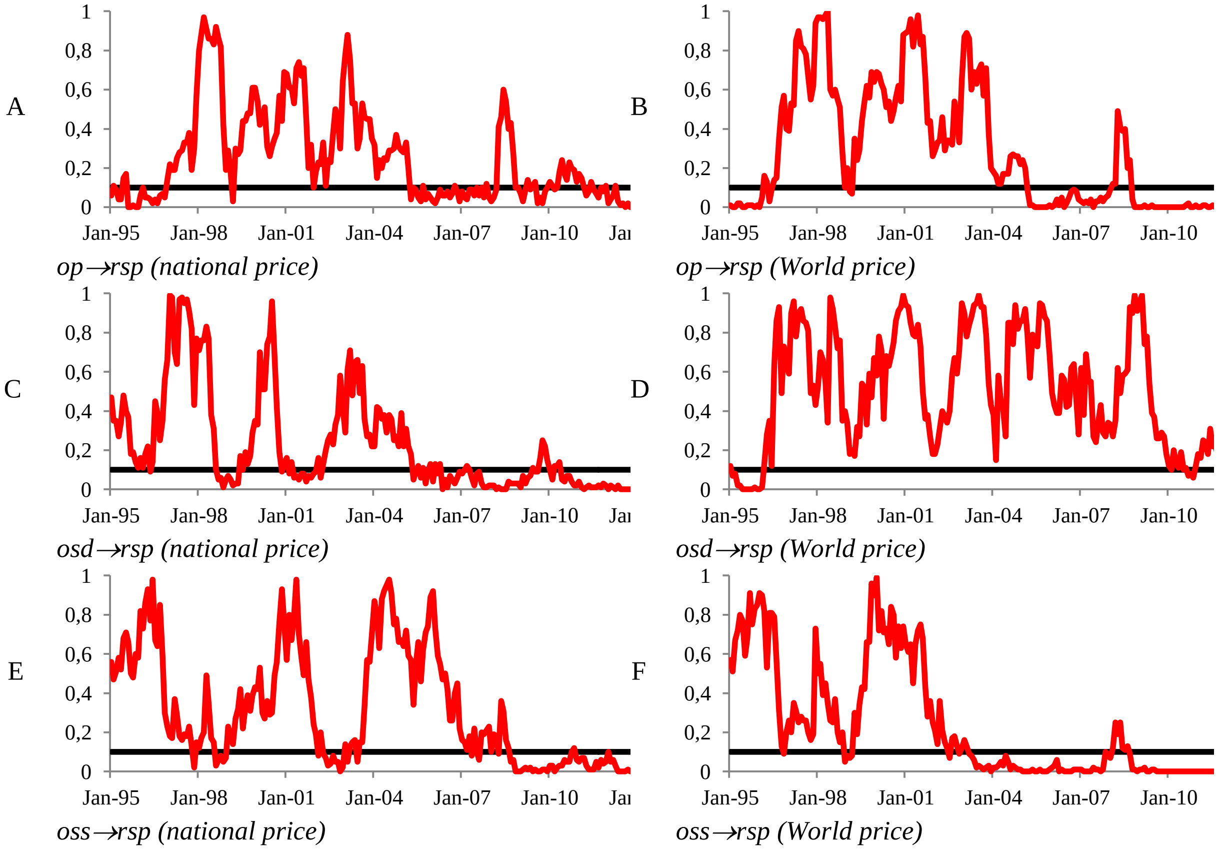


Fig. 1. Rolling estimation results for Canada.

Fig. 2 shows the following results for the Czech Republic. The null hypothesis that national oil price does not Granger cause stock price is rejected over about all the sub-period from September 2003 to November 2010, with a significant negative impact on stock price. While the world oil price presents a significant positive predictive power over the sub-period from April 2004 to March 2008. The national oil price demand does Granger cause the stock price over the following sub-periods September 1999 to May 2002 with a positive impact and from May 2009 to March 2012 with negative predictive power. The world oil demand shocks exert however a significant and negative impact on stock price over the sub-periods from February 2003 to January 2004, July and August 2006, from May 2007 to October 2007, and from November 2008 to September 2013. As for the world oil supply shocks the impact on the stock price seems to be significantly positive over the sub-periods from July 2009 to May 2001 and from January 2006 to March 2008. As regards Denmark, results in Fig. 3 shows that national oil price, world oil price, as well as national demand, shocks a positive impact over about the sub-period from May 2004 to January 2008. For the world oil demand shocks the impact is positive during the sub-periods from May 2005 to September 2005 and negative over the sub-periods from September 2008 to March 2008 and from February 2008 and from February 2009 to December 2013.

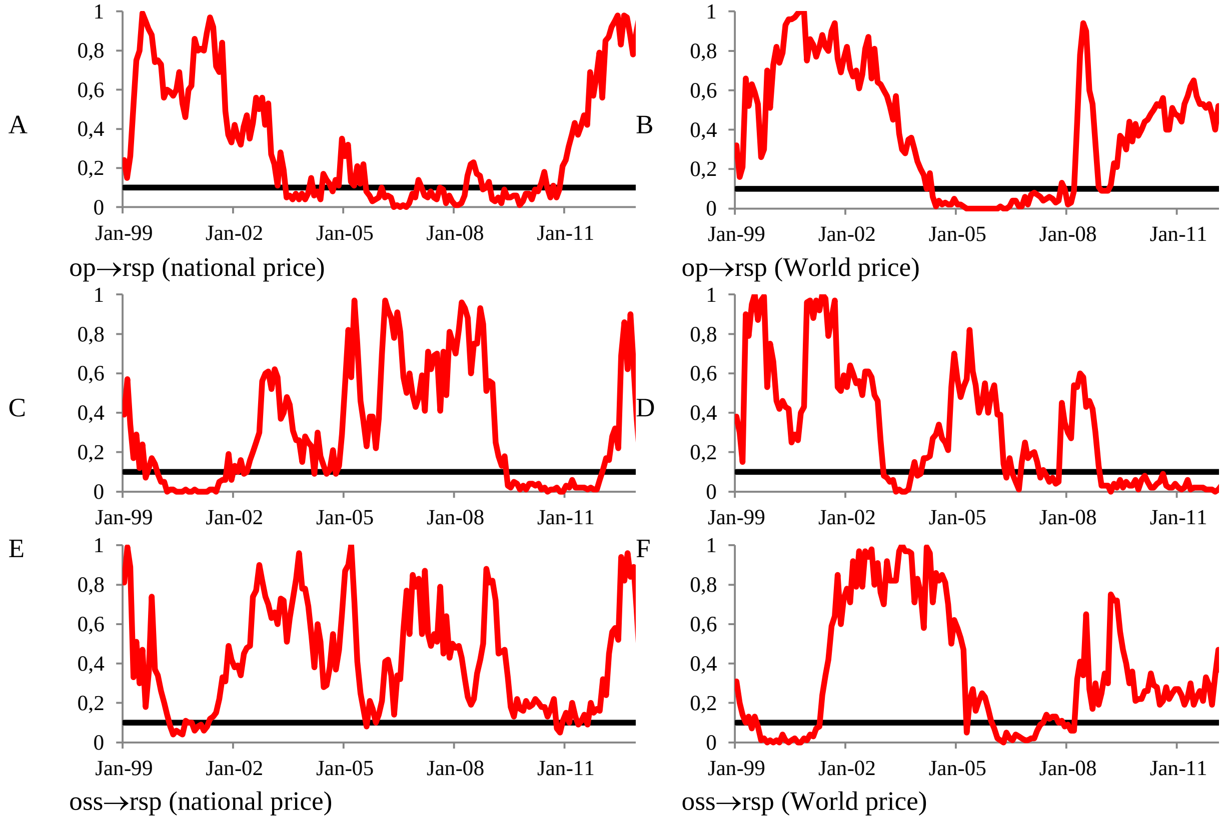


Fig. 2. Rolling window estimation results for the Czech Republic.

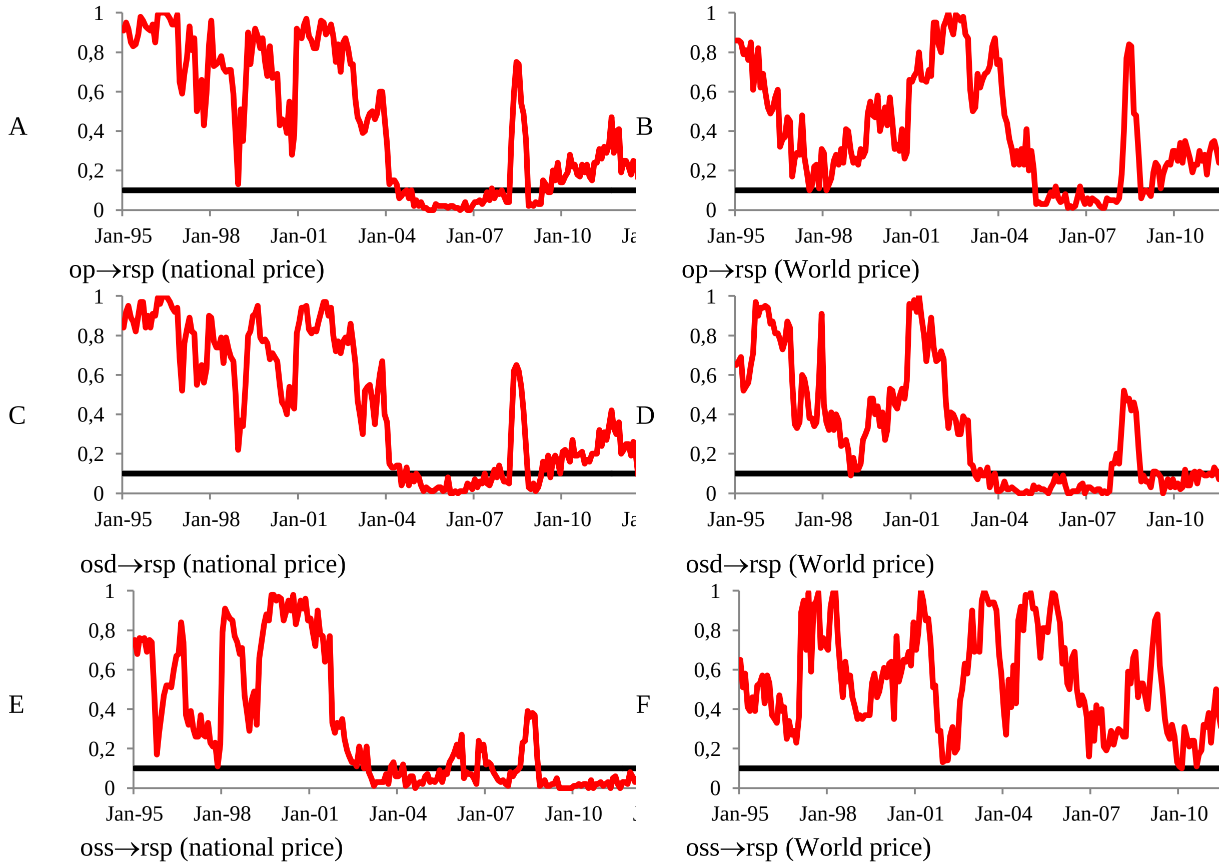


Fig. 3. Rolling window estimation results for Denmark.

The Fig. 4 shows the rolling window estimates for the Hungarian. The null hypothesis that oil price does not Granger cause the stock price can be rejected at the 10% significance level for the national as well as world oil prices specification during the sub-periods from about the end 2003 to April 2008 with a negative and positive predictive power, respectively. For South Korea, Fig. 5 shows a rejection of the null hypothesis for about the major sub-periods with negative impacts on the stock price. For the world oil price, the null hypothesis is clearly rejected during the sub-periods from January 1995 to March 1997 and from March 1998 to December 2006 and with the negative predictive power of world oil price for stock price over the different sub-periods. For the world oil demand shocks, the null hypothesis is rejected during the sub-periods from February 1997 to March 1999, from December 1999 to February 2005, and from July 2006 to January 2008 with negative impacts on stock price.

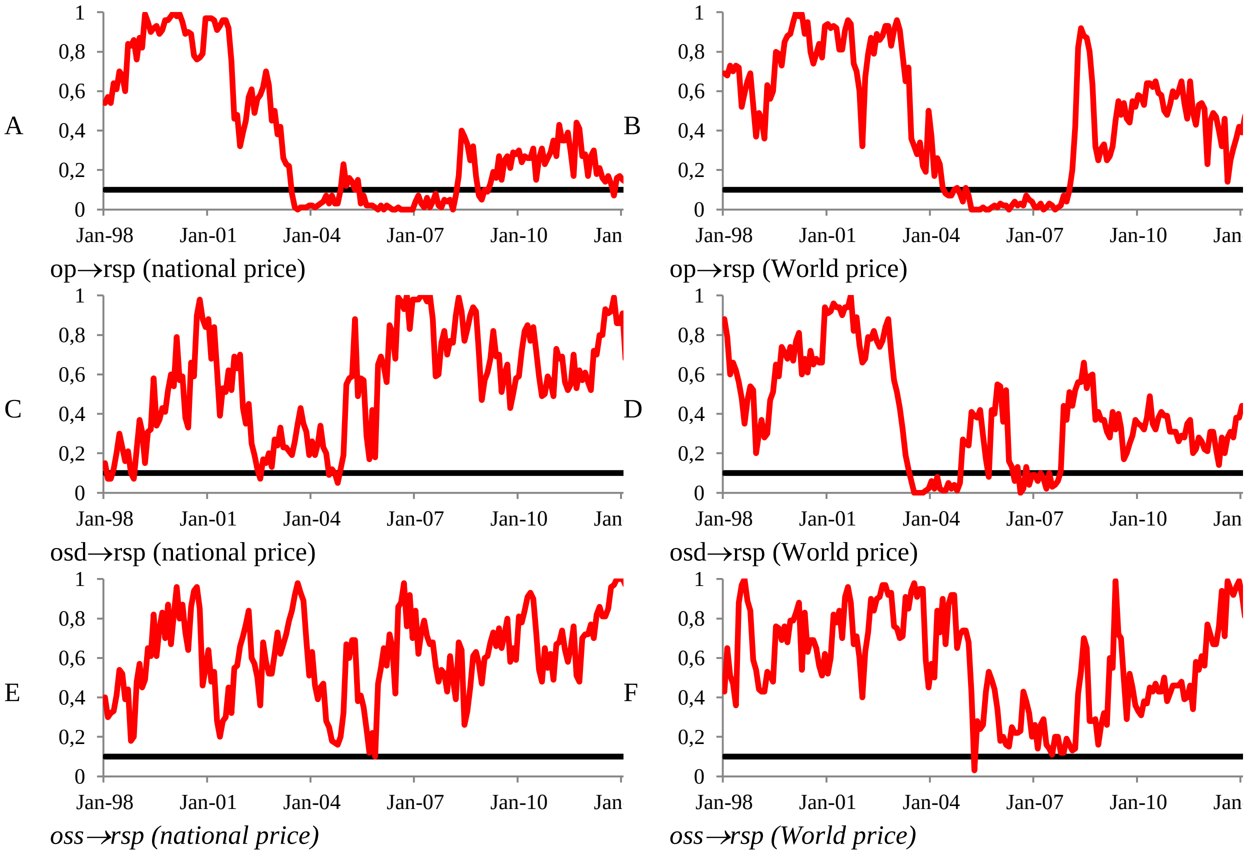


Fig. 4. Rolling window estimation results for Hungary.

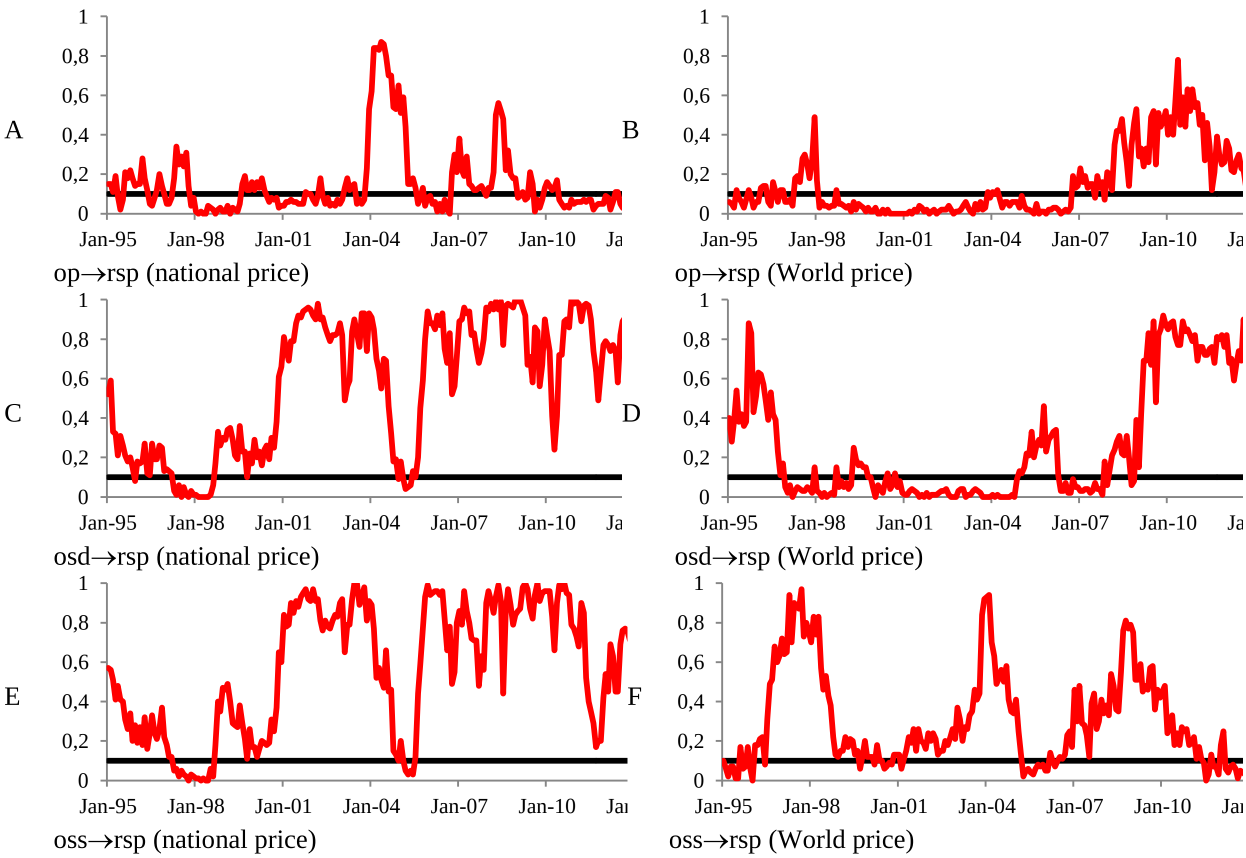
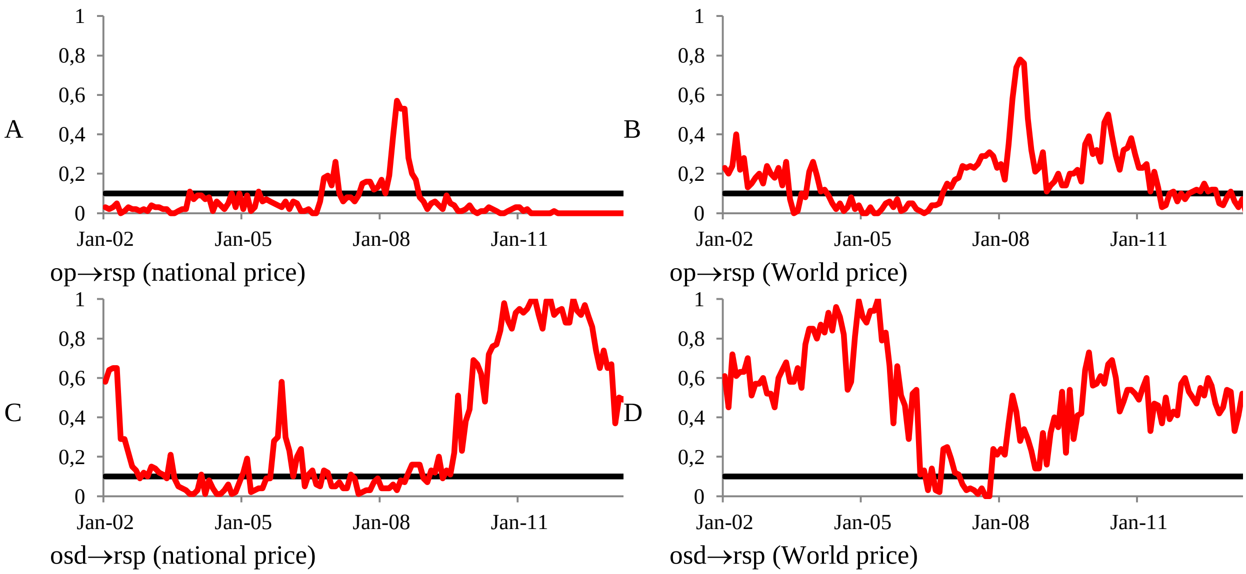


Fig. 5. Rolling window estimation results for South Korea.

In the case of Mexico, Fig 6 shows the following results. The null hypothesis that national oil price does not Granger cause the stock price is rejected over about the whole sample period, except the sub-period from November 2006 to October 2008 with a positive impact during the period starting January 2002 till the beginning 2007 and a negative impact during the remainder of the sample period. The national oil demand shocks do Granger cause stock price with a positive impact on the sub-period from July 2003 to October 2008 except the months from August 2005 to July 2006. As regards the national oil supply shocks the impacts seems to be significant during the sub-periods between March 2005 and October 2008 and between June 2013 and October 2013. The impact seems to be quite negative. While the world oil supply shocks do Granger cause the stock price with a positive impact during the sub-period from June 2011 to August 2013.



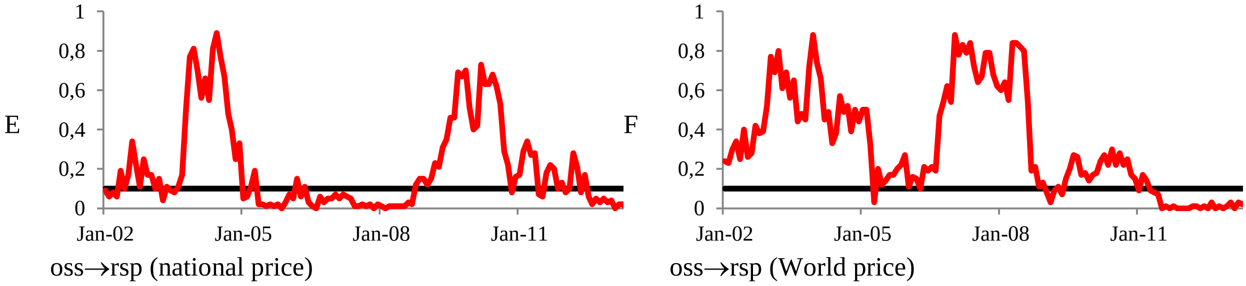


Fig. 6. Rolling window estimation results for Mexico.

For the case of Norway, Fig. 7 shows the following results. The national oil price does Granger cause the stock price during the sub-periods from April 2004 to February 2008 and from December 2011 to November 2013 with positive predictive power and during the sub-period from January 2009 to March 2010 with negative predictive power. The world oil price does Granger cause the stock price over the sub-periods from December 1995 to January 1997 and from October 2008 to March 2010 with a negative impact and during May 1997 to January 1999 and from June 2012 to October 2013 with positive predictive power. As regards the world oil demand shocks, the impact seems to be significant during the sub-period from September 2003 to March 2005 with positive predictive power and from March 2006 to November 2007 and from October 2008 to December 2013 with a negative impact.

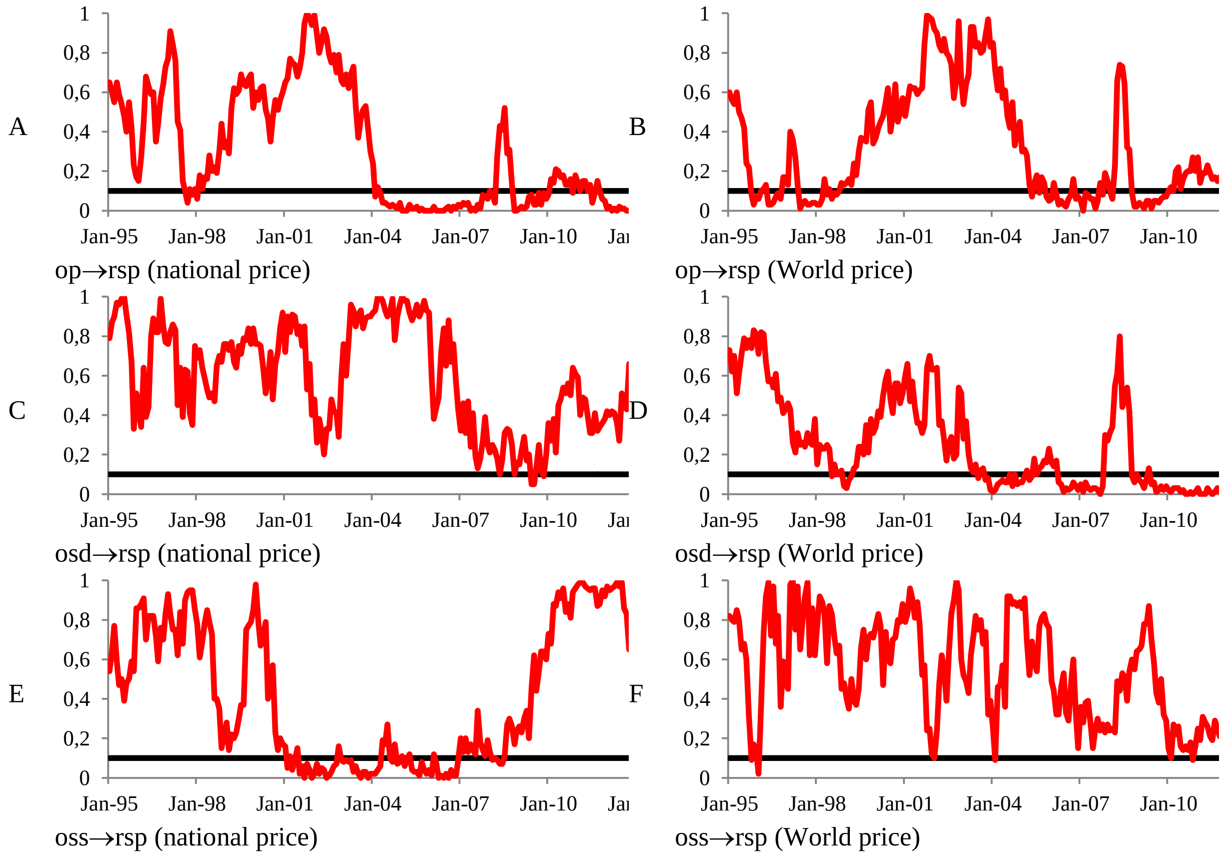


Fig. 7. Rolling window estimation results for Norway.

Fig. 8 shows the results for Poland. The national price does not Granger cause stock price with a quite positive predictive power during the sub-periods from January 2004 to February 2007 and from September 2012 to September 2013. However, the stock price over the sub-period spanning from May 2004 to July 2007 with a quite a negative impact on the stock price. While the oil supply shocks have a significant positive predictive power during the sub-periods from July 1998 to October 2000 and from October 2003 to February 2007. As regards the world oil price, the impact on stock price seems to be with a positive predictive power during the sub-periods from March 2004 to September 2006 and with a negative predictive power from August 2012 to

October 2013. Fig. 9 shows for the case of Sweden quite rare significant sub-periods in which stock price is Granger caused by some specifications of oil price supply and demand shocks.

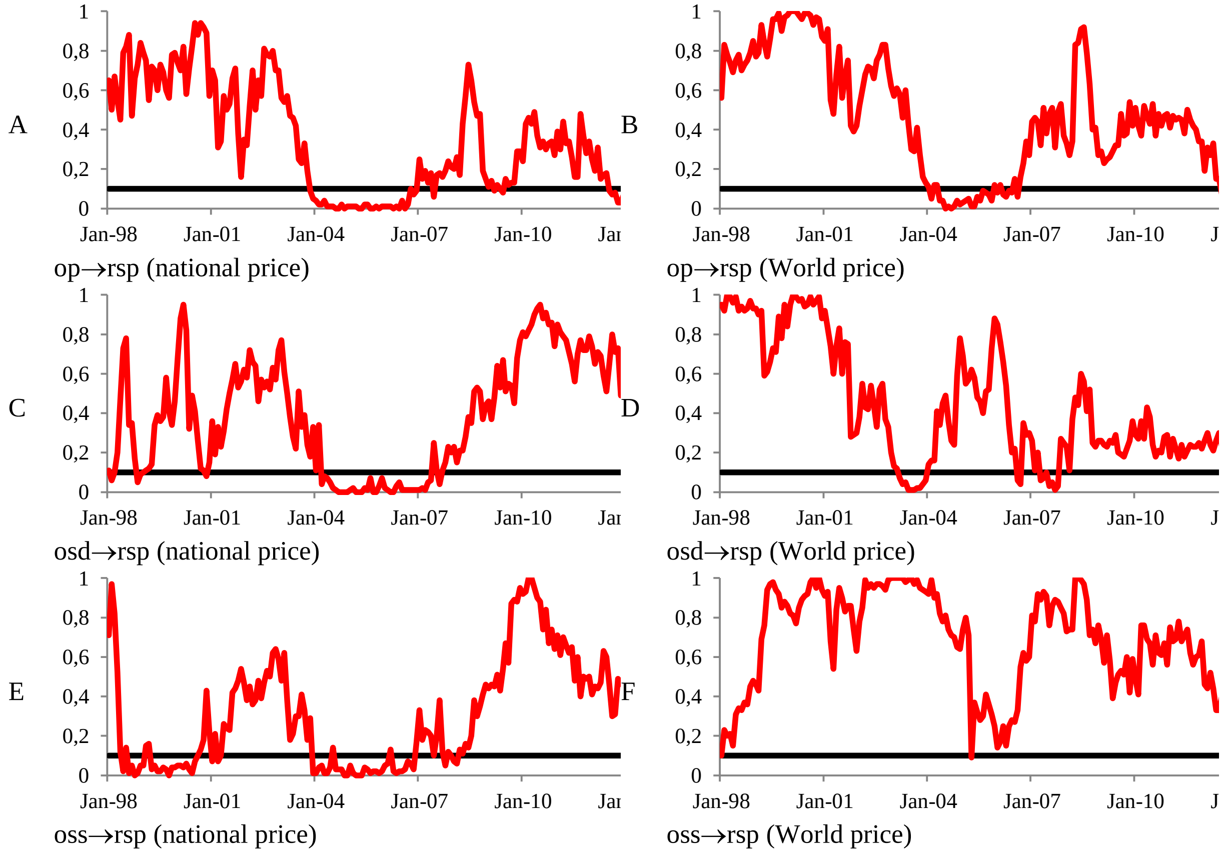


Fig. 8. Rolling window estimation results for Poland.

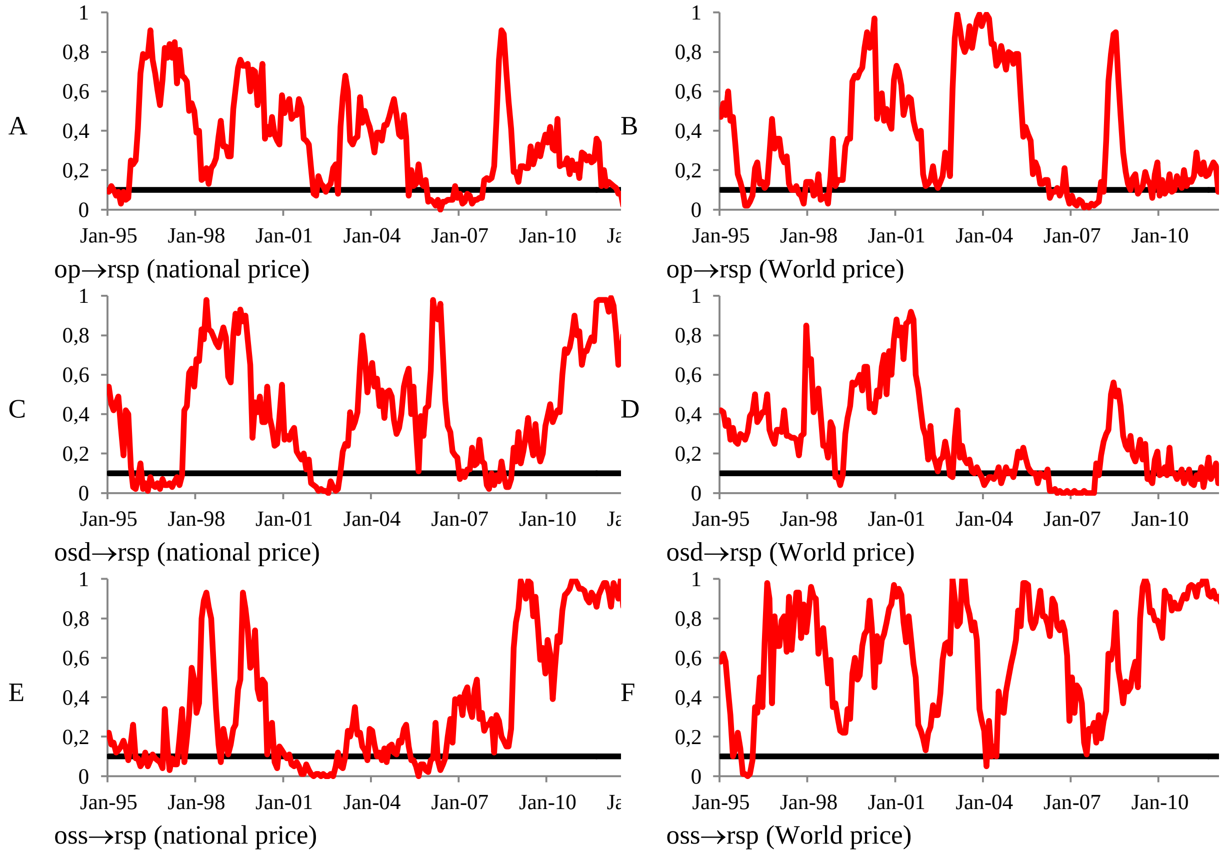


Fig. 9. Rolling window estimation results for Sweden.

Fig. 10 gives the results for the UK. National oil price does Granger causes the stock price during the sub-periods from October 1997 to May 1999, from April 2000 to November 2002, and from June 2012 to August 2013. During the first two sub-periods, the impact is negative, and over the latter sub-period, the impact is rather positive. The national oil demand shock exerts, however, a quite a significant positive impact, during the sub-periods from February 2001 to April 2002 and from January 2004 to February 2006. For the national oil supply shocks, a significant quite negative impact is observed over the sub-periods from February 2004 to March 2006 with exception to November and December 2004, from August 2008 to March 2010, and from July 2011 to December 2013. The world oil price does Granger cause the stock price over the sub-periods from January from April 2000 to October 2002, with a quite negative predictive power, and from May 1997 to September 1999, from August 2007 to October 2013 with a quite positive predictive power. For the world oil demand shocks, a quite negative predictive power is shown during the sub-periods from January 1995 to August 1995, from October 2005 to October 2007, and from February 2009 to April 2011.

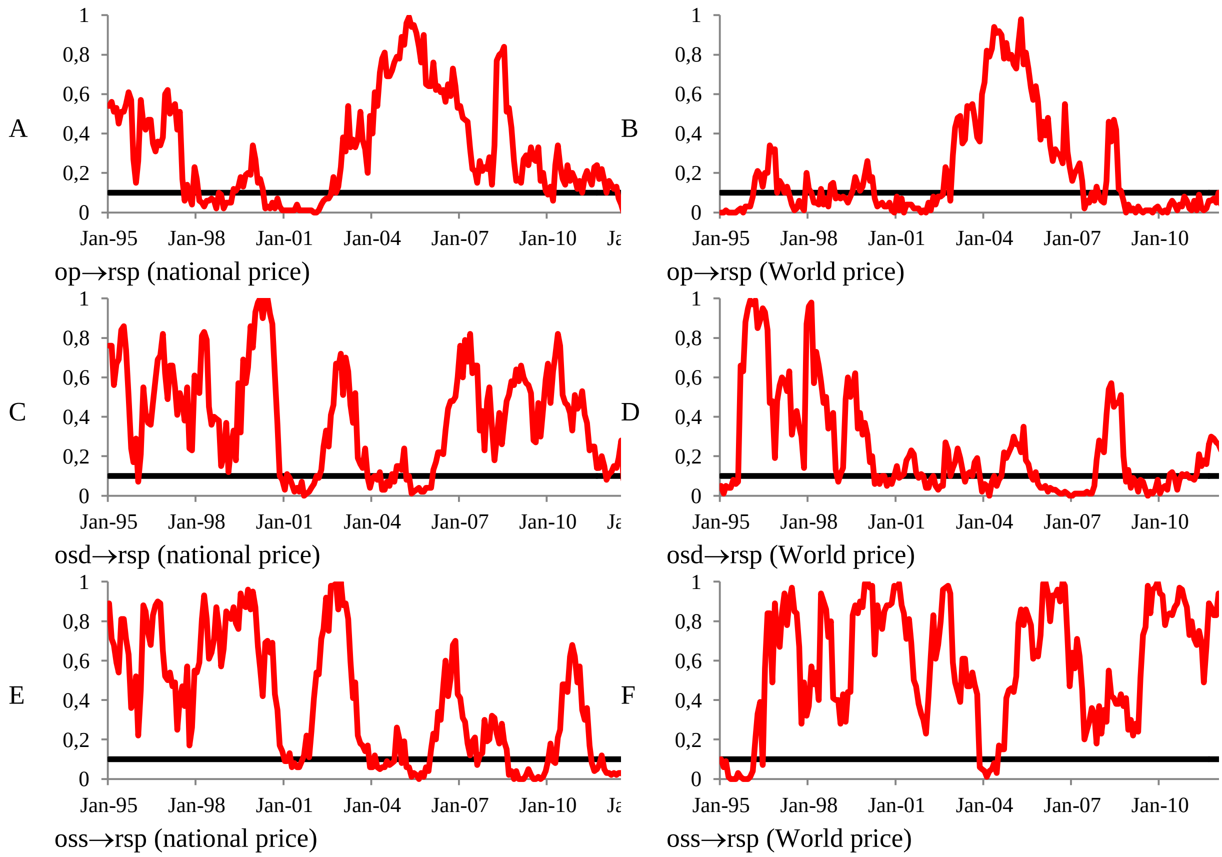


Fig. 10. Rolling window estimation results for the UK.

Finally, Fig. 11 shows the following results for the US. National oil price does Granger causes the stock price is rejected during the sub-periods from February 2005 to March 2008 and February 2012 to September 2013 with positive predictive power and from August 2008 to June 2010 with negative predictive power. For The national oil demand, shocks have a significant impact on the stock price over the sub-periods from September 2001 to June 2002 and from August 2007 to November 2013. The impact is negative until July 2008 and become positive after that. As regards the world oil price a significant Granger causality is shown during the sub-periods from March 2005 to March 2008 and from December 2011 to August 2013 with positive predictive power, and from October 2008 to May 2011 with negative predictive power. For the oil demand shocks, a smoothed negative predictive power is observed during the sub-periods from January 2002 and October 2004 while a negative predictive power is shown from October 2008 to June 2013.

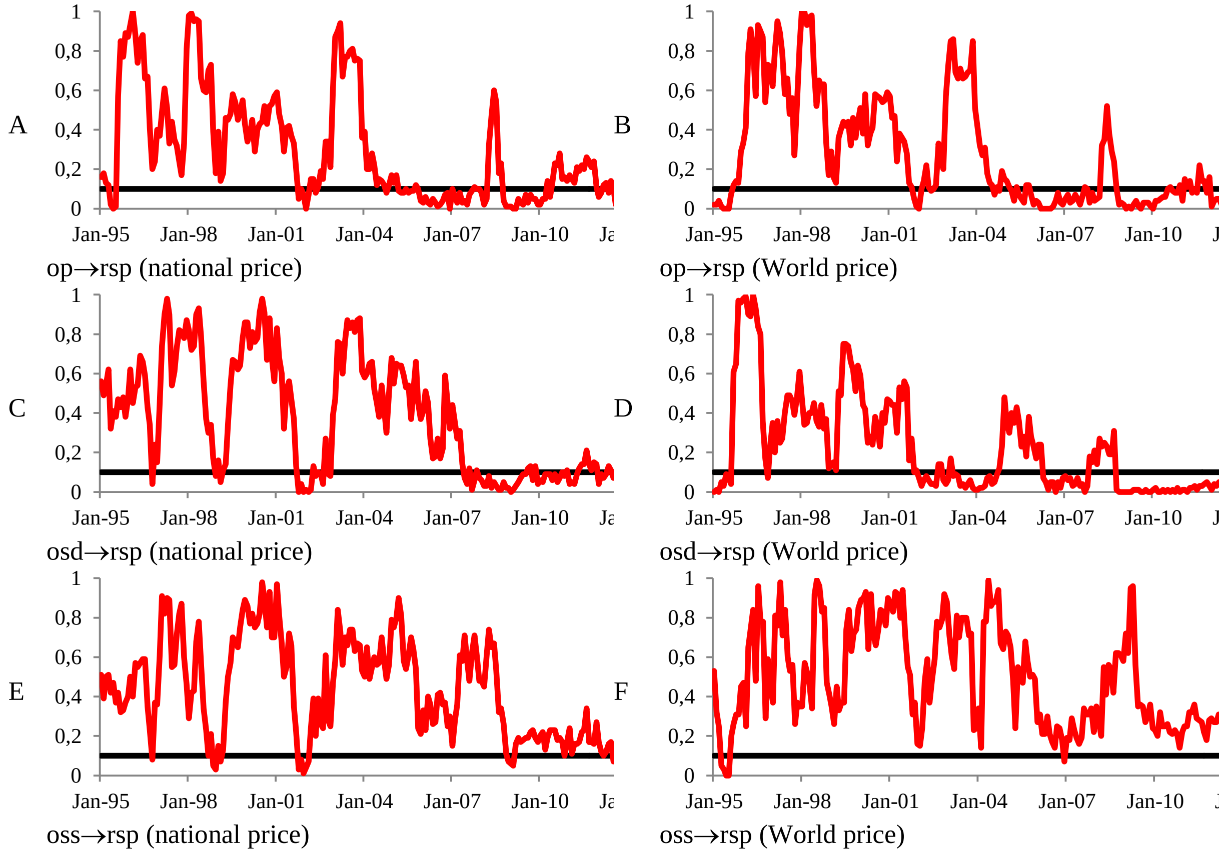


Fig. 11. Rolling window estimation results for the US.

Conclusion

The reaction of stock returns to oil shocks can be accounted for by their impact on current and expected future real cash flows. Oil price also acts as an inflationary factor since oil constitutes a substantial resource for industrial as well as the other sectors inducing an increase in operating costs and therefore an increase in prices. In fact, oil price can corporate cash flow since the oil price constitutes a substantial input in production. In addition, oil price changes can influence the supply and demand for output significantly, and, therefore, decrease the firm performance through its effect on the discount rate for cash flow because the direct effect that may exert on the expected rate of inflation and the expected real interest rate. The results in this paper show that the effect of real oil changes on real stock returns in the considered 11 OECD countries may differ depending on the nature of the oil shock. Our results show that the impact of oil price shocks substantially differs along the countries and that the significance of the results also differs along the oil prices specification. The finding suggests that oil supply shocks have a negative effect on stock market returns in the net oil importing OECD countries since oil represents an essential input and the increase in oil prices induce a rise in industrial costs. However, the stock markets are negatively impacted by oil demand shocks in the oil importing OECD countries due to higher energy costs and positively impacted by the oil exporting OECD countries due to the perspective of increasing world income and consumption. Finally, oil demand shocks have only a negative effect on stock markets in most of the net oil exporting and importing OECD countries. As predicted in previous theoretical works and empirical studies, the results we found the support that oil price shocks contribute significantly to systematic risk at the financial market level. The response of stock returns to oil price shocks can be attributed to their impact on current and expected future real cash flows.

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