Acta Montanistica Slovaca
ISSN 1335-1788
actamont.tuke.sk

Contents

Acta Montanistica Slovaca
ISSN 1335-1788
actamont.tuke.sk

Environmental Impact of The Mechanical Coal Processing Plant

Witold BIALY[1], Wes GREBSKI[2], Greg GALECKI[3] and Wojciech KANIAK[4]*

Authors' affiliations and addresses:
[1] Silesian University of Technology, Faculty of Management and Organization, Department of Production Engineering, ul. Roosevelta 26, 41-800 Zabrze, Poland
e-mail: wbialy@polsl.pl

[2] The Pennsylvania State University, 76 University Drive, Hazleton, PA 18202, USA
e-mail: wxg3@psu.edu

[3] Missouri University of Science and Technology, Rolla, MO 65409, USA
e-mail: ggalecki@mst.edu

[4] Rexroth Bosch Group Canada, Canada

***Correspondence:**
Witold Bialy, Silesian University of Technology, Faculty of Management and Organization, Department of Production Engineering, ul. Roosevelta 26, 41-800 Zabrze, Poland
e-mail: wbialy@polsl.pl

How to cite this article:
Bialy, W., Grebski, W., Galecki, G. and Kaniak, W. (2020). Environmental Impact of The Mechanical Coal Processing Plant. *Acta Montanistica Slovaca,* Volume 25 (2), 139-149

DOI:
https://doi.org/10.46544/AMS.v25i2.1

Abstract
The enrichment of hard coal is one of the stages of mineral resources management. It is aimed at adapting its quality parameters to different recipients' requirements, considered as a stage of mineral resources management. This process is treated as a stage of clean coal technologies or as a process of improving the economics of mining plants, which takes place in the Mechanical Coal Processing Plant (ZMPW). Adaptation of the quality of commercial coal products to the needs of specific recipients consists of removing useless components of the excavated material. In this publication, factors having a negative impact on the environment as a result of the refining process of useful minerals carried out at the Mechanical Coal Processing Plant were analysed.
All departments and workstations in the Mechanical Coal Processing Plant (ZMPW) were analysed. The measurement results and proposals of solutions which have an impact on reducing the nuisance of working conditions on people working in these places were presented. The analysis results show that noise is an important factor influencing work comfort. The actions taken by the Plant will allow eliminating the negative impact of equipment emitting excessive noise on the environment.
The process related to the processing and adaptation of coal to market requirements was also analysed. This analysis of the production process allowed to determine the impact that this process has or may have on the natural environment. The presented results were obtained from one of the Hard Coal Mines of the Polish Mining Group S.A.

Keywords
hard coal, enrichment, Mechanical Coal Processing Plant, noise, standards, analysis

Introduction

Coal, which is extracted from deposits, is mostly unsuitable for direct use. This is due to the high content of impurities in the form of various types of admixtures, excesses, which reduce its energy value. The extracted mineral in its volume constitutes only a part of coal; thus, it cannot be used in this form. Therefore (in order to be used), it is necessary to apply an appropriate process to obtain a commercial product of appropriate quality required by the recipient (customer) (Bolewski, 1991; Bolewski & Gruszczyk, 1980; Blaschke, 2009; Nycz, 2000; Baic & Blaschke, 2017). The final product is thermal or coking coal. The main parameters of thermal coal are: the grain size, calorific value, ash content, etc. In the case of coking coal, this parameter is sinterability (Bielewicz et al., 1993).

Depending on the needs and measures applied, a distinction is made between the following types of processing (Bielewicz et al., 1993):

- mechanical – in which the processing of mineral is carried out by mechanical means through:
  - coal classification, in which the raw material's grains are divided into appropriate groups with specific grain sizes or desired density,
  - enrichment of the excavated material, which involves the removal of unusable grains from the extracted mineral to increase the proportion of useful mineral,
- chemical – consisting in changing the chemical and mineral structure of a useful mineral.

Each Hard Coal Mine (Mining Plant) has a separate plant in which the processing of mineral into a suitable product is carried out using specialised technological processes.

The results of these processes are:

- concentrate, i.e. a raw material composed of grains of a useful mineral,
- an intermediate product, i.e. a raw material consisting of grains of waste rock grown together with grains of a useful mineral,
- waste, i.e. waste rock grains.

The plant where processes are carried out to remove impurities, admixtures and excesses in order to increase the share of coal in the unit of volume (or weight of the extracted mineral) is the Mechanical Coal Processing Plant (ZMPW) (Bielewicz et al., 1993).

The basic functions of ZPMW include:

- coal classification – screening,
- hydraulic and aerodynamic classification,
- grinding coal,
- gravity separation,
- flotation.

The extracted mineral is a mixture of grains of different sizes; thus, it cannot be used directly in this form. Therefore, it is fed to the appropriate equipment to divide the material by grain size.

A distinction is made between the following classification:

- mechanical – carried out on sieves,
- hydraulic – carried out in a water centre,
- air (aerodynamic) – carried out in a gas (air) centre.

In a joint project, conducted by consortium members: GIG and KOMAG, a review of the processing technology was carried out. The technology analysis showed that these technologies, and consequently machine systems for hard coal processing, are adapted to the characteristics of enriched coal, mainly type and degree of its contamination, and to quality requirements of both domestic and foreign recipients. In general, higher types of hard coal are currently enriched to a wider extent, using more modern machinery (https://www.wnp.pl, 2020).

Pro-Environmental Activities

Growing environmental awareness of the population causes that enterprises which do not respect the environment face problems in achieving their goals. Lack of activities (or limited activities) to improve the environment creates barriers to economic development. The problem of environmental protection has been partially regulated by introducing barriers in the form of legal regulations (standards). Most often, these regulations refer to the requirements for products. Pro-ecological improvement (rationalisation) of products results in such activities where the improvement process takes place in a manner conducive to maintaining the environmental balance (Adamczyk, 2004; Góralczyk, 2011). Pro-ecological activities in the production process and use of products must take place at each stage of the enterprises' operations.

Sectors and branches of the economy are connected by a network of mutual dependencies expressed in the exchange of materials and energy, not only within one country or continent. Therefore, changes occurring in one sector of the economy can (and will) affect changes in another sector and even a region or a country. For this reason, the principle of sustainable development is used as a leading concept in all environmental activities (Kołodziej & Maruszewska, 2015; Hąbek et al., 2019).

The essence of sustainable development principle is to carry out activities in particular sectors of the economy and social life in such a way that they will protect the resources of the natural environment while using them in a sustainable way now and in the future, thus creating the possibility of simultaneous functioning of economic and natural processes (Górzyński, 2004; Scherz et al., 2019). In particular, it concerns the natural resources mining industry.

Introduction of the principle of sustainable development in the mining industry imposes the following obligation (among others):

- the use of non-renewable natural resources must not be at the expense of future generations,
- decreasing natural resources force changes in the material flow from the moment of extraction, through processing, consumption and use (the so-called raw material life cycle) in such a way that their reuse becomes more common.

Introduction to the market of an increasing number of new products, as well as development and implementation of modern technologies, is related to the acquisition of large quantities of useful minerals (natural resources). It is connected with an increase in the environmental load and impact related to production, exploitation and management of products in their final phase (Klouda et al., 2018; Dyczkowska et al., 2020). Therefore, in addition to ecological factors, the environmental impact assessment also takes into account economic and social factors (Kołodziej et al., 2015; Maruszewska 2015; Maruszewska et al., 2020; Černecký et al., 2015). Such an activity is called eco-balance.

A comparative analysis of the environmental impact of at least two objects, such as products and their groups, processes or their elements, systems and algorithms of operation and combinations of these factors, carried out to the extent possible, is defined as eco-balance (Nowak, 2001; Podsiadłowska & Foltynowicz, 2002; Górzyński, 2004; Adamczyk, 2004; Przybyłowski, 2005). An eco-balance is the ecological material and energy balance of a product, process, company or region (Fig. 1).

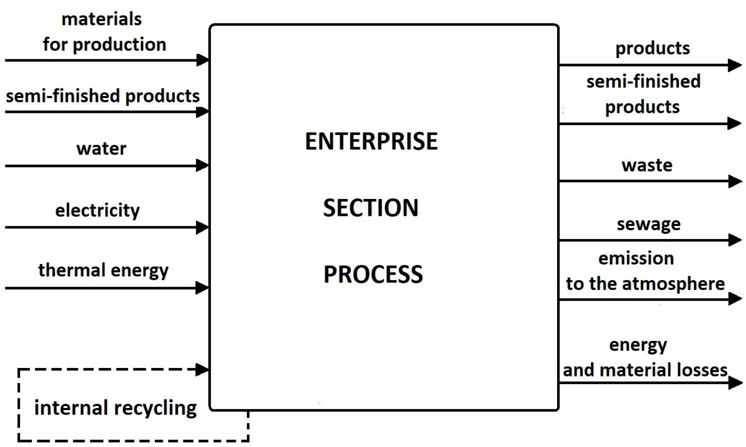

Fig. 1. Eco-balance flow

The eco-balance enables the assessment of economic processes that function in the environment both in relation to existing production systems and planned investments.

The dynamic development of new manufacturing processes and products in relation to the deteriorating natural environment conditions forces the necessity to apply comprehensive methods of environmental impact assessment.

Methodology of Research

The production process of hard coal (thermal coal, coking coal) requires a number of operations which form a logical technological sequence (Fig. 2). The extracted useful mineral (hard coal) is transported from the mining department by means of conveyors (scraper, belt conveyors) to the shaft tanks. Next, the mineral is transported to the surface, where it is refined (enriched) to obtain the final product, i.e. thermal (coking) coal. Such a process takes place at the Mechanical Coal Processing Plant (ZMPW).

This process is very similar to different mines (Mining Plants) and is widely known and used in the mining environment (Blaschke, 2009).

The excavated mineral is initially classified on screens in two classes: 0-200 mm and over 200 mm. The +200 mm class is directed to the conveyor belt to remove impurities (wood, scrap, etc.). Next, the mineral is directed to the crushers. As a result of these processes, the raw material is obtained, which is directed to tanks. This tank (the so-called retention tank) is used to store the excavated material (coal), where it is then directed to the primary classification screens.

The excavated material (mineral) in the 0-200 mm class is directed to the screens (usually vibrating) for initial classification. Here it is divided into two classes, i.e. 0-20 mm class and 20-200 mm class.

Grain class 20-200 mm is enriched in suspension separator chambers. The material of 0-20 mm size is transported to jig (washer).

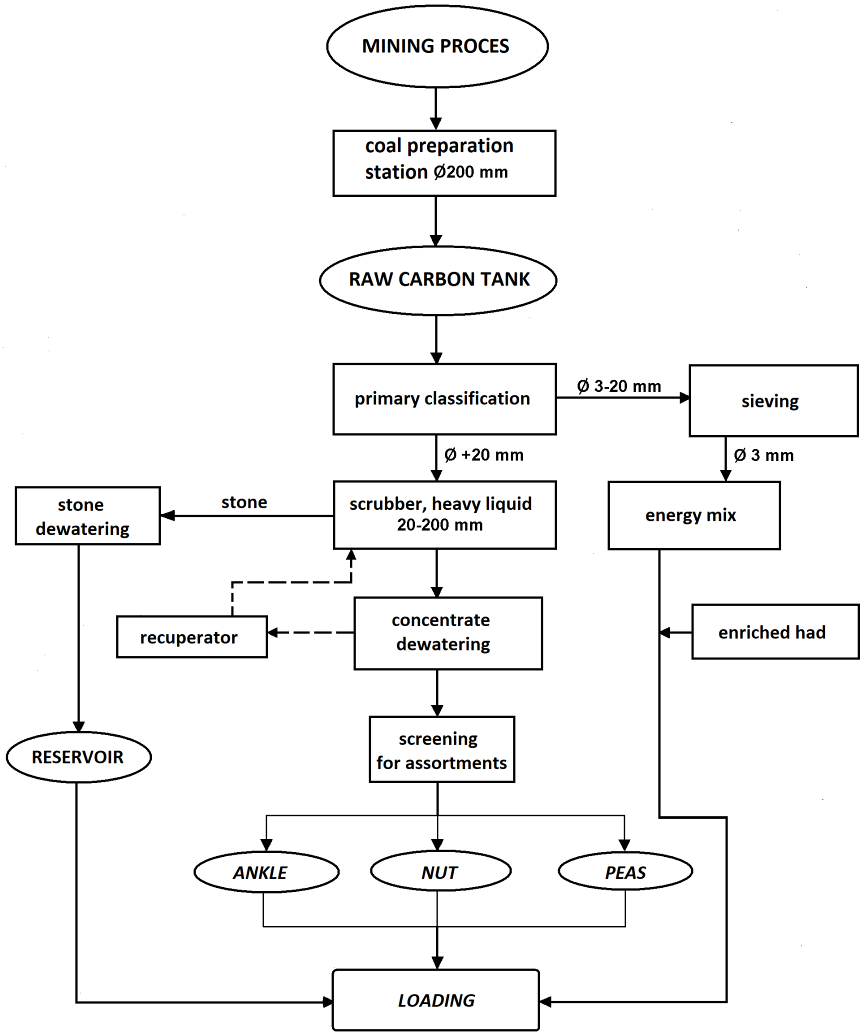

Fig. 2. Technological diagram of coal production

Enrichment in a heavy liquid is carried out on separator chambers from which coal goes to drainage screens, cooperating with a recuperator (magnetic recuperator). After enrichment in heavy liquid, the next stage is drainage of the concentrate (coal) and waste, i.e. scale. Enrichment in a heavy liquid causes the coal to contain a lot of moisture, which makes it impossible to sell it immediately (in the case of scale this is not an important reason).

The concentrate (coal) obtained in this way is then drained on screens in the next stage. The water recovered in this process is directed to a recuperator which has the task of recovering magnetite from the previously drained water. Magnetite recovery is 99%. The essence of this process is also that a certain amount of water is recovered, which reduces costs.

After drainage, the enriched concentrate (thermal coal) is directed to screens to be divided into grain classes for sale (secondary classification). In this process, a finished product is obtained for sale. The waste is stored in tanks and then disposed of.

An important element of this process is a closed water cycle. This circuit includes: heavy liquid scrubber, drainage on sieves, recuperator, water tank and magnetite. This closed-circuit allows to minimise water consumption and to recover the component necessary in this process (magnetite).

In most cases, ZMPW facilities operate for 16 hours a day – the engine power of individual devices during operation is used in about 50%. The installed power is used only in case of a start-up or in case of unfavourable operating conditions.

Strict EU legislation on environmental requirements forces mines (Mining Plants) to carry out tasks that reduce the negative impact on the environment.

Results of Research – Mine Pro-Ecological Activities

KWK's surface protection activities

KWK's mining operations have a significant impact on the natural environment. In order to protect the surface against the unfavourable effects of mining exploitation, the mine takes actions to protect the surface on an ongoing basis and conducts rehabilitation operations covering the areas of municipalities where the mining area is located (Białecka & Biały, 2014; Biały & Mroczkowska, 2015).

In order to minimise the adverse effects of mining exploitation on the surface, the mine's activity consists of the following:

- underground exploitation includes surface protection and proper management of the deposit,
- coordination of mining operations in order to minimise the adverse summation of surface impacts,
- cavings are sealed on an ongoing basis with a mixture of smoke-box dust and flotation waste, which reduces the reduction of the land surface,
- the mine bears the costs of protection against the impact of mining operations on the facilities under construction.

Waste management activities of KWK

Post-production waste management at KWK is an important element supporting activities related to environmental protection. This waste, generated mainly in the mining and processing operations, is recorded and minimised.

Table 1 shows the types and quantities of waste generated in these processes in one of the hard coal mines. It follows (Table 1) that most of the waste is generated in the process of mineral cleaning and washing (flotation).

Table 1. Waste generated in KWK

Lp	Code	Waste type	Quantity Mg
1.	01 01 02	Waste from the mining of minerals other than metal ores	22137
2.	01 04 12	Wastes from mineral washing and cleaning other than those mentioned in 01 04 07 and 01 04 11	690656
3.	01 04 81	Wastes from the flotation enrichment of coal other than those mentioned in 01 04 80	40300
4.	07 02 13	Plastic waste	0.40
5.	15 01 02	Plastic packaging	0.20
6.	16 02 14	Discarded equipment other than those mentioned in 16 02 09 and 16 02 13	42.30
7.	16 05 09	Spent chemicals other than those mentioned in 16 05 06 and 16 05 07 or 16 05 08	1.40
8.	17 02 01	Wood	24.50
9.	17 04 05	Iron & Steel	1160.50
10.	17 04 07	Mixtures of non-ferrous metals	2.90
11.	17 04 11	Cables other than those mentioned in 17 04 10	69.80
12.	19 13 06	Sludges from groundwater treatment other than those mentioned in 19 13 05	3430.00
13.	06 02 01	Calcium hydroxide (ostarite)	0.73
14.	06 04 05*	Waste containing other heavy metals (sludge from electrolyte filtration)	0.002
15.	13 01 10*	Mineral hydraulic oils free of halogenated organic substances	7.353
16.	13 02 08*	Other engine, gear and lubricating oils	5.23
17.	16 02 13*	Discarded equipment containing hazardous components other than those mentioned in 16 02 09 to 16 02 12	0.224
18.	16 02 15*	Hazardous components removed from used equipment (mercury)	0.022
19.	10 06 01*	Lead batteries and accumulators	2.42
20.	16 06 02*	Nickel-cadmium batteries and accumulators	0.66
21.	16 06 06*	Selectively collected electrolyte from batteries and accumulators	1.52
22.	18 01 03*	Other wastes that contain live pathogens	0.083

** – hazardous waste*

The reasons for waste generation are related to the basic activity of the mine – they are unavoidable, but their reduction should be a priority of pro-ecological activities.

KWK carries out activities to recover waste generated in the mining process – some of this waste is managed by KWK, some is transferred to other (external) companies that specialise in the disposal or recovery of certain raw materials, compounds (Table 2).

Table 2. Waste transferred to external companies

Lp.	Code	Waste type	Quantity Mg
1.	06 02 01*	Calcium hydroxide (ostarite)	1.594
2.	06 04 05*	Waste containing other heavy metals	0.005
3.	16 06 02*	Nickel-cadmium accumulators	0.80
4.	16 02 13*	Used equipment containing hazardous components	0.339
5.	16 02 15*	Hazardous components removed from used equipment (mercury)	0.022
6.	18 01 03*	Other wastes that contain live pathogens	0.083
7.	01 01 02	Waste from the mining of minerals other than metal ores	22137
8.	01 04 12	Wastes arising from washing and cleaning of minerals	690656
9.	07 02 13	Plastic waste	1.08
10.	15 01 02	Plastic packaging	0.51
11.	16 05 09	Used chemicals	2.56
12.	16 02 14	Discarded equipment other than those mentioned in 16 02 09 and 16 02 13	42.30
13.	17 02 01	Wood	24.50
14.	17 04 05	Iron & Steel	1160.50
15.	17 04 07	Mixtures of non-ferrous metals	2.90
16.	17 04 11	Cables other than those mentioned in 17 04 10	69.80

** – hazardous waste*

Protection of ambient air

Emissions from the combustion of fuels and dust, methane (annual average) were shown in Table 3.

Table 3. Gaseous pollutants emitted

Type of emission	Mg emissions
Dusts	7.07
Methane	15479.77
Combustion of fuels	65.88

In order to reduce dust emissions, special devices have been installed in many places – mainly in the places where they arise.

These places include:

- transfer stations,
- dust and concentrate tanks.

Protection against noise emissions

Noise penetrating into the environment from the area of KWK operations results in exceeding the limit values both during day and night time (Engel et al., 2005; PN, 2000; PN 2005; Biały & Żukowska, 2011). The mine carries out activities aimed at limiting the noise penetrating to the environment in order to achieve a satisfactory effect at the border of objects subject to noise protection. Therefore, the building of fan stations has been soundproofed, the exit has been suppressed, and the air inlet and outlet suppressors for cooling the fan motors have been enclosed. The concept of soundproofing the equipment emitting excess noise to the environment was developed, and a schedule of activities aimed at reducing its nuisance was defined.

The adopted schedule of investment activities will enable the elimination of the negative impact of equipment emitting excessive noise to the environment.

Water protection, water and wastewater management

The ecological effect in the area of water and sewage management at KWK has been achieved thanks to activities in which the "produced" waste is reused and does not constitute a nuisance to the environment. The activities of KWK in order to reduce the discharge of polluted groundwater into surface watercourses were presented in Table 4.

The underground water from KWK drainage is used for:

- fire prevention,
- depositing flotation waste,
- backfill,
- filling the closed circulation of a scrubber,
- production of drinking water.

Table 4. Measures to reduce the discharge of polluted water

Lp.	Task name	Task description	Achieved environmental effect
1	Placing smoke-box dust in underground excavations	Use of saline water and reduction of salt load discharged to surface water	317.7 Mg
2	Placing flotation tailings in underground excavations	Use of saline water and reduction of salt load discharged to surface water	392 Mg
3	Use of underground water in the fire protection and sprinkler system	Use of saline water and reduction of salt load discharged to surface water	2640 Mg
4	Use of underground water in a mechanical processing plant	Use of saline water and reduction of salt load discharged to surface water	3315.6 Mg
5	Selective abstraction and management of drinking water	Limitation of underground water discharge	643.1 thousand m^3 Salt load limitation quantity of 770 Mg
6	Suspension precipitation in water galleries – suspension storage in underground workings	Limitation of suspended solids discharge	3430 Mg
7	Construction of threshold and dam systems	Reduction of incoming slurry discharge	498 Mg
8	Traffic elimination	Reduction of the inflow from the eliminated traffic by retaining water in the underground excavations and backing up some inflows to the equilibrium level	1624 thousand m^3
9	Level elimination	Reduction of water inflow from the decommissioned level through blocking	62.5 thousand m^3

Environmental Impact Assessment

Based on the adopted environmental priorities, as a result of mining activities, the significance of potential environmental impacts in the adopted categories was determined (Table 5) (Łozińska, 2006).

Table 5. Categories of environmental impacts of production processes

Impact category	Description	Protection areas		
		Resources	Health human	Ecosystem quality
RESOURCE DEPLETION				
Depletion of abiotic resources	Coal production takes place on the extracted raw material. Production affects the use of non-renewable resources through significant use of electricity, which is produced, among others, from coal.	+		
CONTAMINATION				
Greenhouse effect	No impact		(+)	+
Ozone depletion	No impact		(+)	+
Contamination of people	Coal production exposes workers to an environment where dust content and noise emission standards are exceeded.		+	
Water and soil contamination	Contamination of soil or water may be caused by muddy or dirty water and residues from flotation enrichment – flotation reagent and flutulant		(+)	+
Creation of photochemical oxidants	No impact		+	+
Acidification	No impact		(+)	+
Eutrophication	No impact			+
ECOSYSTEM AND LANDSCAPE DEGRADATION				
Land use	ZMPW occupies a certain area of the earth's surface			+

+ – direct impact
(+) – indirect impact

Discussion

By assigning revenues to the ZMPW activities, it can be concluded that the coal production processes affect humans mainly by exceeding the permissible noise level. They also have a negative impact by exceeding the permitted dust concentration and "land use". The impact of fine dust enrichment and subsequent processes (ZMPW) on the environment is also important in this process. These processes generate a huge quantity of dirty water, and flotation enrichment additionally exposes the environment to contact with flotation reagent and flocculant.

All tasks related to this production stage for environmental safety and reduction of enrichment costs are combined and form one closed water-sludge circuit, which reduces the environmental impact quite significantly.

Negative impacts on the environment in the water-sludge cycle can only occur in emergency situations, and therefore have to be classified into two categories: water and soil contamination.

The production also has an indirect environmental impact. It can be included in the category "depletion of abiotic resources", because there is a significant demand for electricity, which is produced from non-renewable resources.

It is also important that the process of coal processing does not occur spontaneously, but is inseparably related to mining.

The environmental aspects arising from coal production and their impact on the environment were presented in Table 6.

Table 6. Environmental aspects and their impact on the environment

Effect	Environmental aspect	Environmental impact
ENVIRONMENT		
Carbon transport	Noise emissions from conveyor belts	Increasing noise emissions
Carbon transport	Electricity consumption	Exhaustion of resources
Carbon transport	Dust emissions to the atmosphere	Air pollution
Screening of coal	Noise emission from the screen	Increasing noise emissions
Screening of coal	Electricity consumption	Exhaustion of resources
Screening of coal	Dust emissions to the atmosphere	Air pollution
Screening of coal	Waste: scrap metal, wood, plastic and other	Soil contamination, surface occupation
Crushing of coal	Noise emissions from the crusher	Increasing noise emissions
Crushing of coal	Electricity consumption	Exhaustion of resources
Crushing of coal	Dust emissions to the atmosphere	Air pollution
PRIMARY CLASSIFICATION		
Screening of coal	Noise emission from the screen	Increasing noise emissions
Screening of coal	Electricity consumption	Exhaustion of resources
Screening of coal	Dust emissions to the atmosphere	Air pollution
Carbon transport	Noise emissions from conveyor belts	Increasing noise emissions
Carbon transport	Electricity consumption	Exhaustion of resources
Carbon transport	Dust emissions to the atmosphere	Air pollution
SCREENING		
Screening of coal	Noise emission from the screen	Increasing noise emissions
Screening of coal	Electricity consumption	Exhaustion of resources
Screening of coal	Dust emissions to the atmosphere	Air pollution
Carbon transport	Noise emissions from conveyor belts	Increasing noise emissions
Carbon transport	Electricity consumption	Exhaustion of resources
Carbon transport	Dust emissions to the atmosphere	Air pollution
FINE DUST ENRICHMENT PROCESS		
Carbon transport	Noise emissions from conveyor belts	Increasing noise emissions
Carbon transport	Electricity consumption	Exhaustion of resources
Carbon transport	Dust emissions to the atmosphere	Air pollution
Enrichment in the jigging machine	Waste formation – scale	Occupancy
Enrichment in the jigging machine	Waste formation – muddy water	Pollution of soil, water, surface area occupation
Enrichment in the jigging machine	Electricity consumption	Exhaustion of resources
Enrichment in the jigging machine	Noise emissions	Increasing noise emissions
SLUDGE DRAINAGE		
Sludge drainage	Noise emissions	Increasing noise emissions
Sludge drainage	Waste formation – muddy water	Pollution of soil, water, surface area occupation
Sludge drainage	Electricity consumption	Exhaustion of resources
CENTRIFUGATION OF CARBON CONCENTRATE		
Centrifugation of carbon concentrate	Noise emissions	Increasing noise emissions
Centrifugation of carbon concentrate	Waste formation – dirty water	Pollution of soil, water, surface area occupation
Centrifugation of carbon concentrate	Electricity consumption	Exhaustion of resources
Carbon transport	Noise emissions from conveyor belts	Increasing noise emissions
Carbon transport	Electricity consumption	Exhaustion of resources
Carbon transport	Dust emissions to the atmosphere	Air pollution
FLOTATION ENRICHMENT		
Flotation enrichment	Waste generation – flotation reagent, flocculant	Pollution of soil, water, surface area occupation
Flotation enrichment	Waste formation – dirty water	Pollution of soil, water, surface area occupation

The occurring environmental aspects have been divided into activities that are implemented in the main processes. As shown in Table 6, environmental impacts occur in all processes – these impacts as a result of coal production are repeated and can be appropriately grouped.

The coal processing causes (or may cause) a negative impact on the environment, which may be classified into certain areas (issues).

These areas are:

- increase in noise emissions,
- depletion of natural resources,

- air pollution,
- soil contamination,
- water pollution,
- surface occupancy.

Certain processes arising in relation to coal production are influenced by us. Some of them can be reduced, while some are not influenced by us.

Processes over which we have no influence may include:

- depletion of natural resources,
- surface occupancy.

We have an influence on other processes to reduce the nuisance of their impact on the environment – at the same time, we must be aware that we are not able to eliminate their negative impact completely.

Conclusion

The assessment of the environmental impact of the coal production process was based on research conducted at the Mechanical Processing Plant in one of the hard coal mines. The main objective of ZMPW is to process the excavated mineral in order to ultimately provide the market with a product of appropriate quality and meet customer requirements.

The analysis of production processes at ZMPW allowed to determine the impact they have (or may have) on the natural environment.

The main processes (Fig. 2), which have a negative impact on the environment in which this process takes place are the following:

- primary classification, which is carried out on vibrating screens. The screens and auxiliary processes generate high levels of noise emission and dust concentration. These parameters exceed acceptable standards and pose a threat to both employees and the environment,
- screening (separation into grain classes 0-3 mm and 3-20 mm). Also in this process, noise and dust are emitted that exceeds acceptable standards, which also poses a threat to employees and the environment,
- flotation enrichment, which is used to extract the smallest grains of carbon from the water. The chemicals used in this process may have a negative impact on the environment. However, by incorporating this process into a closed water cycle, environmental risks are minimised. However, it is recommended to continuously monitor this process, which is related to the storage and supply of chemicals to this process.

The results of conducted analyses stated that there are also processes which take place in ZMPW and do not have a negative impact on the environment – they fall within the adopted standards. These processes belong to the following:

- preparation (sorting) stage of coal, where sieves and crushers are used. There is a problem of noise emission and dust generation. It was found that these parameters are included in acceptable standards,
- enrichment of the dust – this process takes place in an aqueous environment. Negative effects on the environment result from the formation of muddy water, which can be dangerous if penetrated into the environment. This also applies to the coal/scale drainage process. This problem is solved by a closed water cycle.

Conducted analysis indicates that pro-ecological activities of the mine are correct but not satisfactory manner. Those places of the production process of ZMPW have been indicated which should be given special attention.

In accordance with conducted measurements, the factor that occurs in practically each analysed place is noise.

Workers exposed to loud noise, in addition to hearing damage, are more likely to develop a variety of conditions, especially cardiovascular, respiratory and digestive tract disorders. In addition, high noise levels reduce the ability to hear, communicate and warn each other, which increases the potential risk of errors at work and thus accidents. Forced by excessive noise, the need for raising voice causes additional stress, which increases these adverse effects (Baranov et al., 2017).

Hard coal mines, in particular, the Mechanical Coal Processing Plant is characterised by a large number of workstations with noise standards exceeded. The hearing loss is irreversible as a result of excessive noise and largely limits the ability to work – this is a very serious problem of modern hard coal mines.

The harmful effects of noise on human health depend on many factors, such as: frequency of noise, the intensity of noise, duration of exposure to noise, type of noise (intermittent, continuous, impulsive), individual susceptibility to noise and the influence of other factors, such as ototoxic substances.

For the assessment of noise harmfulness, it has been assumed (in accordance with PN-EN ISO 9612:2009) that the level of noise exposure related to the 8-hour daily working time (Lex,8h) should not exceed 85 dB, the maximum A-noise level (LAmax) should not exceed 115 dB, and the peak C-noise level (LCpeak) should not exceed 135 dB.

For the assessment of noise harmfulness, it has been assumed (in accordance with PN-EN ISO 9612:2009) that the level of daytime noise exposure should not exceed 65 dB, and the level of night-time noise exposure should not exceed 45 dB.

Knowledge of the above values allows for the determination of the level of occupational risk to workers resulting from exposure to audible noise, by means of a comparison with the limit values in force.

This analysis allows to compare environmental loads of particular processes of ZMPW and on this basis to make decisions related to modernisation of particular technological processes.

References

Adamczyk W.: (2004). Ekologia wyrobów. Polskie Wydawnictwo Ekonomiczne. Warszawa.

Baic I, & Blaschke W.: (2017). Przeróbka węgla kamiennego w Polsce – trendy rozwoju w zakresie zwiększenia efektywności produkcji. Inżynieria Mineralna, lipiec-grudzień 2017. Journal of the Polish Mineral Engineering Society.

Baranov, M.N., Božek, P., Prajová, V., Ivanova, T.N., Novokshonov, D.N. and Korshunov, A.I. (2017). Constructing and calculating of multistage sucker rod string according to reduced stress. In Acta Montanistica Slovaca. Vol. 22, no. 2, pp. 107-115.

Białecka B, & Biały W.: (2014). „Tereny pogórnicze – szanse, zagrożenia. Analiza przypadku" Wydawnictwo PA NOVA SA. Gliwice. ISBN 978-83-937845-4-7. p. 202

Biały W, & Mroczkowska P.: Influence of coal waste heaps on water environment in upper silesian borderland areas – case study. 15th SGEM GeoConference on Science and Technologies In Geology, Exploration and Mining, SGEM2015 Conference Proceedings, June 18-24, 2015, Vol. III, BUŁGARIA ISBN 978-619-7105-33-9/ISSN 1314-2704. pp. 675-682.

Biały W, & Żukowska T.: (2011). Przekroczenia hałasu na terenie zakładu przeróbki mechanicznej węgła. „Rola informatyki w naukach ekonomicznych i społecznych". Tom 1. Wydawnictwo Wyższej Szkoły Handlowej. Kielce. ISBN 978-83-89274-60-1. pp. 221-232.

Bielewicz T., Prus B., Hołysz J.: (1993). Górnictwo. Część 1. Śląskie Wydawnictwo Techniczne. Katowice.

Blaschke W.: (2009). Przeróbka Węgla Kamiennego – Wzbogacanie Grawitacyjne. Wydawnictwo Instytutu Gospodarki Mineralnymi i Energią PAN, Kraków.

Bolewski A.: (1991). W sprawie surowców mineralnych. Instytut Geologii i Surowców Mineralnych Akademii Górniczo Hutniczej w Krakowie. Wydawnictwo AGH Kraków.

Bolewski A, & Gruszczyk H.: (1980). Geologia Gospodarcza. Skrypt AGH nr. 738. Kraków.

Černecký, J., Valentová, K., Pivarčiová, E. and Božek, P. (2015). Ionization impact on the air cleaning efficiency in the interior. Measurement Science Review [electronic source]. Vol. 15, No. 4, online, pp. 156-166

Engel Z., Sadowski J., et al.: (2005) Noise protection In Poland In European Legislation. The Committee on Acoustics of the Polish Academy of Science & CIOP-PIB Warszawa.

Dyczkowska J, Bulhakova Y, Łukaszczyk Z, Maryniak A.: (2020) Waste Management as an Element of the Creation of a Closed Loop of Supply Chains on the Example of Mining and Extractive Industry. Management Systems in Production Engineering. Volume 28, issue 1. pp. 60-69, DOI 10.2478/mspe-2020-0010

Góralczyk S., (red).: (2011). Gospodarka surowcami odpadowymi z węgla kamiennego. Publikacja opracowana w ramach projektu: "Foresight w zakresie priorytetowych i innowacyjnych technologii w zakresie zagospodarowywnia odpadów pochodzących z górnictwa węgla kamiennego".

Górzyński J.: (2004). Kierunki i możliwości działania w proekologicznej racjonalizacji wyrobów przemysłowych. Gospodarka Paliwami i Energią. 11-12/2004.

Hąbek P., Biały W., Livenskaya G.: (2019) Stakeholder engagement in corporate social responsibility reporting. The case of mining companies. Acta Montanistica Slovaca. ISSN 1335-1788. Volume 24 (2019), number 1, pp. 25-34.

Klouda P, Moni V, Řehoř M, Blata J, Helebrant F.: The Evaluation of a Risk Degree for the Process of a Brown Coal Spontaneous Ignition on Dumps with Using of Modern Numeric Methods. Management Systems in Production Engineering. Volume 26, issue 2. pp. 71-75, DOI 10.2478/mspe-2018-0011

Kołodziej S, & Maruszewska E.W., (2015). Economical Effectiveness and Social Objectives in Corporate Social Reports – a Survey Among Polish Publicly Traded Companies. 2nd International Multidisciplinary Scientific Conference on Social Sciences and Arts SGEM2015, www.sgemsocial.org, SGEM2015

Conference Proceedings, ISBN 978-619-7105-47-6/ISSN 2367-5659, Aug 26-Sept 01; Book 2, Vol. 2, pp. 161-167 DOI: 10.5593/SGEMSOCIAL2015/B22/S6.021

Łozińska M.: (2006). Wpływ procesów produkcyjnych Zakładu Mechanicznej Przeróbki Węgla na środowisko. Praca dyplomowa (niepublikowana) Gliwice.

Maruszewska E.W.: (2015) Applicability of activity based costing in new product development processes. Management Systems in Production Engineering 1(17). ISSN 2299-0461. pp. 35-39. DOI: 10.12914/MSPE-06-01-2015.

Maruszewska E.W, & Strojek-Filus M.: (2020) Research and Development in the Service Sector – Vague Definition and Problematic Application. Management Systems in Production Engineering. Volume 28, issue 1. pp. 53-59, DOI 10.2478/mspe-2020-0009

Nycz R.: (2000). Aktualny stan przeróbki węgla kamiennego w Polsce. Inżynieria Mineralna, lipiec-grudzień 2000. Journal of the Polish Mineral Engineering Society.

Nowak Z. Zarządzanie środowiskiem cz. II, Wydawnictwo Politechniki Śląskiej, Gliwice 2001

Podsiadłowska A, & Foltynowicz Z.: Ocena Cyklu Życia (LCA). Nowa metoda szacowania ekologicznych skutków działalności gospodarczej. Recykling 9/2002.

Przybyłowski P. Podstawy Zarządzania środowiskiem, Wydawnictwo Akademii Morskiej, Gdynia 2005

https://www.wnp.pl/wiadomosci/problemy-mechanicznej-przerobki-wegla-kamiennego-w-perspektywnie-roku-2020,-4344.html

Scherz C, Hahn J, Ladikas M.: (2019) Technology Assessment in a Globalized World. Management Systems in Production Engineering. Volume 27, issue 3. pp. 149-152, DOI 10.1515/mspe-2019-0024

PN-EN ISO 9612:2009 Hałas. Dopuszczalne wartości hałasu w środowisku pracy. Wymagania dotyczące wykonywania pomiarów.

PN-ISO 1999:2000 Wyznaczanie ekspozycji zawodowej na hałas i szacowanie uszkodzenia słuchu wywołanego hałasem.

Acta Montanistica Slovaca
ISSN 1335-1788
actamont.tuke.sk

Vibrations diagnostics and analysis in operator's and passenger cabins of a suspended monorail

Kamil SZEWERDA[1]***, *Jarosław TOKARCZYK*[1], *Pavol BOŽEK*[2], *Dariusz MICHALAK*[1] and *Andrzej DRWIĘGA*[1]

Authors' affiliations and addresses:
[1] KOMAG Institute of Mining Technology, Laboratory of Modelling Methods and Ergonomics, Pszczyńska 37, 44-101 Gliwice, Poland
e-mail: kszewerda@komag.eu

[2] Slovak University of Technology in Bratislava Faculty of Materials Science and Technology Institute of Production Technologies
Slovakia
e-mail: pavol.bozek@stuba.sk

***Correspondence:**
Kamil Szewerda, KOMAG Institute of Mining Technology, Laboratory of Modelling Methods and Ergonomics, Pszczyńska 37, 44-101 Gliwice, Poland
tel: +48 32 237 45 31
e-mail: kszewerda@komag.eu

Acknowledgement:
The paper was written as part of the work carried out under the European project INESI, "Increase efficiency and safety improvement in underground mining transportation routes". This project is financially supported by the Research Fund for Coal and Steel under the Grant Agreement No 754169.
Calculations were carried out at the Academic Computer Centre in Gdańsk, Poland

How to cite this article:
Szewerda, K., Tokarczyk, J., Božek, P., Michalak, D. and Drwięga, A. (2020). Vibrations diagnostics and analysis in operator's and passenger cabins of a suspended monorail. *Acta Montanistica Slovaca,* Volume 25 (2), 150-158

DOI:
https://doi.org/10.46544/AMS.v25i2.2

Abstract
One of the negative factors affecting operators and passengers of suspended monorails moving to their workplaces are the vibrations that act on the entire human body. These vibrations are related to the design of the suspended monorail and the route on which it moves. Excessive exposure to this negative factor adversely affects the human body. The results of numerical simulations aimed at comparing the vibration level during travelling along a straight section of the route, in which the operator's cabin and passenger cabin were rigidly connected to the trolley and innovative design in which yielding suspension was introduced are presented. Such damping of vibrations acting on passengers significantly improves the safety and comfort of miners in underground mining plants. Application of the computational model presented in the article and the method of analysing the results of the simulation enables optimal selection of materials with appropriate damping characteristics. A properly selected vibration damping system increases the comfort of the operator and transported people, and may become an element of competitive advantage when benchmarking transportation systems with the same operating parameters. The application of the proposed approach allows us to optimise, in terms of costs, the selection process of the optimal damping system, thanks to the possibility of verification of various damping parameters, without the necessity to investing in the real components and performing a real test, but only based on the results of the multibody simulation. The use of these numerical simulations is an example of a modern way of supporting the design and perfecting processes of state-of-the-art machines used in underground coal mines.

Keywords
mining, suspended monorails, vibrations, numerical analysis, dynamics, multibody simulation, exposure to vibrations, virtual prototyping

Introduction

A suspended monorail is one of the main means of auxiliary transportation in underground hard coal mines is. The suspended monorail is usually propelled by its own drive, which are diesel engines or electric motors, and the whole train moves over the rail fixed to the roof support arches. This type of transportation has many advantages, such as increased safety, the comfort of use or no need to maintain the floor and the track in the proper condition. However, research work is continuing to improve and extend the existing solutions. Innovations introduced in the design of suspended monorails are aimed at improving comfort, safety and increasing the permissible speed during transportation of people (Budniok et al., 2014; INESI, 2019; Tokarczyk, 2017; Zasadni et al., 2015; Lesiak and Brzeżański, 2018; Tokarczyk and Kania, 2016). Intensive work in this area is carried out within the INESI project coordinated by KOMAG (INESI, 2019; Pieczora and Suffner, 2017; Polnik, 2018). As part of the project, survey research for operators and passengers of suspended monorails were carried out to assess the current conditions and development trends regarding sub-assemblies of suspended monorails (Bozek et al., 2016). In these surveys, about 56% of surveyed operators of suspended monorails stated that vibrations in the operator's cabin are unfavourable (13.64% of respondents) or very unfavourable (39.39% of respondents). The suggestion to modify and improve vibration damping system in the operator's seat was assumed as important by 30.30% of the surveyed operators, while as very important by 40.91% of the surveyed operators. Thus, 71.21% of operators consider reducing the impact of vibrations while driving as a very important aspect of the development of the suspended monorail design. Moreover, 63.64% of operators considered a modification of suspension of the entire operator's cabin as important (19.7% of respondents) or very important (43.94% of respondents). The same questions were asked, in a separate survey, to people who were carried in passenger cabins. In this case, 34.71% of surveyed passengers travelling in suspended monorails found that vibrations have a large (23.97%) or very large (10.74%) negative impact on the comfort of travelling in the passenger cabin. However, the concept of reducing the impact of vibrations on the seats was considered to be important or very important by 42.98% of passengers. Modification of suspension of the passenger cabin was considered to be important or very important by 44.62% of passengers (22.31% - very important, 22.31% - important). Based on the surveys, it can be stated that vibrations adversely affect both operators and passengers of the suspended monorails, significantly reducing the comfort of work (INESI, 2019). It should be noted that vibrations are also a risk factor at the workplace and excessive exposure to this factor may have its health consequences (Kowalski and Zając, 2017; Kowalski and Zając, 2012; Kiełbasa and Juliszewski et al., 2017; Bovenzi 2005; Krajnak 2018; Basri and Griffin 2013; Muravev et al., 2019). Maximum allowable exposure to vibrations during a work shift as well as the method of measuring and calculating the daily exposure at the workplace are specified by the regulations and standards (PN-EN 14253+A1:2011; Dz.U. 2018 poz. 1286; Nędza et al., 2006). Regular exposure to excessive vibration can have adverse health effects, such as reduced concentration, poor mood or the vibrational syndrome, which in many countries, including Poland, is considered as a professional disease. The biggest irritation of the labyrinth and the strongest vibration sensation occurs for the frequency of the vibrations up to 35Hz. This is related to the resonance of each organ (Harazin, 2002; Kiełbasa et al., 2019; Kowalski, 2019; Szczepaniak and Kromulski, 2011; Koradecka, 1999; AlShabi et al., 2016; Issever et al., 2003).

In the light of ongoing work aimed at increasing the permissible speed of suspended monorails while moving people, it seems very important to minimise vibrations and overloads that affect both the operator and the suspended monorail passengers (Budniok et al., 2014) Reduction of total vibrations is especially important. For this purpose, in the INESI project, the suspension of the operator's cabin was modified, and the damping inserts with appropriate stiffness were selected. A new cabin design was also developed, where a flexible suspension was used (INESI, 2019; Szewerda, 2019; Tokarczyk et al., 2019). This article presents a computational model of a suspended monorail, used to simulate and compare vibrations affecting the operator and passengers during travelling along a straight section of a route in the case of a rigid connection of cabins with trolleys and in the case of yielding suspension components. This model enables verifying the correct operation of the components that dampen vibrations affecting both the comfort of work and its safety.

Material and Methods

The computational model of the suspended monorail, used during numerical simulations, consisted of operator's cabin, machine part, two rack and pinion drives, cabin for people movement and a braking trolley. This transportation set moved on a track constructed of a new type of straight 4m long rails, hanging on suspensions by means of transverse traverses (Figure 1).

Within the project, two variants of the computational model were developed to compare the vibration and overloads acting on both the suspended monorail operator and the passengers. In variant 1, both the operator's cabin and the passenger cabin were rigidly connected to the trolleys. In variant 2, the system damping the vibration and reducing overloads acting on the operators and passengers of the suspended monorail was modelled. In the case of operator's cabin, four elastic-damping components connecting the cabin with the trolley from the top and four elastic-damping components connecting the cabin with the trolley from the bottom (Figure 2) were introduced. These components replaced elastic inserts used in the design of cab suspension. Analysis of stiffness parameters of those components was carried out in the previous research projects, the results of which were presented in (Szewerda, 2019).

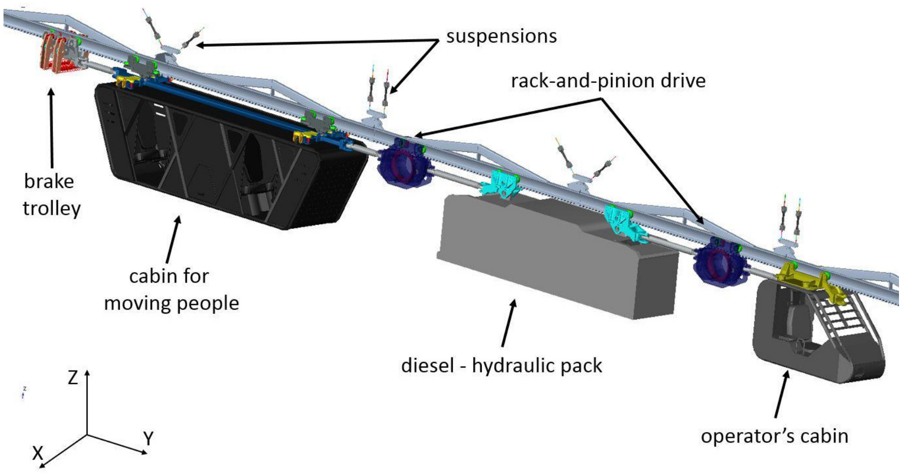

Fig. 1. A computational model of the suspended monorail (INESI, 2019)

The "upper" elastic-damping components were compressed, and they transferred main loads during operation. In the computational model, their stiffness $1.64 \cdot 10^6$ N·m^{-1} and a damping factor of $1.5 \cdot 10^4$ N·s·m^{-1} were assumed. The "lower" elastic-damping components task is to protect the operator's cabin against its direct hit on the trolley in the result of dynamic phenomena and deflection of the upper damping components. In the calculation model, the following parameters were adopted in relation to "lower" elastic-damping components: stiffness equal to 10 N·m^{-1} and damping factor equal to 4000 N·s·m^{-1}. The difference between variant 1 and 2 regarding the operator's cabin is shown in Figure 2.

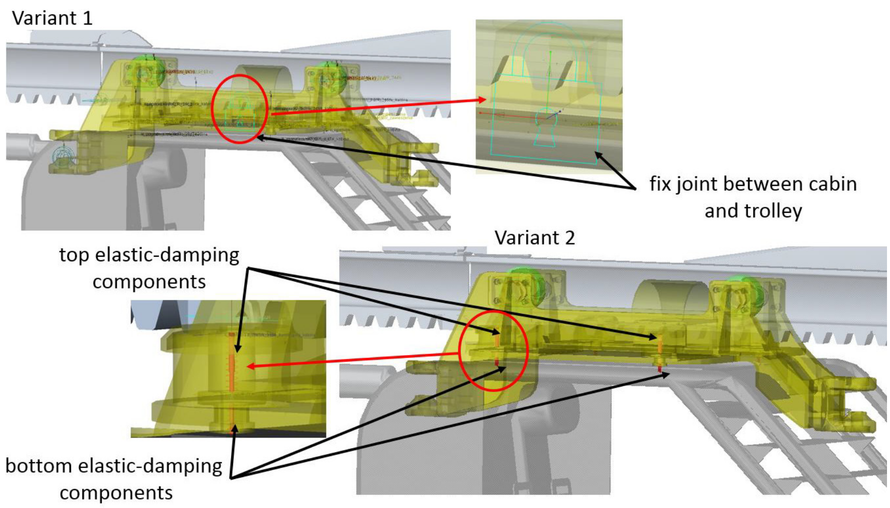

Fig. 2. Driver's cabin suspension method: variant 1 (top left), variant 2 (bottom right) (INESI, 2019)

At present, there are no yielding systems for suspending the cabins conveying passengers. The innovative method for suspending the passenger cabin was developed by Becker Warkop within the INESI project (INESI, 2019; Tokarczyk et al., 2019). In the computational model in Variant 1, the passenger cabin was rigidly connected to the supporting frame. In Variant 2, there is a possibility of moving the passenger cabin in relation to the load-bearing frame. This effect was achieved by the use of control arm system and implementation of elastic-damping components with the parameters selected by the cabin manufacturer. The elastic-damping components used in the computational model of passenger cabin had the stiffness of $1.189953 \cdot 10^5$ N·m^{-1} and the damping factor of 1900 Nsm^{-1}. The difference between Variant 1 and 2 regarding the passenger cabin is shown in Figure 3.

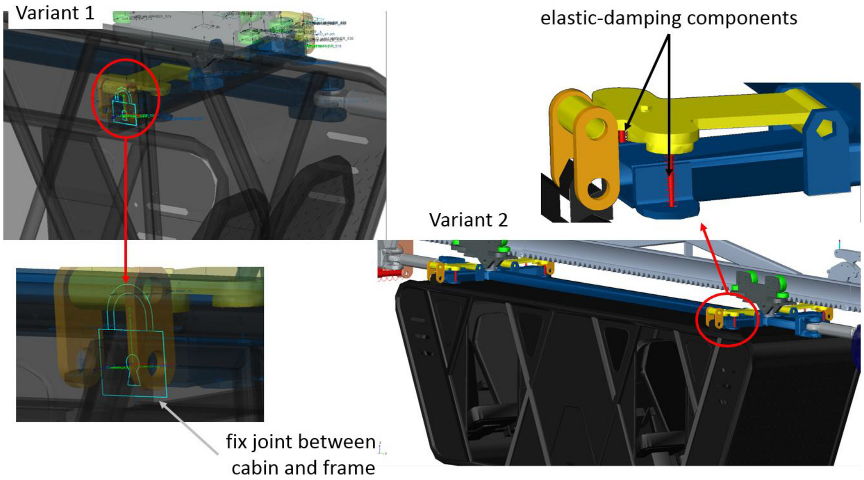

Fig. 3. Method for suspending the passenger cabin: Variant 1 (left), Variant 2 (right) (INESI, 2019)

The suspended monorail set is driven by two rack and pinion drives. In the computational model, the contact parameters between the gears and the rack on each rail were defined. The suspended monorail was accelerated to the set speed, after defining the torque applied to the gears in a drive. Displacements, accelerations of all components of the suspended monorail as well as forces and torques in the selected nodes, e.g. in the route suspensions, were recorded during the simulation.

Simulation results

With regard to both variants of the computational model, the suspended monorail movement along a straight track section was simulated. The simulation consisted of accelerating the suspended monorail to the set speed, and then passing through another rails without changing the travel speed. The acceleration stage of the suspended monorail lasted from 0 to 2 s, then it moved at a speed of about 3.5 m/s. The velocity graph in the axis of travel (Y axis), as regards the driver's cabin in both variants, is presented in Figure 4. The graph shows regular cyclical speed disturbances occurring at regular intervals (Turygin et al., 2016). They result from passing through the joints of successive rails. The speed was measured at the place of operator's seat. The graph shows smaller speed disturbances in variant 2 simulations. This is the result of action of the elastic-damping components of the cabin suspension.

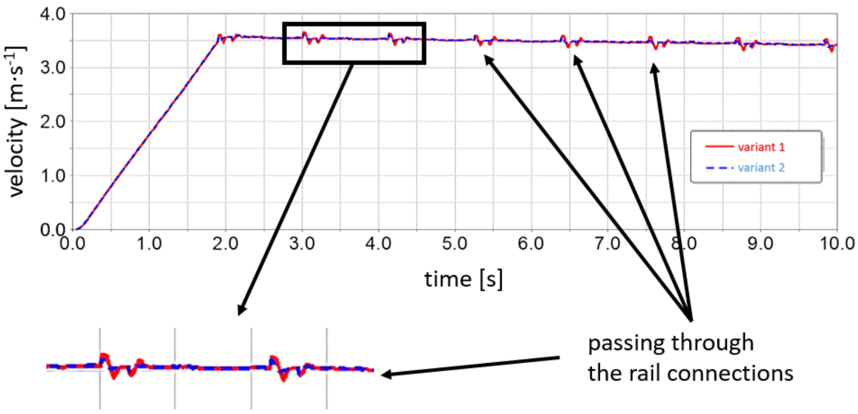

Fig. 4. Speed chart recorded during the travel simulation of operator's cabin (INESI, 2019)

Figures 5 - 7 show the acceleration graphs recorded in three axes of the coordinate system, on the operator's seat, during the simulation. The X-axis is a horizontal axis perpendicular to the travel direction of the suspended monorail, the Y-axis is the axis along travel direction, while the Z-axis is a vertical axis.

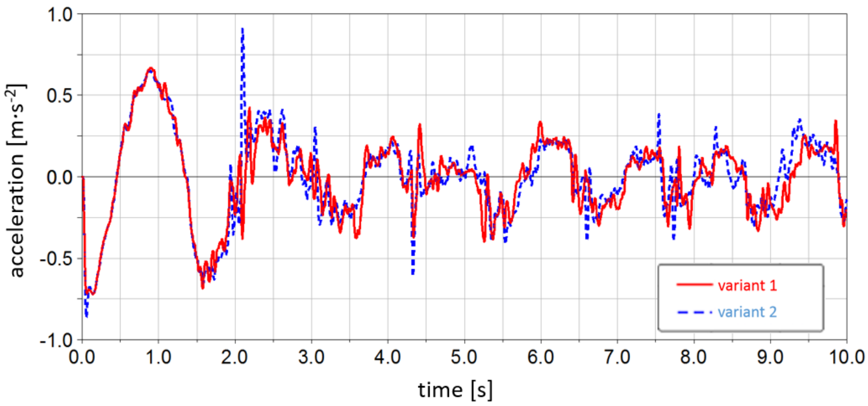

Fig. 5. Diagram of acceleration vs time recorded at the operator's seat in the X-axis (INESI, 2019)

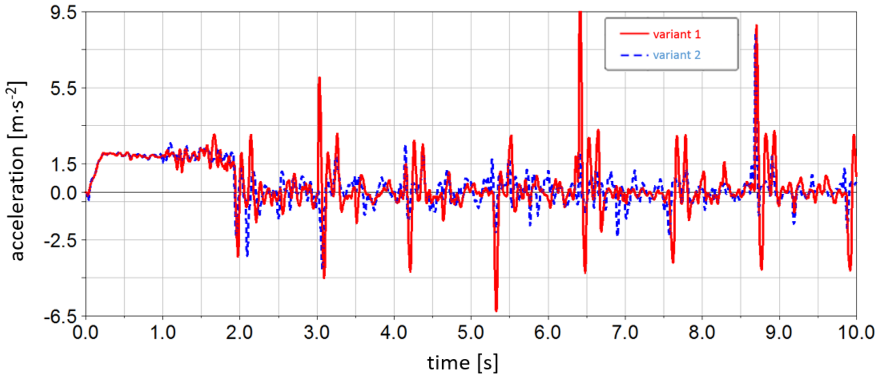

Fig. 6. Diagram of acceleration vs time recorded at the operator's seat in the Y-axis (INESI, 2019)

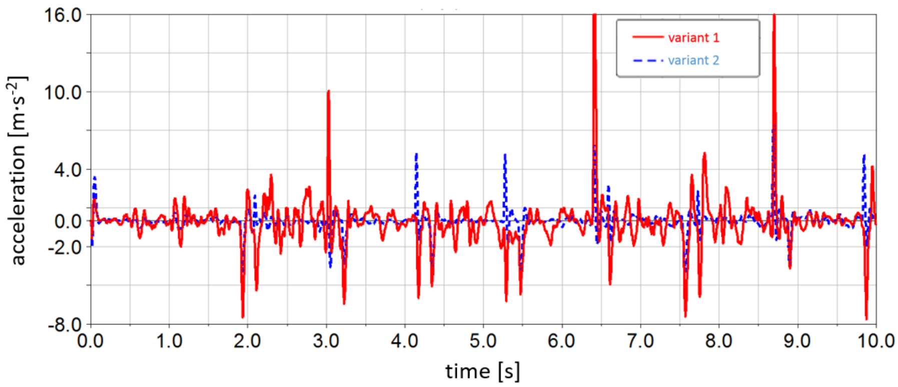

Fig. 7. Diagram of acceleration vs time recorded at the operator's seat in the Z-axis (INESI, 2019)

By analysing the acceleration curve on the operator's seat, it can be observed that in the X-axis in Variants 1 and 2, the accelerations on a similar level were recorded. In the other axes in variant 2, much lower accelerations were recorded compared to Variant 1. This is especially evident when passing through the rail joints, which is represented by peaks in diagrams. It proves that the introduction of yielding components in the suspension of the operator's cabin has a positive effect on reducing the level of vibrations.

In the same way, accelerations in the passenger cabin were recorded, the result of these records is shown in Figures 8 - 10.

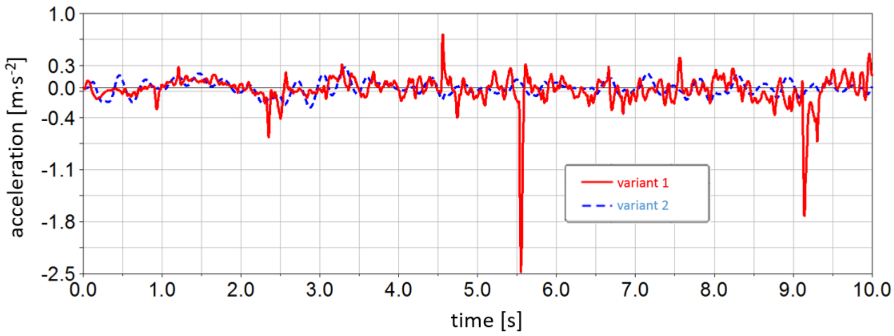

Fig. 8. Diagram of acceleration vs time recorded in the passenger cabin in the X-axis (INESI, 2019)

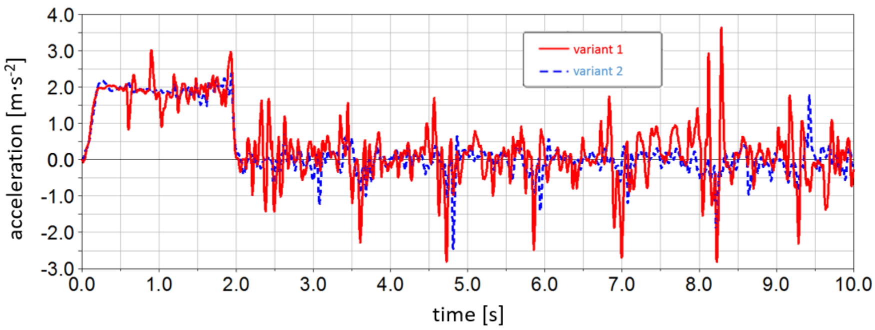

Fig. 9. Diagram of acceleration vs time recorded in the passenger cabin in the Y-axis (INESI, 2019)

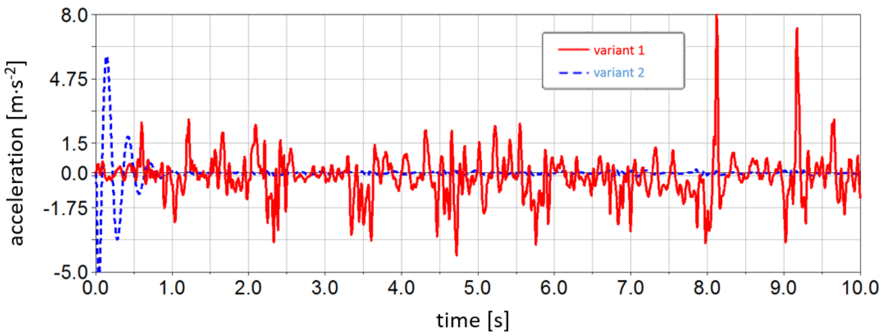

Fig. 10. Diagram of acceleration vs time recorded in the passenger cabin in the Z-axis (INESI, 2019)

As in the case of the operator's cabin, the use of a yielding suspension in the passenger cabin resulted in the reduction of accelerations recorded in Variant 2 in relation to accelerations recorded in Variant 1. In the case of passenger cabins, the reduction in accelerations was observed in all three axes.

The results presented in the diagrams were further analysed. Table 1 shows the root mean square (RMS) accelerations in three axes, both in relation to the operator's cabin and the passenger cabin. In addition, the RMS accelerations were determined in relation to the full simulation (acceleration and travelling stage) as well as limited only to the suspended monorail travelling stage with a set speed, neglecting the acceleration stage (time: 2 - 10 s).

Table 1. Root mean square (RMS) accelerations in three axes in relation to the operator's cabin and the passenger cabin (INESI, 2019)

	RMS of the X-axis [m·s-2]	RMS of the Y-axis [m·s-2]	RMS of the Z-axis [m·s-2]
Operator’s cabin			
variant 1 – full	0.26	1.50	2.00
variant 1 – 2 – 10 s	0.17	1.41	2.18
variant 2 – full	0.27	1.11	0.86
variant 2 – 2- 10 s	0.18	0.82	0.89
Passenger cabin			
variant 1 – full	0.21	1.03	1.13
variant 1 – 2 – 10 s	0.23	0.68	1.21
variant 2 – full	0.09	0.88	0.69
variant 2 – 2- 10 s	0.09	0.35	0.06

Then, according to the standard provisions (PN-EN 14253+A1:2011), daily vibration exposure (A(8)) was calculated. The calculations were made with the assumption of an 8-hour working day, during which the operator of the suspended monorail was exposed to vibrations in the cabin for 4 hours, while the time of exposure of the passenger in the passenger cabin was assumed to last for 2 hours. The results of the calculations are presented in Table 2.

Table 2. Daily exposure to vibrations on the operator and passenger of the suspended monorail (INESI, 2019)

	Ax(8) [m·s-2]	Ay(8) [m·s-2]	Az(8) [m·s-2]	A(8) [m·s-2]
Operator's cabin (exposure time 4h)				
variant 1 – full	0.25	1.49	1.42	1.49
variant 1 – 2 – 10 s	0.17	1.39	1.54	1.54
variant 2 – full	0.26	1.09	0.6	1.09
variant 2 – 2- 10 s	0.18	0.8	0.64	0.8
Passenger cabin (exposure time 2h)				
variant 1 – full	0.14	0.72	0.56	0.72
variant 1 – 2 – 10 s	0.16	0.48	0.6	0.6
variant 2 – full	0.06	0.62	0.34	0.62
variant 2 – 2- 10 s	0.06	0.24	0.03	0.24

In the case of Variant 1 during the full simulation (acceleration and travel stage), both in relation to the operator's cabin and the passenger cabin, the dominant influence on the human body is acceleration in the Y-axis (consistent with the direction of travel). The acceleration in the Z (vertical) axis is dominant when analysing the travel stage alone without the acceleration stage. The introduction of a yielding suspension in Variant 2 decreases the significance of accelerations acting in the Z (vertical) axis. In the Variant 2 in both cases (with and without the acceleration stage) acceleration direction consistent with the Y-axis (consistent with the direction of travel) - the dominant direction.

Introduction of a yielding suspension significantly reduces the daily exposure to vibration by the suspended monorail operators and passengers. Significant reduction in exposure to vibration can be observed when analysing only the railway travel without the acceleration stage. In the case of analyses also covering the acceleration stage, the observed small improvement in the vibration exposure coefficient results from the acceleration in the Y-axis required to speed up the suspended monorail.

Discussion

The analyses carried out, the results of which are given in the paper, were aimed at analysing the impact of the use of a flexible suspension of the operator's cabin and passenger cabin on the level of vibration acting on the operator and passengers. Due to health hazards associated with long-term exposure to vibrations, estimating its level - at the design stage, before building a prototype, is highly expected. As was shown in the article, it is possible to predict the level of vibration, based on the virtual model of the machine and suspension. An extremely important aspect of the analysis is the ability to change the mechanical properties of the suspension system elements and the observation of the impact of these changes on the level of vibration affecting the human travelling in the suspended monorail.

It is worth to mention, that vibration analysis on the stage of the virtual prototyping of the new machine design extends the range of simulated phenomena, related to the human factor. In a typical approach, analyses like an ergonomic assessment are focused on the analysis of the workplace dimensions (field of view, optimal reaching zones) and their influences on the operator's posture (static comfort coefficient). Extending simulation scope also to the vibration analysis, significantly brings virtual prototyping closer to reality.

Conducting the numerical simulations allowed for objective and quantitative comparison of two constructions of the operator's cabin. As a result of the analyses, it can be determined which of the cabs is safer and more comfortable for the operator. However, it should be taken into account that some simplifications in the carried out simulations were applied and they may affect the recorded accelerations (vibrations). The introduction of such simplifications was necessary to optimise the computational model construction and to reduce the simulation time. The computational model can accelerate in a slightly different way than the real object. It results from simplifications in the driving system, which were limited to defining the driving torque acting on the gear wheels. Neglecting the vibrations generated by the machinery part and engine part is another important simplification regarding the vibrations. This may cause discrepancies between the vibrations obtained in numerical simulation and measured on the real object. Other simplifications concern the operator's seat and the passenger seats. The calculation model does not take into account the material from which the seats are made, and thus their vibration damping characteristics were neglected. This fact, according to the authors, does not disqualify using the simulations for cognitive and comparative purposes in the analysis of vibrations generated during suspended monorail travel along a rail and rail joints, and from the possibility of analysis of vibration and overloading acting on the operator or passengers of the suspended monorail in emergency situations, such as emergency braking. The justification for the above statement is the fact that the vibrations presented in the article are mainly caused by passing through the route joints and unevenness of the route, as well as dynamic phenomena such as the process of accelerating and braking the transportation system. At the same time, the modification of the monorail suspension system is aimed at suppressing vibrations arising during the ride.

Conclusions

The discussed simulations were aimed at comparing the level of vibrations affecting the operator and passengers of the suspended monorail in the case of using a rigid connection between the operator's cabin and the passenger cabin with the trolley and cabins connected to the trolleys with a yielding suspension. The analyses of the results confirm the possibility of using numerical simulations to compare the impact of vibrations on men at their workplace. As it was suggested on the basis of the analyses, the yielding suspension of operator's and passenger cabins significantly improves the comfort of the operator's work and passenger travel. In addition, the use of numerical simulations allows analysis and comparison of vibration damping efficiencies using materials of different stiffness and damping coefficients. In this way, the optimal materials for manufacturing the yielding components of the cabin suspension can be selected. The simulations conducted at the design stage enable selecting the optimal materials, changing the maximum allowable deflections of the yielding suspension components or introducing changes to the assumed concept of the suspension system. The presented method of using numerical simulations to analyse the vibrations, acting on the operator, and passengers of the suspended monorail, together with the calculation of the daily exposure to vibrations, can also be implemented for the analysis of any machine. The use of the simulation software, and developed algorithm, allows estimating the amount of exposure of any machine operator to vibrations. With knowledge of the vibrations course and the possible overloads attributable to the operator, both at the design stage and as part of the modernisation of existing machines, develop a way to improve working conditions by reducing daily exposure to vibrations.

It should be noticed that too high vibration levels affect other parameters, such as dynamic overloads in the suspended route and in components of the transportation unit, as well as noise. The latter is particularly troublesome when it is generated in closed and limited spaces. It should be avoided if passenger transport takes place over long distances between the shaft and the crew's workplace. In addition, unsprung masses excited by vibrations of a certain frequency may, as a consequence, be a source of resonance, i.e. a rapid increase in the amplitude of their vibrations.

As part of future work, the authors plan to validate the calculation model by comparing the results of numerical analyses with the values recorded on the test track. The next step will be to analyse dynamic phenomena such as emergency braking at different speeds of the suspended monorail. Further simulations will be focused on the analysis of the impact of the suspended monorail speed on travelling comfort and safety of the monorail operator and passengers in normal conditions and in emergency situations.

References

AlShabi, M., Araydah, W., ElShatarat, H., Othman, M., Younis, M.B. and Gadsden, S.A. (2016) Effect of Mechanical Vibrations on Human Body. *World Journal of Mechanics, 6, 273-304. doi: http://dx.doi.org/10.4236/wjm.2016.69022*

Basri B., Griffin M.J. (2013) Predicting discomfort from whole-body vertical vibration when sitting with an inclined backrest. *Appl. Ergon., 44, pp. 423-434*

Bovenzi M. (2005) Health effects of mechanical vibration. *Giornale italiano di medicina del lavoro ed ergonomia, 27:1, pp. 58-64*

Bozek, P., Ivandic, Z., Lozhkin, A., Lyalin, V., Tarasov, V. (2016). Solutions to the characteristic equation for industrial robot´s elliptic trajectories. In Tehnički Vjesnik - Technical Gazette. Vol. 23, iss. 4, pp. 1017-1023.

Budniok T., Zasadni W., Mrowiec H., Kania J., Rusinek J., Szymiczek K. (2014) Analiza możliwości zwiększenia prędkości jazdy ludzi kolejkami podwieszonymi z napędem własnym. *Conference Proceedings: XXII Międzynarodowa Konferencja Trwałość Elementów i Węzłów Konstrukcyjnych Maszyn Górniczych, TEMAG 2014*

Dz.U. 2018 poz. 1286 - Rozporządzenie Ministra Rodziny, Pracy i Polityki Społecznej z dnia 12 czerwca 2018 r. w sprawie najwyższych dopuszczalnych stężeń i natężeń czynników szkodliwych dla zdrowia w środowisku pracy

Harazin B. (2002) Zawodowa ekspozycja na ogólne wibracje w Polsce. *Medycyna Pracy, Vol. 53, No. 6, p. 465-472*

INESI European Project: Increase Efficiency and Safety Improvement in Underground Mining Transportation Routes. RFCS, Contract No. 754169 (2017-2020)

Issever H., Aksoy C., Sabuncu H., Karan A. (2003) Vibration and Its Effects on the Body. *Medical Principles and Practice;12: pp.34-38. doi: 10.1159/000068155*

Kiełbasa P., Dróżdż T., Wojtas D. (2019) Analiza drgań ogólnych i miejscowych na stanowisku pracy operatora specjalistycznej maszyny drogowej. *Autobusy 1-2/2019. pp. 281 – 286 doi: 10.24136/atest.2019.051*

Kiełbasa P., Juliszewski T., Smółka Ł., Zięba A. (2017) Ergonomiczna ocena środowiska Drganiowego istotnego z punktu widzenia komfortu pracownika i organizacji pracy wybranego procesu produkcyjno – naprawczego. *Autobusy 6/2017, p.242 - 246*

Koradecka D. (1999) Bezpieczeństwo pracy i ergonomia Tom 2. *Centralny Instytut Ochrony Pracy, Warszawa ISBN 83-91074-6-5*

Kowalski P. (2019) Drgania mechaniczne. Zagrożenia i profilaktyka. *Materiały szkoleniowe Serwis Internetowy Bezpieczniej CIOP PIB: https://www.ciop.pl/CIOPPortalWAR/appmanager/ciop/pl?_nfpb=true&_pageLabel=P62002986134017789831 1*

Kowalski P., Zając J. (2012) Research on simultaneous impact of hand-arm and whole-body vibration, *International Journal of Occupational Safety and Ergonomics (JOSE), Vol. 18, 1, s. 59-66*

Kowalski P., Zając J. (2017) Influence of vertical and horizontal whole-body vibration on some psychomotor and cognitive functions of employees age 50+ (pilot study)., *Journal of Vibroengineering, Vol. 19, Issue 3, p.2174-2179*

Krajnak K. (2018) Health effects associated with occupational exposure to hand-arm or whole body vibration, *Journal of Toxicology and Environmental Health, Part B, 21:5, 320-334, doi: 10.1080/10937404.2018.1557576*

Lesiak K. Brzeżański M. (2018) Concept of the exhaust system for diesel engines used in underground mining. Conference proceedings: *KONMOT 2018, International Automotive Conference, Kraków, pp. 1-6, ISSN 1757-899X*

Muravev V.V., Muraveva O.V., Volkova L.V., Sága M., Ságová Z. (2019) Measurement of residual stresses of locomotive wheel treads during the manufacturing technological cycle. *Management Systems in Production Engineering. Vol. 27, Issue 4. pp. 236-241. doi: 10.1515/mspe-2019-0037*

Nędza Z., Gola S., Madeja –Strumińska B. (2006) Wczesna diagnostyka choroby wibracyjnej na stanowisku pracy w zakładach górnictwa skalnego. *Mining Science, VIII(1): p.145–154*

Pieczora E. Suffner H. (2017) Rozwój napędów dołowych kolejek podwieszonych. *Maszyny Górnicze 2017 3 pp. 44-57, ISSN 2450-9442.*

PN-EN 14253+A1:2011 Drgania mechaniczne. Pomiar i obliczenia zawodowej ekspozycji na drgania o ogólnym działaniu na organizm człowieka dla potrzeb ochrony zdrowia. Wytyczne praktyczne (Mechanical vibration - Measurement and calculation of occupational exposure to whole-body vibration with reference to health - Practical guidance).

Polnik B. (2018) An Innovative Power Supply System Dedicate for Roadheading Mining Machines. *Conference proceedings: ABAF 2018, 19th International Conference on Advanced Batteries, Accumulators and Fuel Cells, Brno, 26-29 August 2018 349-362, ISSN 1938-6737*

Szczepaniak Jan, Kromulski Jacek (2011) Analysis of energy flow model in the Biomechanical system human operator – agricultural combination. *Journal of Research and Applications in Agricultural Engineering, Vol. 56(4)*

Szewerda K. (2019) Supporting development of suspended underground monorails using virtual prototyping techniques. *INNOVATIVE MINING TECHNOLOGIES (IMTech Scientific and Technical Conference) IOP Conf. Series: Materials Science and Engineering 545 (2019) 012018 IOP Publishing, doi: 10.1088/1757-899X/545/1/012018*

Tokarczyk J., Michalak D., Rozmus M., Szewerda K., Żyrek L., Železnik G. (2019) Ergonomics Assessment Criteria as a Way to Improve the Quality and Safety of People's Transport in Underground Coal Mines. *In: Rebelo F., Soares M. (eds) Advances in Ergonomics in Design. AHFE 2019. Advances in Intelligent Systems and Computing, vol 955. Springer, Cham, DOI: https://doi.org/10.1007/978-3-030-20227-9_28*

Tokarczyk J. (2017) Methodology for identifying the selected mechanical hazards in auxiliary transport of underground mines, *Monograph vol. 52, Institute of Mining Technology KOMAG, Gliwice*

Tokarczyk J. Kania J. (2016) Systems and tracks of self-powerd suspended monorails for transportation of people in horizontal workings and workings with inclination up 45°. *Mining Informatics, Automation and Electrical Engineering, Vol. 3, p.31-39.*

Turygin, Y., Bozek, P., Abramov, I., Nikitin, Y. (2018) Reliability determination and diagnostics of a mechatronic system. *In Advances in Science and Technology Research Journal.* Vol. 12, iss. 2, pp. 274-290.

Zasadni W., Kania J., Tokarczyk J., Rusinek j., Szymiczek K. (2015) Możliwości zwiększenia prędkości jazdy kolejkami podwieszonymi z napędem własnym. *Conference proceedings: XVII Konferencja: Problemy bezpieczeństwa i ochrony zdrowia w polskim górnictwie.*

Acta Montanistica Slovaca
ISSN 1335-1788
actamont.tuke.sk

Controlling the longwall coal mining process at a variable level of methane hazard

Stanisław TRENCZEK[1]*, Aleksander LUTYŃSKI*[2]*, Artur DYLONG*[3]
and Piotr DOBRZANIECKI[4]*

Authors' affiliations and addresses:
[1] KOMAG Institute of Mining Technology, Pszczyńska 37, 44-101 Gliwice, Poland
e-mail: strenczek@komag.eu

[2] KOMAG Institute of Mining Technology, Pszczyńska 37, 44-101 Gliwice, Poland
e-mail: alutynski@komag.eu

[3] Silesian University of Technology, Faculty of Mining, Safety Engineering and Industrial Automation, Department of Electrical Engineering and Industrial Automation, Akademicka 2, 44-100 Gliwice, Poland
e-mail: Artur.Dylong@polsl.pl

[4] KOMAG Institute of Mining Technology, Pszczyńska 37, 44-101 Gliwice, Poland
e-mail: pdobrzaniecki@komag.eu

***Correspondence:**
Piotr Dobrzaniecki, KOMAG Institute of Mining Technology, Pszczyńska 37, 44-101 Gliwice, Poland
tel: 32 237 46 50
e-mail: pdobrzaniecki@komag.eu

How to cite this article:
Trenczek, S., Lutyński, A., Dylong, A. and Dobrzaniecki, P. (2020). Controlling the longwall coal mining process at a variable level of methane hazard. *Acta Montanistica Slovaca,* Volume 25 (2), 159-169

DOI:
https://doi.org/10.46544/AMS.v25i2.3

Abstract
The systems for monitoring the mine atmosphere, especially in the longwall panels, have been used for many years. Thanks to their use, it was possible to reduce the number of hazardous events (accidents). Until now, the attention was paid primarily on securing the mine personnel as the most important aspect of the methane explosion hazard. Recent years show that the number of accidents in Poland decreased to several cases per year. Such an event can cause a risk of damage. In order to further reduce the number of hazardous events, the existing solutions will not be enough, so a new approach to monitoring and using the methane concentration prediction methods in longwall panels is necessary to be applied.
The reasons for changes in methane hazard level at the coalmine longwall faces are discussed at the beginning. Then, the methods for controlling the longwall shearer's operation depending on methane hazard level are presented. Dangerous events caused by the sudden outflow of methane into the longwall panel were recalled. In the further part, an additional subsystem for monitoring the methane concentration in the longwall panel in the context of controlling the operation of the longwall shearer and the run-of-mine transportation in the longwall area is described. Finally, the importance of the new way of controlling the mining process and run-of-mine transportation for work safety and mining efficiency was emphasized.

Keywords
hard coal mining, methane hazard, controlling the longwall shearer's operation, monitoring.

Introduction and base information

As it is known, methane in the rock mass occurs as:

- adsorbed methane, physically and chemically bonded to the carbonaceous substance,
- free methane, in pores and crevices of waste rock and coal seams.

The amount of methane flowing from the rock mass into the longwall area is determined by many factors, but the thickness and permeability of the overburden resting on the carbonaceous layer are important - the thicker and less permeable overburden, the higher methane content of the deposit underneath.

In methane seams, methane flows into the longwall face in two ways (Szlązak et al., 2005). It may be a direct inflow - i.e. from the coal of the mined seam in each phase of the mining process (mainly, during mining and transportation of excavated material), and from the exposed solid coal of a longwall panel in the zone of operating pressure. It can also be an indirect inflow - in the case of using a block caving method in the longwall panel.

Post-mining gob in an operating mine includes large rock mass volumes to which permanent methane emissions occur. In addition, they are a reservoir of free methane and create their migration pathways. There are also gaseous-geological dynamic phenomena which, as a result of rock mass burst, cause the inflow of large volume of high concentrated methane to the workings in the area of the longwall panel (Karacan et al., 2007; Karacan et al., 2010). Moreover, gaseous dynamic phenomena cause the inflow of relatively small volumes of methane with often explosive concentration.

Each of the above inflows is troublesome. In the case of methane inflow with a lower concentration than the lower explosion limit (CH_4 below 4.5%) requires stopping the operation of cutting machines and transportation equipment, while in the case of an explosive mixture (methane in concentration 4.5-15%, oxygen in a concentration above 16%), methane can ignite and even explode if at the same time (one of many) initials occur (Mathatho et al., 2019; Trenczek, 2015). Therefore, it is extremely important to recognize the area of the longwall panel and its neighbourhood in terms of the possibility of methane inflow to the longwall and longwall workings.

The standard method for controlling the methane concentrations in the longwall area

Regardless of the recognized conditions in which the exploitation of the coal seam is planned and realized, the legal regulations of the Polish mining industry (Mathatho et al., 2019) require monitoring the methane concentration in a specified way depending on how the longwall is ventilated.

Typical location of methane sensors (methane meters) in the longwall area, in accordance with the regulations (Dz.U. nr 1118, 2017), with the most common ventilation methods, are presented in Figures 1-3.

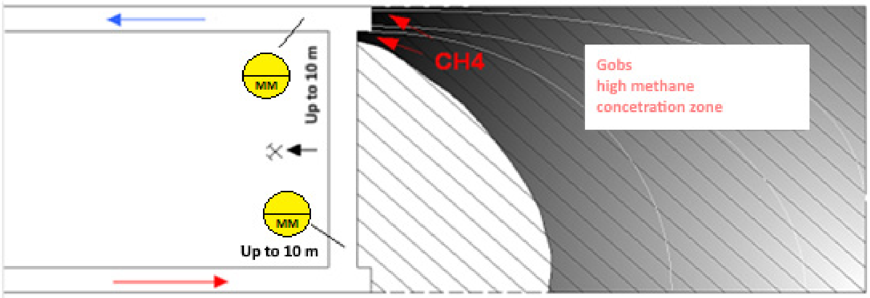

Fig. 1. Example of a typical arrangement of methane meters together with the model of methane distribution in gob at U ventilation method (developed on the basis of (Dziurzyński, 2009))

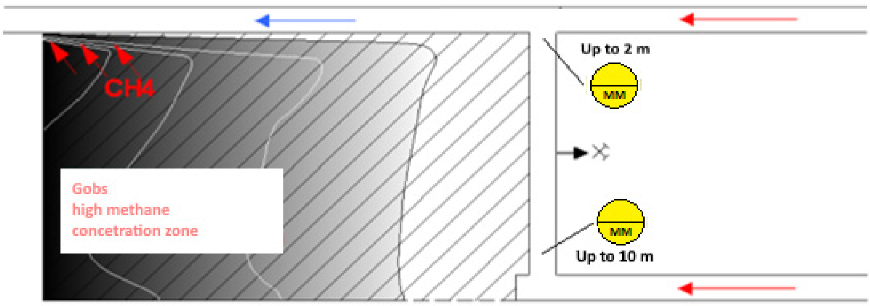

Fig. 2. Example of a typical arrangement of methane meters together with the model of methane distribution in gob at Y ventilation method with a refreshment of outflow air (developed on the basis of (Dziurzyński, 2009)

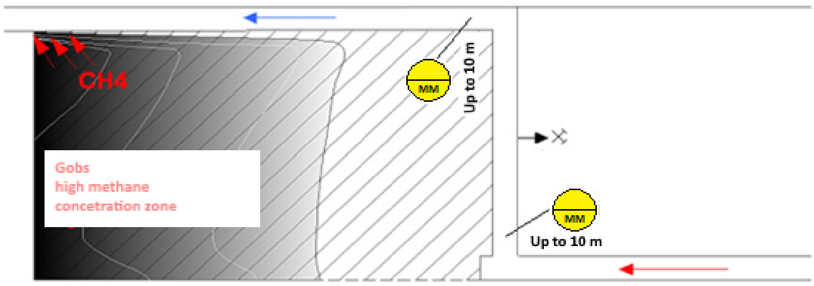

Fig. 3. Example of a typical arrangement of methane meters together with the model of methane distribution in gob at Z ventilation method (developed on the basis of (Dziurzyński, 2009)

Cutting off the power supply of electrical machines and devices operating in the area is the reaction for the signal from the methane sensor informing about exceedance of the threshold concentration (Mathatho et al., 2019). This allows, as already mentioned, to protect the region against the possibility of the appearance of an ignition initial from the operating machines and equipment, and at the same time causes a break in coal mining, what results in economic losses.

However, this method of monitoring is insufficient both to completely eliminate methane ignition from the operation of machines and equipment, and to ensure rational, optimally economical coal mining. In the case of sudden methane inflow - for example, from roof fall due to a dynamic change in atmospheric pressure (Zhu et al., 2007), or disturbances in airflow, or due to gaseous geodynamic phenomena (Lutyński, 2010), - locally, outside the place of control by a methane meter - an explosive mixture of small volume can appear. As a result, methane can be ignited from the operating longwall shearers or roadheaders - in the years 2005-2019 in the Polish mining industry, there were 21 such ignitions (Wu et al., 2005), (Trenczek et al., 2019). In turn, the inability to respond to a gradual increase in methane concentration due to its release from the mined seam, for example, by slowing down the mining process, causes the electricity to be turned off and thus production downtime.

The above drawbacks of the method used to monitor the longwall area can be eliminated by improving the effectiveness of the monitoring and switching off the system using the additional longwall methane-metric system (Dylong, 2019).

Current methods for controlling the longwall shearer operation

Longwall shearer, due to its complicated design, has few control systems connected to the central controller.

Main shearer modules are the following:

- central controller – responsible for the control of the shearer systems,
- power supply control module – responsible, for example, for the control of insulation condition,
- hydraulic systems and driving systems control module – responsible for pressure control in a hydraulic system, control of voltage and current in electric motors,
- system for controlling the electro valves of the hydraulic installation – responsible for controlling the shearer’s moving parts,
- radio control system – ensuring safe work by use of the remote controller,
- surface system for visualization and monitoring – control of the current condition of the shearer, recording of critical parameters.

The simplified diagram of the shearer control system, presented in Fig. 4, can differ among different manufacturers

None of the currently used longwall shearers uses information from automatic methanometry to control the shearer's output (Sevitel Sp. z o.o., 2012; Dylong et al., 2013). In many cases, based on operational experience, users themselves take the manual measurements of methane concentration in front of the shearer and based on them change the mining rate.

Commonly used automatic methanometry is applied to stop the longwall system operation - by cutting off power supply - when CH_4 exceeds 2% in the air, controlled by a methane meter installed at the longwall outlet. This is to prevent against ignition/explosion of methane in a result of the operation of mechanical or/and electrical equipment in the longwall area if the methane concentration exceeded 4.5%. It means that the methanometry system is a blocking system and not a control system.

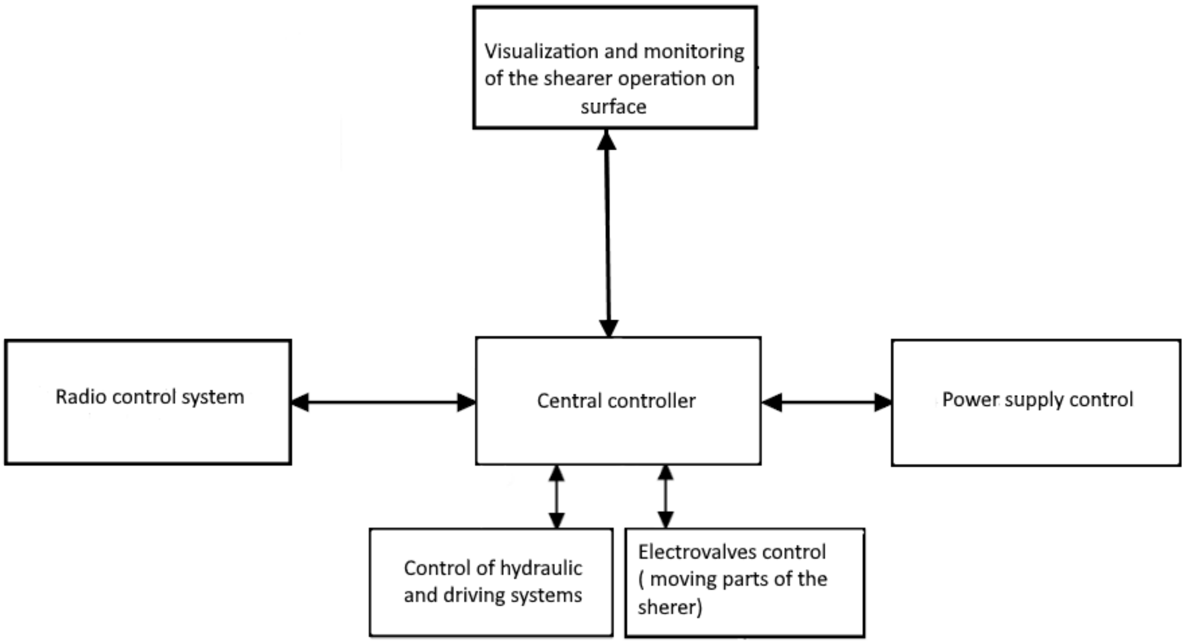

Fig. 4. Simplified block diagram of the shearer control system

Methane hazard monitoring system

The element that distinguishes the methanometric systems used worldwide is the method of the system power supply.

Automatic methanometric system in Poland was based on the OLDHAM CTT-63/40U type of methanometric system imported from France, for which a license was purchased in later years. It allows using the stationary methane meters for measuring low (up to 5%) and high (up to 100%) methane concentrations as well as using the stationary sensors for measuring air flowrate. This system uses a central power supply, which means that subsequent new systems emerging in Poland were also based on the central power supply, requiring a fixed infrastructure. Due to the multi-core cables, their installation in the mine shaft and the roadways must be stable and durable.

In the case of foreign systems, local power supply with a buffer in the form of a battery pack is used. Depending on the regulations being in force in each country, the systems are equipped with batteries that support the operation of devices from 4 to 16 hours. This causes some difficulties, however, compared to the costs associated with the construction of cable installations (cable laying on the surface, in the shaft and mine underground) is accepted. An additional benefit of using the local power supply is the ability to quick movement of the system to any place in the mine.

Regardless of the power source (supplying method), each system - both used in Poland and abroad - has similar functionality. The systems inform about threats in the place of their occurrence and the dispatcher room; then they turn off electricity in the endangered area. Each system stores information on sensor readings in its databases and allows access to this data at any time.

Current methanometry systems used in the mining industry are a part of integrated systems, which are called Integrated Safety Systems. They provide the following:

- continuous measurement and monitoring of methane concentration in workings and methane drainage systems, for the realization of local automated methane safety systems,
- continuous measurement and monitoring of selected air parameters, enabling early detection of underground fires,
- continuous measurement and monitoring of air parameters and its composition for ongoing analysis of ventilation conditions for undertaking the preventive measures,
- monitoring the conditions of ventilation equipment (air stoppings, main ventilation fans, auxiliary fans and ventube fans) as well as equipment and machinery for technological lines,
- monitoring of climatic conditions in underground workings and the condition of air-conditioning devices,
- location and register of employees in underground workings,
- remote control of equipment and machines,
- cooperation of systems through the automatic transmission of warning and alarm signals,

- time synchronization in each security, communication and alarm system.

Such a system enables the following:

- implementation of the hierarchical production and safety management system adopted in the mining industry,
- operating the devices in a non-intrinsically safe version, under the condition that adequate regulations are met,
- implementation of tasks required by regulations, in particular: data visualization at the dispatching point, archiving and reporting the measurement data and events as well as control of underground power supply and signalling devices,
- automatic information of crew working in the hazardous area by generating alarm signals through signalling devices controlled by system object's outputs and/or through alarm and broadcasting systems integrated at the level of surface IT network,
- integration, at the surface IT network level, with geophysical systems for the implementation of automatic pre-emptive shutdowns of electricity in regions with a rock burst of energy that could cause a rapid methane release,
- cooperation (downloading and/or transferring data via a surface IT network) with other data acquisition and visualization systems working in mining plants.

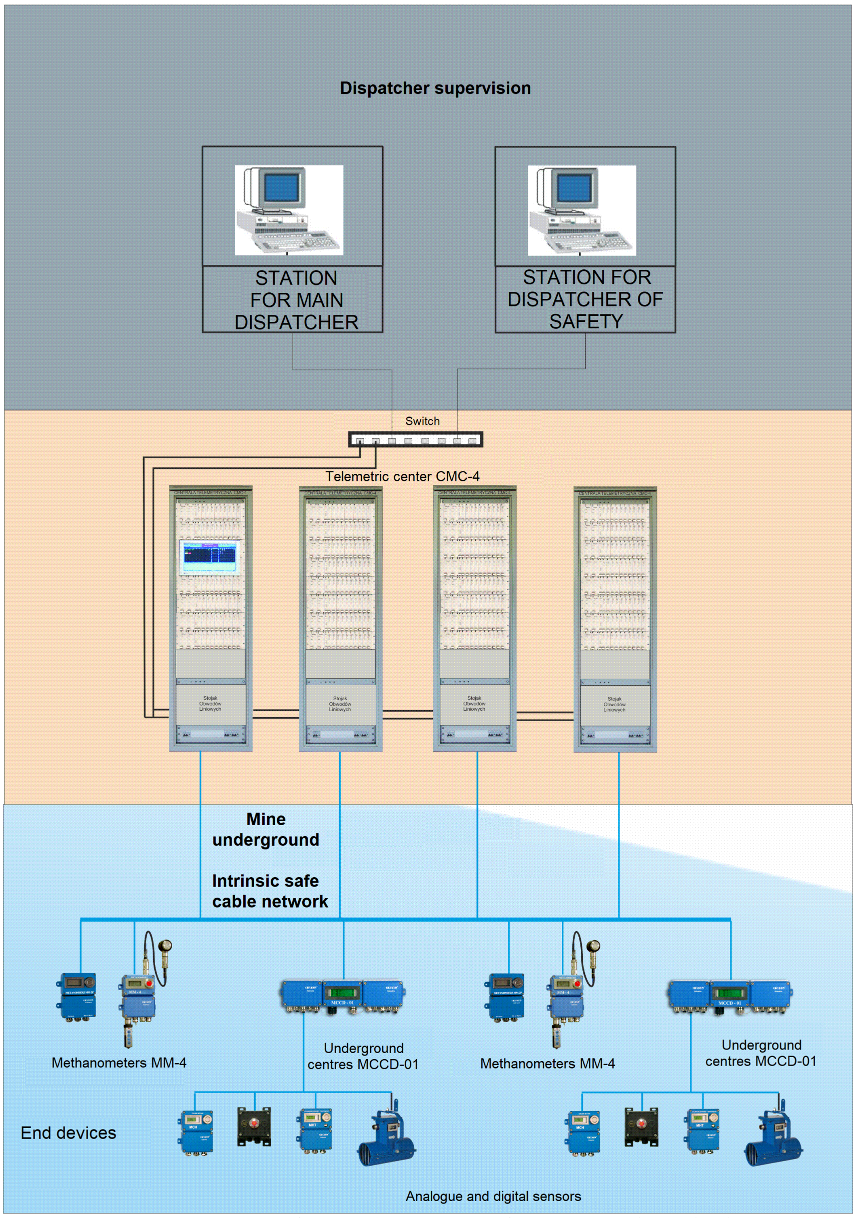

Fig. 5. Structure of a typical gasometric safety system used in Poland

A typical gasometric system (Fig. 5) consists of the following parts:

- underground part – i.e. measuring and communication devices installed in the underground workings,
- station part - located on the surface, where telemetry systems and additional necessary communication devices are installed,
- dispatcher's part - also located on the surface, in the rooms of nominated persons, where there are computer stands with visualization software.

Such a system structure is universal in the case of all Polish coal mines. Depending on the system, the components of each part change - both quantitatively and functionally, but the overall idea remains the same.

The methane and coal dust explosion hazard in hard coal mines impose using the devices of anti-explosion manufacture intended for operation in the M1 zone at any concentration of methane in the workings. The use of such equipment allows control of the mine atmosphere as well as the condition of machinery and equipment also in the event of the electricity being turned off in the workings and the crew withdrawal from the hazardous area. Sensors and underground devices used for these purposes are divided into:

- underground concentrators, which allow data to be collected from analogue sensors (0.4-2 V signal) and binary signals, and also allow to control the operation of machines and devices through the control outputs,
- underground measuring sensors, which due to the type of output signal are divided into analogue-voltage (0.4-2 V, 0-10 V) or current (4-20 mA) - and digital (for example, modem in the V23 standard).

Sensors with analogue output are connected to the inputs of underground concentrators, while sensors with a digital output (for example, methane meters) are connected directly to the power supply and transmission lines from the surface.

Material and Methods

Concept of improving the effectiveness of methane concentration monitoring systems in longwall panels

Because a typical automatic methane measurement system does not allow controlling the shearer operation depending on methane concentration in the air flowing through the longwall panel, it is necessary to find another, improved method for methane monitoring. Such a method should improve the effectiveness of the existing monitoring and switching off the system in terms of safety and efficiency. That is why the concept of using an improved longwall methane measuring system was developed.

The safety aspect is associated with preventing against methane ignition in the case of a sudden outflow of methane from gobs and/or caverns - forming the methane tank in the mined coal seam - with an explosive concentration level. The concept assumes that it is possible to realize it by detecting such an outflow by a nearly located methane meter. Also, it is required that the methane meter cuts off the power supply for the machines and devices in the longwall area in a short time.

The concept of improving the effectiveness of standard automatic methane measurement consists of complementing the existing automatic methane measurement system with additional functions of the methane measuring system in the longwall panel. This will improve the detection efficiency of dangerous methane concentrations directly in the longwall as well as more rapid response of the system.

The first element of the improved longwall methane measuring system is the extension of continuous control of methane concentration in a longwall panel by installing additional methane sensors in the working itself as close as possible to the emission sources. These additional sensors should be located in the following places:

- in the near-gob zone - to control the outflow of methane from the gobs to the longwall, on a distance covering about 1/3 of the length of the longwall from the side of the roadway discharging the used air, and their number would depend on the ventilation methane content of the longwall area, and it would be not less than 3 methane meters,
- in the mining zone, above the face conveyor - to control the current release of methane from the mined solid coal and transported coal, along the entire length of the longwall at a distance of about 30-50 m from each other, as shown in Fig. 6.

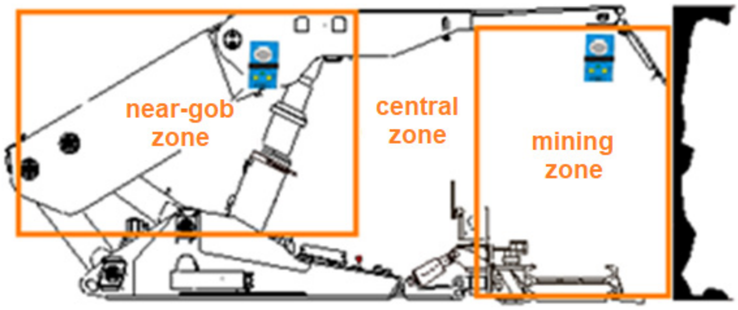

Fig. 6. An example of the location of each methane meter - an additional longwall monitoring system – in the near-gob zone and mining area

Use of short-term forecast of methane concentration in a longwall panel, especially in the area where the highest concentration is usually reported is the second part of additional methanometric system. The main objectives of such forecasting of methane concertation are as follows:

- advance indication of a possibility of exceeding the methane concentration limits,
- recommendation of slowing down or even stop of mining machines operation and eventual stop of transportation machines.

Control of the cutting process, which will use information from the methane concertation forecasting algorithm is the last element of the system. The controlling process has to use programme recommendations what would enable – depending on the forecasting information – to slow down or accelerate the operation of mining machines. This requires the development of another algorithm for controlling the operation of the shearer – AFC system. The algorithm should include the previous important aspects, i.e. operational safety and production effectiveness.

Subsystem for methane monitoring in the longwall area

Methanometric system should have a blocking function in the case of possible methane explosion. It happens, however, that methane released during coal mining flows into the longwall panel, where its concentration may exceed 2%, but usually does not exceed 2.5-3.0%, i.e. it does not approach the concentration equal to the bottom methane explosion limit. Then, in the case of exceeding the accepted methane concentration, the power supply for devices is cut off, and the longwall operations stop, including the run-of-mine transportation (Patra, Das, Mishra, & Senapati, 2017). This can be achieved by slowing down the cutting advance (shearer speed), or stopping the shearer operation, while transportation equipment should still operate considering the fact that restarting the run-of-mine transportation, after it was stopped, can take up to 30 minutes (with a larger number of conveyors). After the methane concentration drops below thresholds, coal mining by a shearer can be intensified or restarted if the shearer was stopped. Such control of the shearer's operation, for economic reasons, is beneficial. Therefore, it is necessary to control the shearer's operation by the local methane concentration monitoring subsystem.

The locally operating methane monitoring subsystem in the longwall panel consists of proper sensors (Dylong, 2019) and standard power supply units, transmission system and computer hardware. Such subsystem enables measurement of methane concentrations in the longwall panel. However, the most important is the short-term forecasting of methane concentration at the outlet from the longwall. It uses elements of the latest trends in forecasting time series (Dylong, 2019; Patra et al., 2017; Qarmalah et al., 2017; RCore et al., 2014; Sanmiquel-Pera et al., 2019; Li et al. , 2019; Liu et al., 2006; Wu et al., 2005; Jian et al., 2008; Zhu et al., 2007).

The subsystem is characterized by:

a relatively large number of additional methane meters placed in the longwall - approx. 10-12 items,

location of methane meters in places of possible methane inflow, i.e. under the canopy of powered roof support, on a gob shield of powered roof support, on an AFC extension,

- relatively high frequency of measuring cycles - methane concentration is measured at least every 1 s,
- short response time of methane measuring heads, less than 5 s (T¬90 < 5 s),
- the power supply of the system within the longwall is based on intrinsically safe battery feeders; with the number of feeders and their locations individually matched to the needs (depending on the length of the longwall and the number of sensors),
- subsystem design ensuring easy integration with existing gasometric systems,
- the modular design of the subsystem enabling adaptation to local conditions.

Special attention should be paid to the location of already mentioned methane meters - they are installed on the powered roof support, and the measuring heads are placed depending on the configuration - in the gob part of the longwall panel, on the mining side and, if necessary, near the longwall conveyor, i.e. near the spill plate if methane is released from the floor. Installation of sensors on a longwall conveyor reduces the time required to detect dangerous concentrations of methane in the case of its presence in the near-floor part of the workings. Figure 7 shows an example of longwall with the installed sensors.

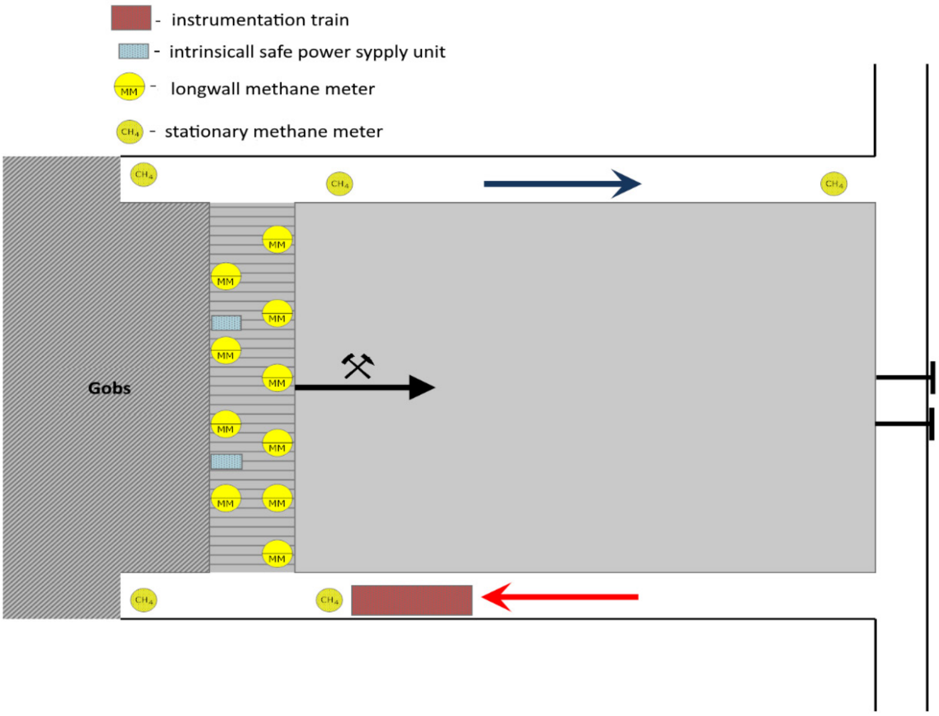

Fig. 7. Longwall panel with sensors installed on the mining and gob side

The distance between the sensors should not exceed 20 m. In the case of using typical longwall shearers a distance from the cutterhead to the nearest sensor is from 10-12 m, regardless of the direction of the shearer's movement. In the case of movement of the shearer with the air flow maximum distance to the sensor installed in front of the shearer is 20 m (Fig. 8). Assuming that the air flowrate in the longwall is up to 2 m/s, a delay in gas transport to the nearest sensor is about 10 s.

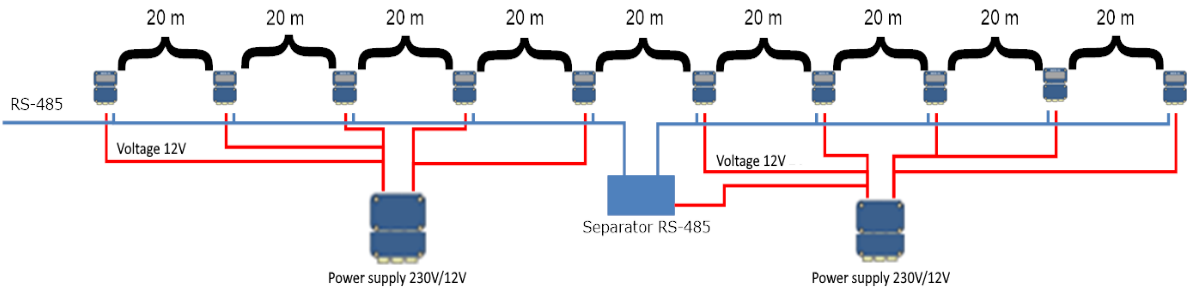

Fig.8. System installation for a 200 m longwall panel

Data recorded by the sensors installed in the longwall are transmitted to the computer on the surface, where they are processed to draw conclusions. Figure 9 is a block diagram of a shearer control system with a local methane concentration monitoring system.

The forecast within a 3-minute horizon is used to develop a discrete signal that is automatically sent to the shearer without personnel intervention. Based on the signal, the shearer's control system introduces the cutting rate limit. The algorithm of the forecasting module and an example of the criteria used to define the discrete control signal is shown in Figure 10.

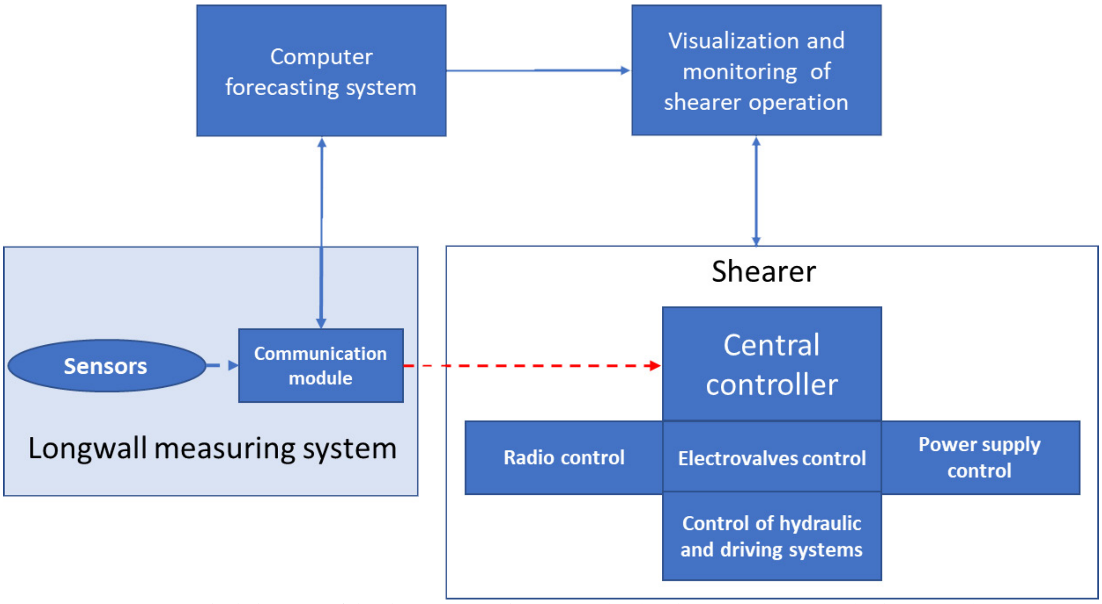

Fig. 9. Block diagram of the shearer control system with a local monitoring system (Dylong, 2019)

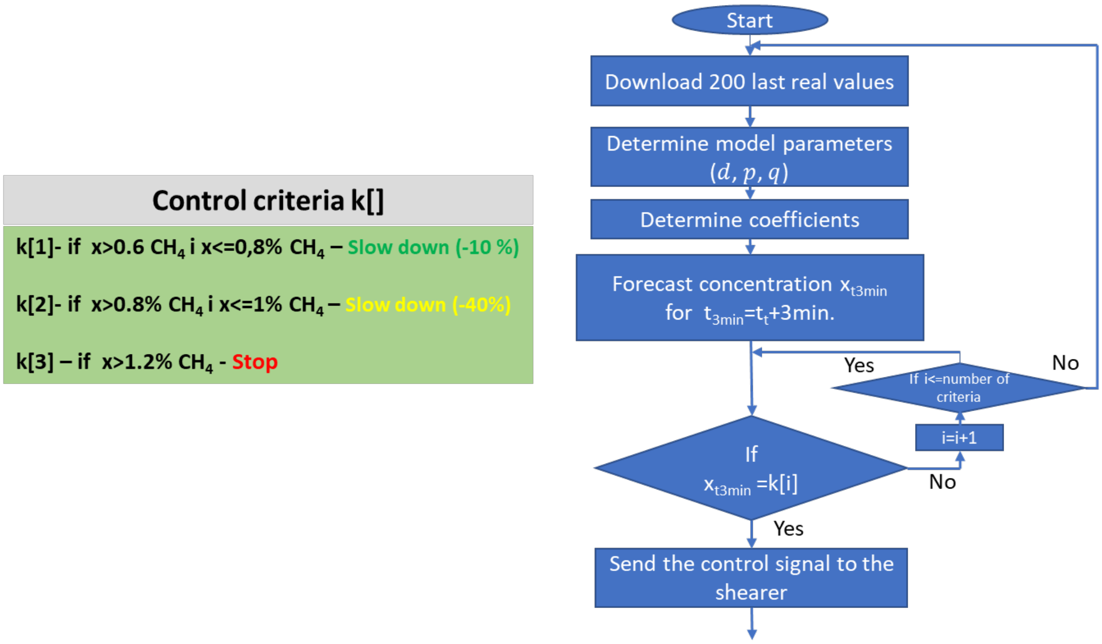

Fig. 10. The algorithm for the forecasting module operation and the defined criteria. (Dylong, 2019)

There are the following defined criteria:

- criterion 1 - when the forecast predicts the methane concentration at the outlet from the longwall in the range of 0.6-0.8 CH_4, a signal is sent to the shearer controller, resulting in a reduction of the cutting rate by 10%,
- criterion 2 - when the forecast predicts the methane concentration at the outlet from the longwall in the range of 0.8-1.0 CH_4, a signal is sent to the shearer controller, resulting in a reduction of the cutting rate by 40%,
- criterion 3 - when the forecast predicts the methane concentration at the outlet from the longwall in the range of 0.8-1.0 CH_4, a signal is sent to the shearer to stop its operation.

If the speed limiter is activated (according to the criterion), the shearer's operator receives information about the reduction in shearer speed (Baranov et al., 2017). If the forecast does not anticipate exceeding dangerous methane concentration, so none of the criterion is met, the signal about deactivating the limiter is sent to the shearer controller. Also in this case, the operator receives information about the status of the limiter.

Importantly, the criteria only apply to the operation of the shearer itself. If the shearer is stopped, the run-of-mine transportation system (longwall conveyor) continues to operate and allows transport of coal from the longwall panel. As we know, coal on a longwall conveyor is one of the most significant sources of methane in the longwall. This situation requires faster ventilation of the longwall panel and faster restarting the shearer and resuming the mining process.

The defined criteria are only examples. In the operating conditions, they should be selected each time when installing the system or changing the ventilation conditions.

Results and discussion

The obtained simulation results indicate that new approach to monitoring the longwall area should significantly increase the safety of mining personnel and reduce the number of downtimes of the longwall systems due to presence of methane in concentrations that make a continuation of work dangerous. Of course, using the new approach will not completely eliminate the methane hazard, but it will reduce the number of hazardous events and reduce the number of downtimes of the system. Use of a new subsystem allows for:

- measurement of methane concentration at the place of its generation,
- using the algorithms for short-term forecast of methane concentration based on data collected from the sensors installed in the longwall panel and at the longwall outflow,
- control of the shearer operation depending on the obtained forecast of methane,
- visualization of current methane hazard in the longwall panel.

According to the mining regulations, the longwall system should be switched off when the methane concentration thresholds are exceeded. Depending on the regulation, it varies from 1.3% CH_4 to 2% CH_4.

Observations show that this action usually eliminates the possibility of a hazardous event. Stopping the longwall system reduces the amount of methane released into the longwall panel during mining. However, the coal on the longwall conveyor is an important source of methane, which, when the conveyor is stopped, increases the amount of methane in the longwall and hence the longer time is needed for ventilation. The application of the solution discussed above, enabling for forecasting the methane concentration at the longwall panel outlet allows for:

- control of methane released during mining by changing the shearer output,
- transportation of run-of-mine by AFC from the longwall panel before the methane hazard occurs and stopping the longwall system,
- reduction of time required for longwall panel ventilation and starting the longwall system again,
- monitoring the methane concentration in the longwall panel not only at its outlet.

Conclusions

In the mining process, besides the semiliquid mixture, mud, slurry, and rocks, there are large volumes of water to remove in order to keep production moving (Qazizada & Pivarčiová, 2018; Turygin et al., 2018).

The variety of sources of methane flowing into the longwall panel in methane mines require using the methanometric systems.

The automatic methanometric system controls the methane concentration in the mine air and switches off mechanical and electrical devices in the longwall area in the case of exceeding the methane threshold concentration.

The blocking nature of the automatic methanometry allows eliminating the possibility of ignition /explosion of methane from the operation of machinery and equipment in the longwall area.

In the case of the presence of methane released during the mining process in the longwall, it is reasonable to introduce control of the longwall shearer enabling the adjustment of mining advance to the present methane concentration.

It is possible to use an additional local methane concentration monitoring subsystem in the longwall, which has the ability to cooperate with the longwall shearer control system according to algorithms for forecasting short-term methane concentration.

Controlling the shearer operation and run-of-mine transportation equipment, to reduce the number of energy shutdowns (longwall system shutdowns) caused by the accumulation of methane in the longwall panel, and slightly exceeding the thresholds, will significantly increase the work safety of mining personnel and ensure continuity of the longwall panel operation.

References

Baranov, M., Božek, P., Prajová, V., Ivanova, T., Novokshonov, D., & Korshunov, A. (2017). Constructing and calculating of multistage sucker rod string according to reduced stress. Acta Montanistica Slovaca. Vol. 22 (2), pp. 107-115.

Dylong, A. (2019). Prognozowanie stężenia metanu w wyrobisku ścianowym na podstawie lokalnego podsystemu sterowania kombajnem. Politechnika Śląska w Gliwicach,

Dylong, A., Knapczyk, J., & Musioł, D. (2013). Wizualizacja bieżącego rozpływu powietrza w sieci wentylacyjnej wraz z jej monitoringiem gazowym. Górnictwo i geologia, 8(4), 5-18.

Rozporządzenie Ministra Energii z dnia 23 listopada 2016 r. w sprawie szczegółowych wymagań dotyczących prowadzenia ruchu podziemnych zakładów górniczych, (2017).

Dziurzyński, W. (2009). Badania modelowe przepływu mieszaniny powietrza i gazów w rejonie ściany w aspekcie walidacji wyników komputerowej symulacji. Przegląd Górniczy, 11-12, 61-66.

Jian, C., Jingjian, B., Jiansheng, Q., & Shiyin, L. (2008). Short-term forecasting method of coalmine gas concentration based on chaotic time series. Journal of China university of mining & technology, 37(2), 231-235.

Karacan, C.Ö., Esterhuizen, G.S., Schatzel, S.J., & Diamond, W.P. (2007) Reservoir simulation-based modeling for characterizing longwall methane emissions and gob gas venthole production, International Journal of Coal Geology Volume 71, Issues 2–3, Pages 225-245

Karacan, C.Ö., & Luxbacher, K. (2010) Stochastic modeling of gob gas venthole production performances in active and completed longwall panels of coal mines. International Journal of Coal Geology Volume 84, Issue 2, Pages 125-140

Krauze, E., & Trenczek, S. (2019). Profilaktyka w pokładach zagrożonych zjawiskami gazogeodynamicznymi. Paper presented at the Górnicze Zagrożenia Naturalne, Jaworze.

Li, M., Lu, J., & Xiong, S. (2019). Prediction of Fractures in Coal Seams with Multi-component Seismic Data. Scientific Reports, 9(1), 58-62.

Liu, J.-J., & Qiao, D.-Q. (2006). Some aspects on the gas outburst/explosion hazard in coal mine of China. Journal of China coal society, 31, No. 1, 58-62.

Lutyński, A. (2010). Warunki bezpiecznej eksploatacji nowoczesnych przenośników taśmowych. Przegląd Górniczy, 12, 80-83.

Mathatho, S., Owolawi, P. A., & Tu, C. (2019). Prediction of methane levels in underground coal mines using artificial neural networks. International Conference on Advances in Big Data, Computing and Data Communication Systems (icABCD), 1-4.

Patra, A., Das, S., Mishra, S. N., & Senapati, M. R. (2017). An adaptive local lenear optimized radial basis functional neural network model for financial time series prediction. Neural Computing and Application, 28(1), 101-110.

Qarmalah, N., Einbeck, J., & Coolen, F. (2017). Mixture models for mrediction from time series, with application to energy use data. Archives of data science, Series A, 2(1), 1-15.

Qazizada, M. E. & Pivarčiová, E. (2018). Reliability of parallel and serial centrifugal pumps for dewatering in mining process. Acta Montanistica Slovaca, 23(2).

RCore, & T.E.A.M. (2014). R: A language and environment for statistical computing. In. Internet: R Foundation for Statistical Computing, Vienna, Austria.

Sanmiquel-Pera, L., Marc Bascompta, M., & Anticoi, H. F. (2019). Analysis of a Historical Accident in a Spanish Coal Mine. Int J Environ Res Public Health, 16(19).

Sevitel Sp. z o.o., K. (2012). Dokumentacja Techniczno-Ruchowa Systemu SMP-NT/S. In.

Szlązak, J., & Szlązak, N. (2005). Zagrożenie metanowe w zrobach ścian zawałowych. Przegląd Górniczy, 10, 20-25.

Trenczek, S. (2015). Zapalenia i wybuchy metanu w kontekście inicjałów związanych z zagrożeniami technicznymi i naturalnymi. Przegląd Górniczy, 2, 87-92.

Trenczek, S., & Krause, E. (2019). Wybrane zagadnienia związane z zapaleniem metanu od pracy kombajnu. Paper presented at the Górnicze Zagrożenia Naturalne, Jaworze.

Turygin, Y., Bozek, P., Abramov, I., & Nikitin, Y. (2018). Reliability determination and diagnostics of a mechatronic system. In *Advances in Science and Technology Research Journal*. Vol. 12, iss. 2, s. 274-290.

Wu, A.-Y., Tian, Y.-L., Song, Y., & He, L.-W. (2005). Application of the grey system theory for predicting the amount of mine gas emission in coal mine. Journal of China coal society, 30(5), 489-592.

Zhu, H.-Q., Chang, W.-J., & Zhang, B. (2007). Different-source gas emission prediction model of working face based on BP artificial neural network and its application. Journal of China coal society, 32(5), 504-508.

Zmarzły M. & Trzaskalik P. (2019). Comparative analysis of methane concentration near the junction of the longwall and top road. Management Systems in Production Engineering, Volume 27, Issue 3, p-ISSN 2299-0461, e-ISSN 2450-5781. pp. 166-173. DOI: 10.1515/mspe-2019-0027.

Acta Montanistica Slovaca
ISSN 1335-1788
actamont.tuke.sk

Coal Handling Operational Risk Management: Stripped Overburden Transport in Brown Coal Open Pit Mines

Michal VANĚK[1], Gregorio Fidalgo VALVERDE[2], Igor ČERNÝ[3] and Vlastimil HUDEČEK[4]*

Authors' affiliations and addresses:
[1] VŠB – Technical University of Ostrava, Faculty of Mining and Geology, Department of Economics and Control Systems, 17. listopadu 2172/15, 708 00 Ostrava-Poruba, Czech Republic
e-mail: michal.vanek@vsb.cz

[2] University of Oviedo, School of Mining, Energy and Materials Engineering of Oviedo, Business Management, St. Independencia, 13, 330 04 Oviedo, Spain
e-mail: gfidaldo@uniovi.es

[3] VŠB – Technical University of Ostrava, Faculty of Mining and Geology, Department of Economics and Control Systems, 17. listopadu 2172/15, 708 00 Ostrava-Poruba, Czech Republic
e-mail: igor.cerny@vsb.cz

[4] VŠB – Technical University of Ostrava, Faculty of Mining and Geology, Department of Mining Engineering and Safety, 17. listopadu 2172/15, 708 00 Ostrava-Poruba, Czech Republic
e-mail: vlastimil.hudecek@vsb.cz

***Correspondence:**
Michal Vaněk, VŠB – Technical University of Ostrava, Faculty of Mining and Geology, Department of Economics and Control Systems, 17. listopadu 2172/15, 708 00 Ostrava-Poruba, Czech Republic
tel: +420596993336
e-mail: michal.vanek@vsb.cz

How to cite this article:
Vaněk, M., Valverde, G. F., Černý, I. and Hudeček, V. (2020). Coal Handling Operational Risk Management: Stripped Overburden Transport in Brown Coal Open Pit Mines. *Acta Montanistica Slovaca,* Volume 25 (2), 170-181

DOI:
https://doi.org/10.46544/AMS.v25i2.4

Abstract
This paper deals with the management of coal handling operational risks related to the transport of stripped overburden in giant brown coal pit quarries. It aims to identify and analyze the operational risks of currently applied continuous conveyance and to consider alternative transport, i.e., discontinuous transport. The Ishikawa diagram was used to identify the degree of operational risks affecting the net present value in both transport technologies. The operational risks examined were: human factor, suppliers, legislation, technology, environment, and market. Failure Mode and Effects Analysis was then used to evaluate the operational risks of continuous and discontinuous overburden transport technologies. The data for the analyses were obtained by means of a survey among experts in the field. The analyses show that the most significant operational risks of continuous transport are: lower demand for coal, an increase in the investment costs, conveyance breakdowns, the quality of the transported material, and work attitude. In the discontinuous technology, the identified operational risks were: increases in the cost of fuels, road maintenance and costs of tires, low-qualified labor; and work attitude. The comparison of the two examined technologies shows that discontinuous transport technology involves more operational risks than the continuous one.

Keywords
Coal handling, operational risk, brown coal, Ishikawa diagram, FMEA, stripped overburden transport.

Introduction

Enterprises are exposed to many simultaneously emerging operational risks associated with individual decisions and actions. Despite a number of particularities, mining and processing of mineral resources is a standard business activity. This means that a mining company management aims for profit, increases in the company's market value, and other goals they should outline. According to Shenkir and Walker (2006), in the 21st century, the technology advancements, such as the internet and global competition, brought a number of operational risks to different companies. These include the use of complex financial instruments, deregulations, downsizing, and consumer demands (Shenkir and Walker, 2006).

To reach their goals, managers need to decide on specific steps and measures of both strategic and operational character. Taking the right decision requires experience and relevant information (Kozel, 2017). In the case of investment decisions, managers may not have the courage to make tough decisions. When making decisions and choosing from possible options or alternatives, managers should rely on the results of various analyses. When decisions need to be supported by investment, studies providing information to answer questions on the effectiveness and return on investment are vital.

Despite being standard businesses, companies in the mining industry face many forms of operational risks, such as government policies, environmental incidents, survival circumstances and market threats (Van Thueyet et al., 2007). Similarly to making decisions on the basis of analyses, operational risks should be managed effectively through their analyses, thus affecting the company value.

Although the operational risk is already included in the economic evaluation of an investment, its analysis may foreshadow significant sources of risk and their possible impacts on the investment in question. No doubt, it is valuable for a manager to be aware of the interval in which the values of the selected economic criterion, for example, net present value (NPV), may range. The awareness of operational risks helps responsible managers to focus on measures in order to reduce or eliminate them.

Surface mining systems comprise a number of stripping, mining, back-filling, and auxiliary works and operations, which are implemented in the most diverse geological and deposition conditions. They also use different technologies and equipment. Mining exploitation includes four basic stages, namely, excavation, loading, transportation, and processing (Singh, 2004; Rahimdel and Bagherpour, 2016). This article does not deal with all the stages, focusing only on the transport of the stripped overburden.

The major function of the so-called technological transport is to move the stripped overburden into dumps, heaps or into settling basins, and to transport the useful materials to further processing or directly to the client (Slivka et al., 2002). It comprises the transport equipment and supplementary and auxiliary mechanization, including the means of control. Something characteristic of these transport systems are the conditions under which the transport routes constantly change, alternating loading and unloading points when dealing with steep slopes, various discharge ends and long distances (Singh, 2004), (Mikoláš et al., 2011). A good choice of suitable load transport undoubtedly belongs to the areas that contribute to the general economic success of a mining company.

Although long-distance belt transport is solely used in the Czech giant brown coal pit quarries to transport the stripped overburden, it may be interesting for mine owners that discontinuous transport brings a comparative advantage as opposed to the continuous conveyance. For example, Seidl et al. (2011) state that in contrast to continuous conveyance the use of rubber-tired haulage ensures stability in time and bigger capacity of exploitation, it is mobile in prioritizing the different mining horizons, there is no need to build costly and difficult working floors, and it is more economical as a complementary technology after mining. Despite the threats, such as the costs of services, repairs, fuel, and capital expenditure, rubber-tired haulage appears optimal for the extraction of residual reserves of coal substance (Seidl et al., 2011).

The study by Seidl et al. (2011) also implies that from an economic perspective, both the overburdened transport technologies (continuous and discontinuous) are sustainable. However, the study did not deal with the operational risks that the transport options are related to. As the economic assessment of the technological options is not enough, this article aims to put through operational risk analysis the two transport technologies and to identify whether the alternatives are comparable as for their degree of risk.

Despite the fact that continuous technology has long been used in Czech brown coal open pit mines and discontinuous technology is a considered alternative. It is possible to ask a research question which of the two alternatives is less risky.

Current literature provides mixed empirical evidence and arguments on the relationships between enterprise risk management and company performance. Some studies focus on enterprise risk management in general (Lai and Shad, 2017; Soomro and Lai, 2017; Meidell and Kaarbøe, 2017). Others deal with risks related to investments (Juchniewicz, 2016; Cehlar et al., 2011). Some authors also report research on specific industries, including the mining industry (Toraño et al., 2012; Badri et al., 2013; Tworek et al., 2018; Sabanov et al., 2008; Bijańska, 2016; Chinbat, 2012).

This article focuses on the risks related to the transport of stripped overburden in giant pit quarries in the Czech Republic. The results may be applied by managers of analogous giant pit quarries or in other fields. It compares the operational risks of two technological solutions to transport stripped overburden: continuous transport technology and, as an alternative, discontinuous transport technology, giving the basis for quality decision making. Results show that there may be antagonist relationships between the values characterizing the operational risk and economic efficiency. When deciding on the choice of the technological solution, this makes the decision-making more difficult. Therefore, risks must be identified and assessed using well-selected methods. When evaluating the economic efficiency of an investment project, in particular, it is important to develop an adequate projection of operational risks.

Methods and materials

A risk is defined as the combination of frequency, probability, and consequences of a specific dangerous situation or event, according to the updated standard on risk management (ISO 31000:2018). It can also be defined as a chance that something will happen and that it will have an impact on a facility (Petrovic et al., 2014). Risk, according to the same standard, is presented as the combination of potential events and consequences associated with the probability of its occurrence. The systematic use of information in order to identify the sources and to estimate the risk is defined as the risk analysis (ISO 31000:2018). Risk analysis provides the basis to assess the risk level, the treatment, and the acceptability of a risk (Petrovic et al., 2014).

The point of departure for the operational risk assessment of the transport options in the conditions of a brown coal opencast mine was the ISO 31000:2018. As the standard outlines a generic approach and can be used within different contexts, for example, environmental risks (Krzemień et al., 2016), it was necessary to adjust the approach for the specific issue under solution. This means that the principles and framework of the risk management architecture were not considered, and the risk management was reduced to the process alone. According to the standard, the risk management process has the following parts: (i) communication and consultation, (ii) determination of the context, (iii) risk assessment, and (iv) risk management.

This paper is focused on the risk assessment, which breaks into the following phases: (i) identification of risks, (ii) risk analysis, and (iii) risk rating.

ISO 31000:2018 is only a conceptual framework for risk management. The standard does not render any specific techniques or tools to be applied in the given conditions or situations. Therefore, the IEC/ISO 31010:2009 on risk management and risk assessment techniques should be consulted.

Risk assessment is the main step in risk management. Risk assessment is the overall process of risk identification, risk analysis, and risk evaluation. It should be conducted systematically, iteratively, and collaboratively, drawing on the knowledge and views of stakeholders. It should use the best available information, supplemented by further inquiry as necessary.

Once this procedure has been carried out, risk management instruments and risk controls can be selected. The results of risk assessment, therefore, affect the scope and intensity of protection. According to Nawrocki and Jonek-Kowalska (2016), the "holistic identification of risk sources" is an extremely important element in risk assessment, being related to all areas of the enterprise's business and its environment (Nawrocki and Jonek-Kowalska, 2016).

Risk assessment may be carried out at various depths and details using one or several methods, either simple or more complex ones. The form of risk assessment and its output should comply with the risk criteria developed as parts of context determination (IEC/ISO 31010:2009).

To assess risks, the standard offers 31 tools and techniques to choose from. In this article about continuous and discontinuous transport of the stripped overburden, two major methods were applied: (i) Cause-and-effect analysis for risk identification and (ii) Failure Models and Effects Analysis (FMEA) for risk analysis and evaluation.

Focusing on the transport of the stripped overburden from the point of extraction to the disposal site, either internal or external spoil heap, belt transport is used in case of continuous conveyance, being an inseparable part of the whole mining complex. Concerning this transport, usually, rubber-tired haulage is used. In giant pit quarries with discontinuous conveyance, they usually use trucks with a working load from 12 – 50 t, the so-called dumpers. Apart from dumpers, there are also dozers, tanks, spray dampers, etc.

Risk identification: Cause-and-effect analysis.

Following ISO 31000 (2018), the first step in risk assessment is risk identification, whose purpose is to find, recognize, and describe risks that might help or prevent an organization from achieving its objectives. Relevant, appropriate, and up-to-date information is important in identifying risks. It is a structured method to identify possible causes of undesirable events or problems and used to classify the possible contributing factors into extensive categories. The information is plotted either into a fishbone diagram (Ishikawa diagram), or a tree diagram (IEC/ISO 31010:2009).

The cause-and-effect analysis renders a structured representation of a list of causes for a specific effect in the form of an image. The cause-and-effect analysis should be performed by a team of experts well aware of the problem requiring solutions. The IEC/ISO 31010:2009 describes the basic steps in the cause-and-effect analysis.

Lehman et al. (1998) generally consider the research process as a series of 10 steps: (1) problem definition, (2) determining information needs, (3) setting research objectives, (4) selection of type of research, (5) design of data collection, (6) development of a plan of analysis, (7) data collection, (8) analysis, (9) drawing conclusions and (10) reporting.

Experts in the field were consulted by means of a two questionnaires survey in order to evaluate or supplement the undesirable events or problems that will drive to a decrease in the Net Present Value (NPV) of the considered technologies.

The NPV was used for the economic evaluation of the assessed technologies, Seidl et al. (2011), the NPV was determined as the head of the Ishikow diagram. This choice was also supported by the fact that the threats considered negatively affect the value of the causal attributes of NPV.

Based on Lehman et al. (1998), Aaker et al. (2003), and Malhotra (2010), no hypotheses were stated as the purpose of the research was to obtain experts' opinions and statements on the given problem.

The first questionnaire dealt with continuous conveyance, and the second questionnaire dealt with discontinuous transport technology. Questionnaires you can see at https://data.mendeley.com/drafts/2vcv8tcpjd. Both questionnaires included seven major risk categories, consisting of specific risks: human factor, supplier, legislation, technology, costs, environment, and market, based on the work developed by (Vaněk et al., 2012). The seven major risk categories are based on the analysis of the macro- and micro-economic environment of the business. According to Janíček (2013), an ideal expert team should have 5 – 7 members and should include respondents from various levels of the company management. The specific risks were identified using Ishikawa diagrams by the authors' team and five experts from the management of coal companies.

By applying the cause-and-effect analysis, it is possible to identify a rather high number of risk sources. These risk sources are later evaluated using the FMEA analysis.

Risk analysis: Failure Mode and Effects Analysis.

The second step in risk assessment, according to ISO 31000 (2018), is risk analysis, which purpose is to comprehend the nature of risk and its characteristics, including, where appropriate, the level of risk. Risk analysis involves a detailed consideration of uncertainties, risk sources, consequences, likelihood, events, scenarios, controls, and their effectiveness. An event can have multiple causes and consequences and can affect multiple objectives.

Failure Mode and Effects Analysis (FMEA) is one of the structured, systematic, and proactive techniques used in failure analysis. The purpose of FMEA is to list out all possible failure modes and evaluate their causes as well as their subsequent effects on the performance of the system under consideration (Bozdag et al., 2015).

According to Nicholas and Steyn (2012), FMEA is used to determine the ways a technical system may fail, as well as how the effects of failure may affect the system's performance, safety, and environment. The model measures the risk level by means of a risk priority number (RPN), a semi-quantitative criticality measure computed by multiplying the severity, the probability of occurrence and the likelihood of detection, of each potential failure mode, using rates from 1 to 10, like the one described in Tab. 1 (Bozdag et al., 2015).

Tab. 1. Severity, probability of occurrence and likelihood of detection scales

Rating	Severity	Probability of occurrence	Likelihood of detection
10	Hazardous without warning	Extremely high	Absolute uncertainly
9	Hazardous with warning	Very high	Very remote
8	Very high	Repeated failures	Remote
7	High	High	Very low
6	Moderate	Moderately high	Low
5	Low	Moderate	Moderate
4	Very Low	Relatively low	Moderately high
3	Minor	Low	High
2	Very minor	Remote	Very high
1	Almost none	Nearly impossible	Almost certain

Source: Bozdag et al., 2015

To ensure as objective inputs as possible, experts in the field were also consulted. Considering the issue under interest, a low number of respondents were expected.

The fundamental difference in the degree of risk in the observed technologies will lay in the RPN interval and in the difference of modus. Potential failure modes are then categorized by the RPN; the highest RPNs have the highest priority (Nicholas, 2012).

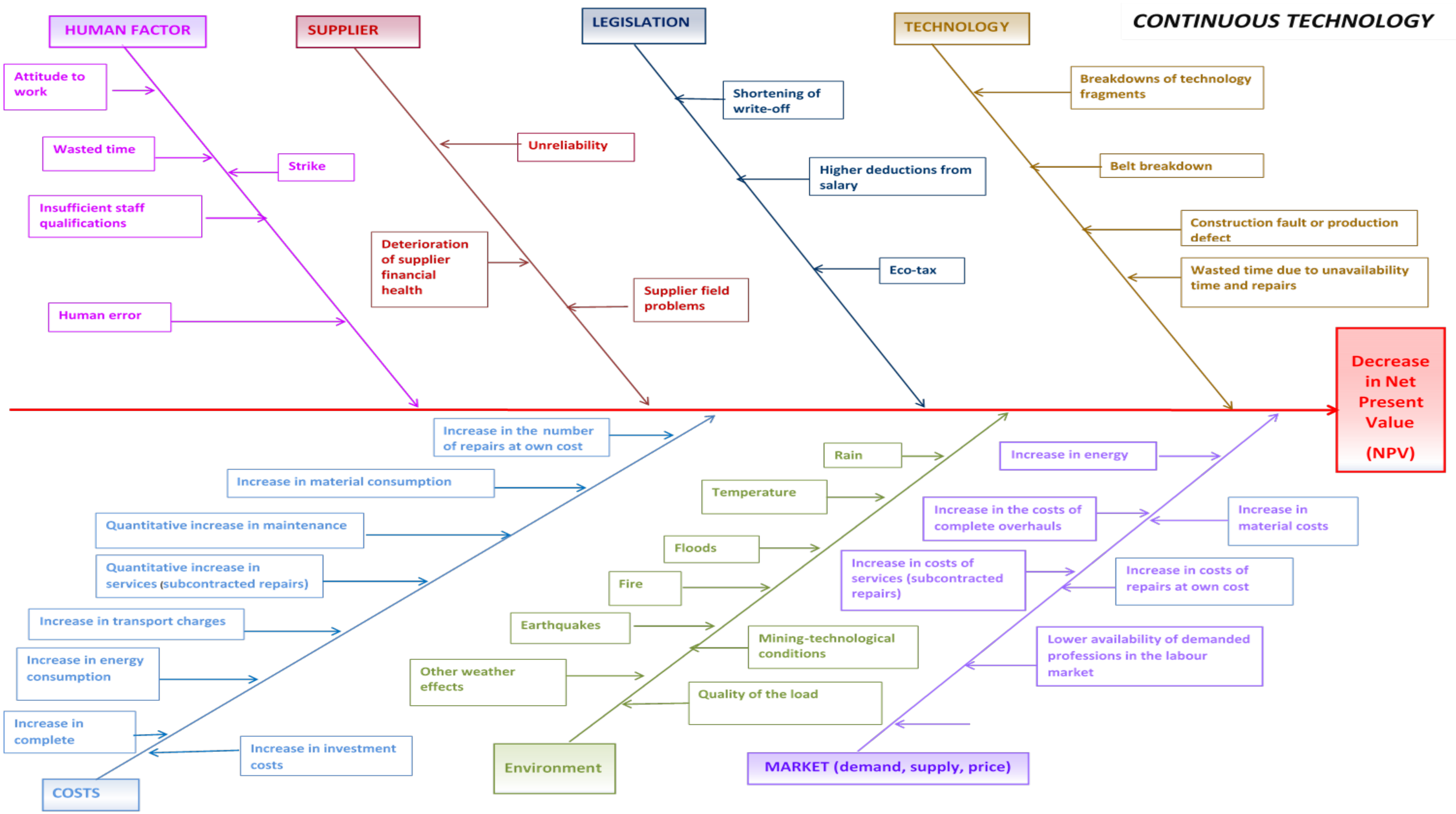

Fig. 1. Ishikawa diagram for continuous technology. Source: own processing.

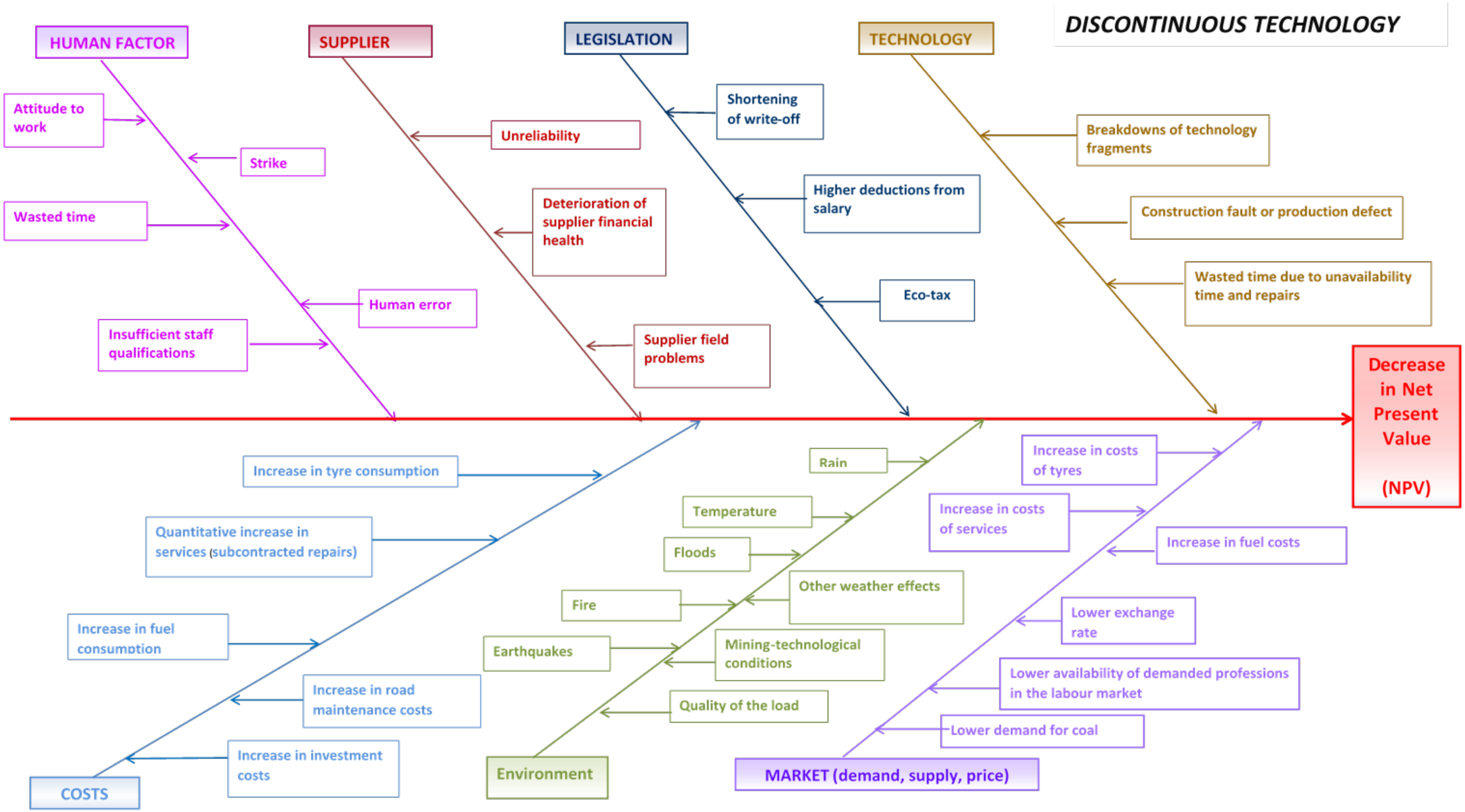

Fig.2. Ishikawa diagram for discontinuous technology. Source: own processing

Results

The first step in the process of risk assessment of the stripped overburden transport options is to identify the risks. Risks were identified using the cause-and-effect analysis (Ishikawa diagram). After making this analysis, it was presented to experts in the field in order to obtain their review. The final form of the analysis, which became the starting point for the subsequent risk analysis, is presented in Fig. 1 (continuous technology) and Fig. 2 (discontinuous technology).

The risk analysis was carried out by means of FMEA. In order to obtain an objective evaluation of the transport option risks, we also addressed experts in the field. Considering the uniqueness of the field, we consider the number of respondents sufficient. In line with the methodology, from the obtained values the modus for severity, probability, and detectability of the risk was calculated and, subsequently, the value of RPN, that are presented for the continuous transport technology (Tab. 2) and the discontinuous transport technology (Tab. 3).

Tab.2. RPN for the continuous transport technology

Area of risk	Type of risk	Severity	Probability	Detectability	RPN	RPN [%]
Human factor	Attitude to work	9	7	5	315	5.7
	Wasted time	9	5	2	90	1.6
	Human error	7	4	2	56	1.0
	Insufficient staff qualifications	9	1	9	81	1.5
	Strike	10	1	1	10	0.2
Supplier	Unreliability	9	3	2	54	1.0
	Deterioration of supplier financial health	7	3	2	42	0.8
	Supplier field problems	7	5	2	70	1.3
Legislatio n	Shortening of write-off period	9	6	1	54	1.0
	Higher deductions from salary	4	2	9	72	1.3
	Eco-tax	9	4	1	36	0.7
Technology	Breakdowns of technology fragments	6	5	9	270	4.9
	Belt breakdown	10	6	6	360	6.6
	Construction fault or production defect	9	5	4	180	3.3
	Wasted time due to unavailability time and repairs	7	3	10	210	3.8
Costs	Increase in complete overhauls	7	1	3	21	0.4
	Increase in the number of repairs at own cost	8	6	5	240	4.4
	Increase in material consumption	8	5	6	240	4.4
	Quantitative increase in services (subcontracted repairs)	4	2	3	24	0.4
	Increase in transport charges	6	6	2	72	1.3
	Increase in energy consumption	8	7	1	56	1.0
	Quantitative increase in maintenance	8	7	4	224	4.1
	Increase in investment costs	10	7	6	420	7.7
Environment	Floods	10	2	1	20	0.4
	Earthquakes	10	1	1	10	0.2
	Fire	10	2	1	20	0.4
	Temperature	9	4	1	36	0.7
	Rain	8	5	5	200	3.6
	Quality of the load	8	8	5	320	5.8
	Other weather effects	8	1	1	8	0.1
	Mining-technological conditions	7	5	3	105	1.9
Market (demand, supply, price)	Increase in costs of services (subcontracted repairs)	8	7	1	56	1.0
	Increase in the costs of complete overhauls	7	7	4	196	3.6
	Increase in energy costs	9	6	1	54	1.0
	Increase in costs of repairs at own cost	7	7	6	294	5.4
	Lower demand for coal	9	7	8	504	9.2
	Increase in material costs	8	7	3	168	3.1
	Lower availability of demanded professions in the labor market□	7	6	5	210	3.8

Source: own processing

Tab.3. RPN for the discontinuous transport technology

Area of risk	Type of risk	Severity	Probability	Detectability	RPN	RPN [%]
Human factor	Attitude to work	9	8	5	360	6.6
	Wasted time	9	4	5	180	3.3
	Human error	9	3	3	81	1.5
	Insufficient staff qualifications	9	6	10	540	9.9
	Strike	10	1	1	10	0.2
Supplier	Unreliability	8	1	1	8	0.1
	Deterioration of supplier financial health	6	2	1	12	0.2
	Supplier field problems	7	3	5	105	1.9
Legislation	Shortening of write-off period	9	5	5	225	4.1
	Higher deductions from salary	5	2	9	90	1.6
	Eco-tax	6	5	1	30	0.5
Technology	Breakdowns of technology fragments	5	5	5	125	2.3
	Construction fault or production defect	5	2	3	30	0.5
	Wasted time due to unavailability time and repairs	9	6	5	270	4.9
Costs	Increase in tire consumption	8	10	3	240	4.4
	Quantitative increase in services (subcontracted repairs)	8	2	4	64	1.2
	Increase in fuel consumption	10	8	1	80	1.5
	Increase in investment costs	8	5	1	40	0.7
	Increase in road maintenance costs	9	9	9	729	13.4
Environment	Floods	10	2	1	20	0.4
	Earthquakes	10	1	1	10	0.2
	Fire	9	2	1	18	0.3
	Temperature	3	2	1	6	0.1
	Rain	9	4	1	36	0.7
	Quality of the load	8	3	4	96	1.8
	Other weather effects	3	2	1	6	0.1
	Mining-technological conditions	8	8	1	64	1.2
Market (demand, supply, price)	Increase in costs of services	7	5	1	35	0.6
	Increase in costs of tires	10	8	9	720	13.2
	Increase in fuel costs	9	10	9	810	14.8
	Lower availability of demanded professions in the labor market	6	7	6	252	4.6
	Lower exchange rate	9	6	1	54	1.0
	Lower demand for coal	10	8	2	160	2.9

Source: own processing

The significance of the different risks is clearly presented in Fig. 3 (continuous transport technology) and Fig. 4 (discontinuous transport technology).

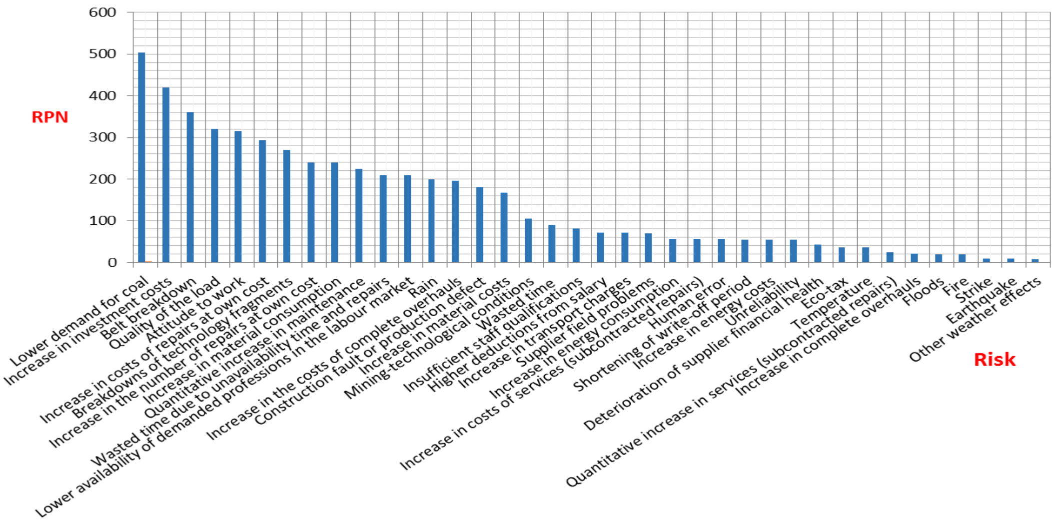

Fig. 3. Risk pattern of continuous transport technology, according to RPN. Source: own processing

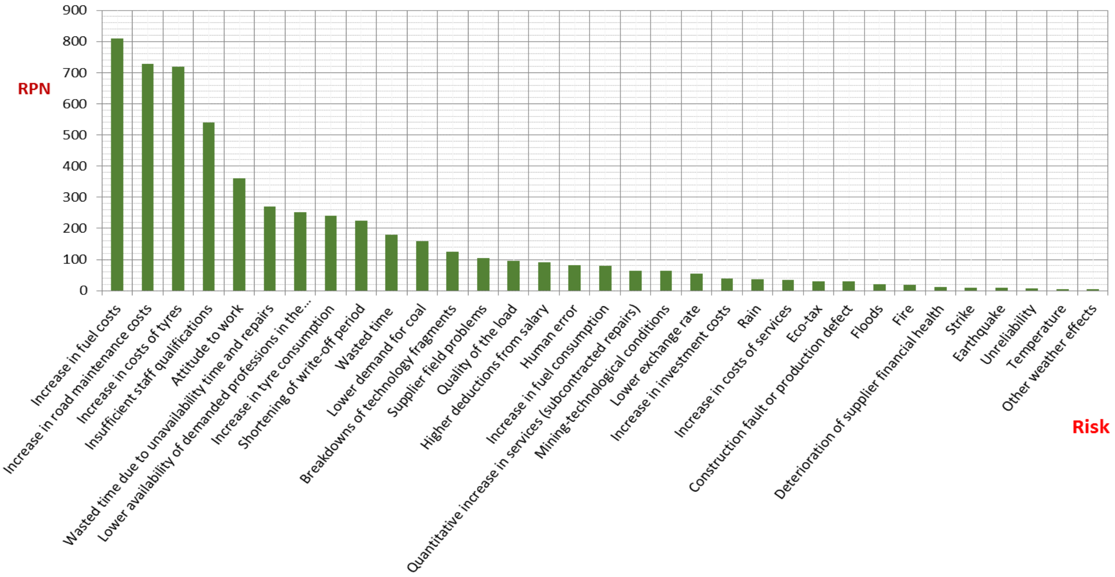

Fig. 4. Risk pattern of discontinuous transport technology, according to RPN. Source: own processing

Discussion

The transport of the stripped overburden during large-scale surface mining of mineral products belongs to the key processes that cardinally influence the overall exploitation of the mineral under interest. Therefore, the choice of transport cannot be underestimated.

Tab. 4 gives the riskiest factors (top five) based on Pareto's analysis in the considered transport alternatives.

It is apparent from Tab. 4 that the top four risks in the discontinuous technology are higher than the most severe risk in continuous technology.

Tab. 4. Comparison of the top five most significant risks.

Continuous technology		Discontinuous technology	
Item	RPN	Item	RPN
Lower demand for coal	504	Increase in costs of fuel	810
Increase in investment costs	420	Increase in road maintenance costs	729
Belt breakdown	360	Increase in costs of tires	720
Load quality	320	Insufficient staff qualifications	540
Attitude to work	315	Attitude to work	360

Source: own processing

Those risks are also specific for this transport technology. They are operational risks and, thus, principally contribute to the overall degree of risk of the technological option under consideration. The occurrence of such risks in practice brings an increase in the costs of operation and, thus, lower cash flow from the investment and a fall in the net present value.

Although input data generated based on brainstorming are subjective, it is useful to distinguish between RPN of continuous and discontinuous transport technology by descriptive statistics (see Table 5).

Tab. 5. Distinguish between RPN of continuous and discontinuous transport technology

Item	Continuous transport	Discontinuous transport
Total number of identified risks	38	33
RPN range	496 (8 – 504)	804 (6 – 810)
The risk median	76.5	80.0
The average value of the risk	142	166
The variance of the value	16,114	48,069
The coefficient of variation	0.8936	1.314

Source: own processing

Figure 5 shows the distribution of risks in the observed transport technologies. It implies that the risk pattern is analogous to both the technologies. The highest number of risks concentrates in the third quartile. The third quartile of the continuous technology includes 23.68 % of risks and 27.27 % of risks in the discontinuous one. The range of RPN in the third quartile of the continuous technology is 144, and in the discontinuous technology, it is 145.

It is also clear from Figure 5 that the fundamental difference in the degree of risk in the observed technologies lies in the RPN interval and the difference in the maximum values of RPN.

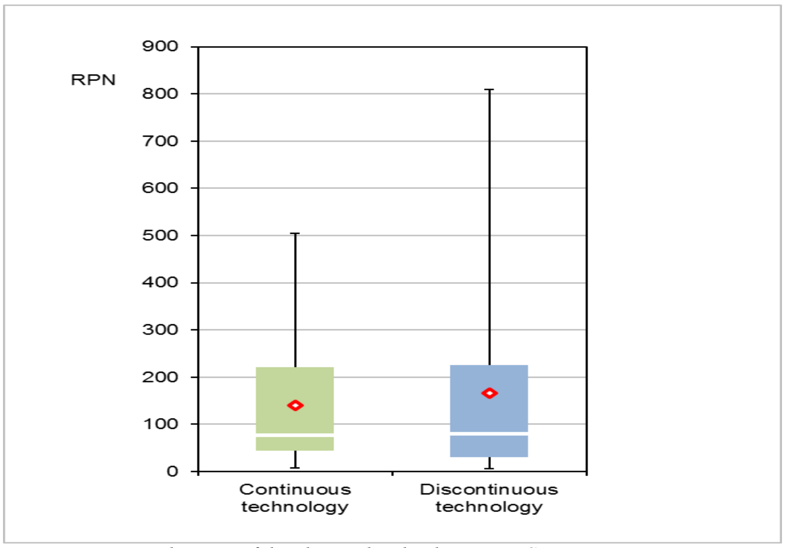

Fig. 5. Box diagram of the observed technology RPN. Source: own processing

The data, as mentioned above, imply that the continuous transport technology shows a 306-point-lower RPN value than the discontinuous one. The discontinuous technology also has a higher risk range, i.e., of 308. This state is caused by four of the most important risks (increase in costs of fuel – RPN 810, increase in road maintenance costs – RPN 729, increase in costs of tires – RPN 720, insufficient staff qualifications – RPN 540).

Figure 5 shows that the risk of both transport technology is almost the same from the large part. However, from a complexity point of view, the data lead to an unambiguous conclusion that the existing continuous technology is less risky than the discontinuous one.

In contrast to the study by Vaněk et al. (2013), using different methods and stating that both the transport technologies are more or less equivalent as for the level of risks involved, the results of the FMEA herein partly disagree. Vaněk et al. (2013) considered the technologies by means of the probability distribution of NPV, while the probability distribution of the evaluation indicator was implemented via scenarios and statistical characteristics (variance, standard deviation, variation coefficient). The risks discussed in Vaněk et al. (2013) were the results of sensitivity analysis. This analysis works only with risks quantified in monetary units. Therefore, it does not cover the whole range of risks.

The methods applied in the research herein enabled us to identify and subsequently analyze a much wider spectrum of risks, and thus offer a more complex view on the issue.

Conclusion

Risk analyses may be carried out using a number of approaches and applying several analytical methods. The choice of the approach or method depends on the purpose of the analysis.

In this case, the purpose of the analysis lay in the assessment of two technological options which may be used to transport the stripped overburden in the giant pit quarries. However, the analysis may serve as the starting point to frame the measures to be implemented within the risks management phase.

Risk identification was carried out by means of a Cause-and-effect analysis, taking into account seven major risk categories (human factor, supplier, legislation, technology, costs, environment, and market), based on the work developed by (Vaněk et al., 2012). The seven major risk categories are based on the analysis of the macro- and micro-economic environment of the business, and addressing a possible decrease in the Net Present Value (NPV) of the considered technologies.

The risk analysis was carried out using the FMEA analysis. The analysis implies that discontinuous technology involves more risks than continuous conveyance. This finding is also the answer to the research question asked by the authors in the Introduction. However, the higher degree of risk in discontinuous technology does not necessarily mean that it cannot be used when deciding on overburden transport technology.

Risk assessment is only a partial assessment. To make a qualified assessment of the technological alternatives, complex approaches must be taken.

By complex approaches, i.e., economic, environmental, etc., the anticipation of risks in the technological options all the way to the discount rate value should be considered. A difference in the discount rate value may thus render a more objective evaluation of the whole economy of the stripped overburden transport in the long run.

The results may be applied by managers of analogous giant pit quarries or in other fields. The knowledge obtained is influenced by the number of localities where brown coal is currently exploited in the Czech Republic. Although the article contributes to filling the gap of knowledge about the risks of technologies used to transport overburden in giant open-pit mines, it is necessary to provide further research. The research should focus on the complex assessment of the economic efficiency of the stripped overburden transport technologies, as well as the possibilities of using other risk analysis methods.

References

Aaker, D.A., Kumar, V. and Day, G.S. (2004). Marketing research. 8th ed. Hoboken: Wiley.

Badri, A., Nadeau, S. and Gdobossou, A. (2013). A new practical approach to risk management for underground mining project in Quebec. Journal of Loss Prevention in the Process Industries [online]. 26, 1145-1158. [Viewed 10 February 2019]. Available from: https://www.sciencedirect.com/science/article/pii/S0950423013001162

Bijańska, J. (2016). Risk management of activating and mining of a longwall in a coal mine. Zeszyty naukowe Politechniki Śląskiej; seria: Organizacja i zarządzanie [online]. 91, 61 – 73. [Viewed 20 January 2019]. Available from: http://yadda.icm.edu.pl/yadda/element/bwmeta1.element.baztech-10f6ebe5-631f-443e-97a1-247570a96cdb

Bozdag, E., Asan, U., Soyer, A. and Serdarasan, S. (2015). Risk prioritization in Failure Mode and Effects Analysis using intervaltype-2 fuzzy sets. Expert Systems with Applications [online]. 42, 4000–4015. [Viewed 20 January 2019]. Available from: https://www.sciencedirect.com/science/article/pii/S0957417415000305

ISO 31000:2018. Risk Management - Principles and guidelines. International Organization for Standardization.

IEC/ISO 31010:2009. Risk management - Risk assessment techniques. International Electrotechnical Commission / International Organization for Standardization.

Cehlár, M. Teplická, K. and Senová, A. (2011). Risk management as instrument for financing projects in mining industry. In: 11th International Multidisciplinary Scientific GeoConference SGEM 2011: Conference Proccedings Volume 1 Surveying Geology & Mining Ecology Management, 20 – 25 June 2011, Albena. Sofia: STEF92 Technology Ltd., 913-920.

Chinbat, U. (2012). Risk Analysis in the Mining Industry. In: M. Savino, ed. Risk Management in Environment, Production and Economy [online]. Rijeka: InTech, pp 103-122. [Viewed 22 February 2019]. Available from: https://www.intechopen.com/books/risk-management-in-environment-production-and-economy/risk-analysis-in-the-mining-industry

Janíček, P. and Marek, J. (2013). Expertní inženýrství v systémovém pojetí. Praha: Grada Publishing.

Juchniewicz, M. (2016). Review and comparative analysis of project risk management concept. Research papers of Wrocław university of economics [online]. 421, 216-228. [Viewed 3 March 2019]. Available from: http://eds.b.ebscohost.com/eds/pdfviewer/pdfviewer?vid=0&sid=f1a2daf6-a1ad-4c7f-baef-a0e09cd7c781%40sessionmgr103

Kozel, R., Vilamová, Š, Baránek, P., Friedrich, V., Hajduová, Z., Behún, M. (2017). Optimizing of the Balanced Scorecard Method for Management of Mining Companies with the Use of Factor Analysis. Acta Montanistica Slovaca [online]. 22 (4), 439-447. [Viewed 28 January 2019]. Available from: https://actamont.tuke.sk/pdf/2017/n4/11kozel.pdf

Krzemień, A., Suárez Sánchez, A., Riesgo Fernández, P., Zimmermann K and González Coto, F. (2016). Towards sustainability in underground coal mine closure contexts: A methodology proposal for environmental risk management. Journal of Cleaner Production [online]. 139., 1044-1056. [Viewed 14 February 2019]. Available from: https://www.sciencedirect.com/science/article/pii/S0959652616313130

Lai, F.W. and Shad, K. (2017). Economic value added analysis for enterprise risk management. Global Business and Management Research: An International Journal [online]. 9(1), 338-347. [Viewed 14 February 2019]. Available from: https://www.researchgate.net/publication/318129580_Economic_Value_Added_Analysis_for_Enterprise_Risk_Management

Lehmann, D.R., Gupta, S. and Steckel, J. H. (1998). Marketing research. Reading MA: Addison-Wesley.

Malhotra, N.K. (2010). Marketing research: an applied orientation, sixth ed. Boston: Pearson.

Meidell, A., Kaarbøe, K. (2017). How the enterprise risk management function influences decision-making in the organization - A field study of a large, global oil and gas company. The British Accounting Review [online]. 49, 39-55. [Viewed 19 February 2019]. Available from: https://www.sciencedirect.com/science/article/pii/S0890838916300439

Mikoláš, M., Vaněk, M., Černý, I., Kučerová, L. and Žoček, F. (2011) Economic modelling under conditions of exploitation of cohesive construction minerals. Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis [online]. 59(7), 249 – 260. [Viewed 10 January 2019]. Available from: https://acta.mendelu.cz/media/pdf/actaun_2011059070249.pdf

Nawrocki, T.L. and Jonek-Kowalska, I. (2016). Assessing operational risk in coal mining enterprises – Internal, industrial and international perspectives. Resources Policy [online]. 48, 50–67. [Viewed 14 February 2019]. Available from: https://www.sciencedirect.com/science/article/pii/S0301420716300137

Nicholas, J.M. and Steyn, H. (2012). Project management for engineering, business and technology, fourth ed. London: Routledge.

Petrovic', D.V., Tanasijevic', M., Milic', V., Lilic', N., Stojadinovic', S. and Svrkota, I. (2014). Risk assessment model of mining equipment failure based on fuzzy logic. Expert Systems with Applications [online]. 41, 8157–8164. [Viewed 10 January 2019]. Available from: https://isiarticles.com/bundles/Article/pre/pdf/46323.pdf

Rahimdel, M.J. and Bagherpour, R. (2016). Haulage system selection for open pit mines using fuzzy MCDM and the view on energy saving. Neural Comput & Applic [online]. 29, 187–199. [Viewed 30 January 2019]. Available from: https://link.springer.com/article/10.1007/s00521-016-2562-7

Sabanov, S., Tohver, T., Vali, E. Nikitin, O. and Pastarus, J.R. (2008). Geological aspects of risk management in oil shale mining. Oil Shale [online]. 25 (2), 145-152. [Viewed 23 January 2019]. Available from: https://www.academia.edu/10570467/Geological_Aspects_of_Risk_Management_in_Oil_Shale_Mining

Seidl, M., Tomášková, Y. and Kolman, P. (2011). Alternative options for deploying extraction equipment at large pit quarries. In: 11th International Multidisciplinary Scientific GeoConference SGEM 2011: Conference Proccedings Volume 1 Surveying Geology & Mining Ecology Management, 20 – 25 June 2011, Albena. Sofia: STEF92 Technology Ltd., 677-684.

Shenkir, W.G. and Walker, P.L. (2006). Enterprise risk management and the strategy risk focused organization. Cost Management [online]. 20, 32-38. [Viewed 27 January 2019]. Available from: https://maaw.info/ArticleSummaries/ArtSumShenkirWalker2006.htm

Singh, R.D. (2004). Principles and practices of modern coal mining. New Delhi: New Age International (P) Limited.

Slivka, V., Grmela, A., Hofrichter, P., Novák, J., Kryl, V., Tichánek, F., Raclavský, K., Dvořáček, J. and Prokop, P. (2002). Těžba a úprava silikátových surovin (The mining and processing of silicate raw materials). Praha: Silikátový svaz.

Soomro, M. A. and Lai, F.W. (2017). Examining a new paradigm of enterprise sustainability risk management. Global Business and Management Research: An International Journal [online]. 9 (1s). [Viewed 3 February 2019]. Available from: https://search.proquest.com/docview/1903433568/fulltextPDF/51868249EDA9440CPQ/1?accountid=26990

Toraño, J., Torno, S., Alvarez, E and Riesgo, P. (2012) Application of outburst risk indices in the underground coal mines by sublevel caving. International Journal of Rock Mechanics and Mining Sciences [online]. 50, 94-101. [Viewed 8 February 2019]. Available from: https://www.sciencedirect.com/science/article/pii/S1365160912000068

Tworek, P., Tchórzewski, S. and Valouch, P. (2018). Risk management in Coal-mines – methodical proposal for Polish and Czech hard coal mining industry. Acta Montanistica Slovaca [online]. 23 (1), 72-80. [Viewed 28 January 2019]. Available from: https://actamont.tuke.sk/pdf/2018/n1/9tworek.pdf

Vaněk, M., Tomášková, Y., Seidl, M. and Kolman, P. (2012) Identification of the threats, and determining their significance, in stripped overburden transport. In: 12th International Multidisciplinary Scientific GeoConference SGEM 2012: Conference Proccedings Volume 1 Geology, Exploration and Mining, 17 – 23 June 2012, Albena. Sofia: STEF92 Technology Ltd., 611-618.

Vaněk, M., Tomášková, Y., Straková, A., Špakovská, K. and Bora, P. (2013). Risk Assessment in Mining-Related Project Management. GeoScience Engineering. 59 (3), 47-53.

Van Thueyet, N., Ogunlana, S. O., and Dey, P. K. (2007). Risk management in oil and gas construction projects in Vietnam. International Journal of Energy Sector Management [online]. 1, 175–94. [Viewed 25 February 2019]. Available from: https://www.researchgate.net/publication/242023693_Risk_management_in_oil_and_gas_construction_projects_in_Vietnam

Acta Montanistica Slovaca
ISSN 1335-1788
actamont.tuke.sk

Preliminary Study of Hydrometallurgical Extraction of Silver from Selected E-Waste

Igor WACHTER[1], Tomáš ŠTEFKO[2], Teagan MACDONALD[3] and Maroš SOLDÁN[4]*

Authors' affiliations and addresses:
[1] Slovak University of Technology in Bratislava, Faculty of Materials Science and Technology in Trnava, Institute of Integrated Safety, Jána Bottu Street, number 2781/25, 917 24 Trnava, Slovakia
e-mail: igor.wachter@stuba.sk

[2] Slovak University of Technology in Bratislava, Faculty of Materials Science and Technology in Trnava, Institute of Integrated Safety, Jána Bottu Street, number 2781/25, 917 24 Trnava, Slovakia
e-mail: tomas.stefko@stuba.sk

[3] The University of Queensland, Australia, School of Civil Engineering, Building 49 Advanced Engineering Building, Staff House Road, St Lucia QLD 4072, Australia
e-mail: 4318707@student.uq.edu.au

[4] Slovak University of Technology in Bratislava, Faculty of Materials Science and Technology in Trnava, Institute of Integrated Safety, Jána Bottu Street, number 2781/25, 917 24 Trnava, Slovakia
e-mail: maros.soldan@stuba.sk

***Correspondence:**
Igor Wachter, Slovak University of Technology in Bratislava, Faculty of Materials Science and Technology in Trnava, Institute of Integrated Safety, Jána Bottu Street, number 2781/25, 917 24 Trnava, Slovakia
tel: +421 906 068
e-mail: igor.wachter@stuba.sk

Acknowledgment:
This work was supported by the Slovak Research and Development Agency under the contract No. APVV-16-0223.
This work was supported by the Mladý výskumník, int. č. 1342 (Young Researcher, number 1342).

How to cite this article:
Wachter, J., Štefko, T., Macdonald, T. and Soldán, M. (2020). Preliminary Study of Hydrometallurgical Extraction of Silver from Selected E-Waste. *Acta Montanistica Slovaca,* Volume 25 (2), 182-191

DOI:
https://doi.org/10.46544/AMS.v25i2.5

Abstract
Electronic relays (ER) are a type of switch which are an essential part of electronic devices used to open or close circuits by using electronic components without any mechanical operation. After decommissioning, it can be considered as an important source of base and precious metals with high economic value. The annual growth rate of about 4-5 % in 2016 is one of the fastest growing waste stream, and only about 20 % of e-waste is recycled. After the use-phase, electronic devices become electronic waste (e-waste); consequently, it is important to consider e-waste as a secondary supply for the recovery of precious metals. In this study, a simple hydrometallurgical recovery method for silver (Ag) extracting from used electronic relays was performed. The silver extractions consisted of six stages: disassembling of relays, removal of base metals, leaching in nitric acid, precipitation, conversion silver oxide and melting. Measurements of extracted precious metals were carried out by scanning electron microscope (SEM) and EDS (Energy Dispersive Spectrum) analysis. The purity rate of the final deposit was 94.9 % on the surface of the sample, and the final silver recovery yielded 0.44 % of the raw material. During the second stage of the experiment, mixed types of electronic relays were used to compare the yields. Electronic relays can be considered as an important source of base and precious metals with high economic value. The final yield of the mixed electronic relays reached up to 0.54 % of Ag with the purity of over 95 %.

Keywords
E-waste, EDS analysis, Hydrometallurgy, Recycling, Silver extraction

Introduction

E-waste has been a major segment of the waste produced in the past decades (Widmer et al., 2005) (Behnamfard et al., 2013). In recent years a huge growth in the use of many information and communication technology products has been observed. In the European Union, approximately 8 million tonnes of e-waste are generated every year with an annual increase of 3 – 5 % (Drechsel, 2006) while approximately 20 – 50 million metric tonnes of e-waste are generated worldwide (Petraniková, 2008). There are also growing concerns about the e-waste generated in developed countries due to the lack of infrastructure for environmentally sound management of e-waste. The reasons for decreasing life span of electrical and electronic devices are as follows (Akcil et al., 2015, Ivanova et al., 2018):

- Incoming of highly advanced and technically skilled devices/equipment at a lower price and more features.
- Rapid growth in the lifestyle of human beings with modern facilities having user-friendly electrical and electronic equipment.
- Stiff competition amongst individuals to use and small enterprises and industries to produce and sell the best products made on advanced technologies.

WEEE (Waste of electric–electronic equipment) contains a variety (>1000) of organic and inorganic substances with its composition depending largely on the type, manufacturer and age of the equipment (Table 1). WEEE can contain up to 61% metals and 21% plastics (Widmer et al., 2005, Biały et al., 2019, Biały et al., 2019a). Polyethylene, polypropylene, polyesters and polycarbonates are typical plastic components (Gramatyka et al., 2007, Sviatskii et al., 2020). Many of the materials such as chlorinated and brominated substances, toxic metals, photoactive and biologically active materials, acids, plastics and plastic additives present in WEEE are highly toxic.

Table 1. Material composition of WEEE (Widmer et al., 2005)

Material	Content [%]
Metals	
Iron and steel	47.9
Copper	7.0
Aluminium	4.7
Non-ferrous	1.0
Total	60.6
Plastics	
Flame retarded plastics	5.3
Non-flame retarded plastics	15.3
Total plastics	20.6
Glass	5.4
Rubber	0.9
Wood and plywood	2.6
Ceramic	2.0
Printed circuit boards	3.1
Other	4.6

E-waste encompasses valuable metals, alongside numerous dangerous materials. An enormous number of dangerous metals (Cd, Hg, Pb, Cr) from e-waste may contribute to increasing the toxicity levels of the ecosystem (Qu et al., 2019). E-waste material in the environment may increase the exposure risk of hazardous materials. Serious pollution of groundwater and human health could be associated with these hazardous materials. One of the important routes to enter toxic chemicals from e-waste to the human body is the soil-crop-food pathway. Toxicity, negative environmental impact, as well as financial reimbursements from e-waste, are necessitated the need for metal recovery from e-waste. The utilization of e-waste could be a potential secondary source of precious and base metals (Otto et al., 2018). Without knowing the hurtful impact, E-waste has been discarded in the open wellsprings of water bodies, the agricultural land, and open landfills by unconscious social people. For the open disposal of the e-waste containing toxic substances in water bodies and landfills pollutes the groundwater (Romaric et al., 2019), as shown in Fig. 1.

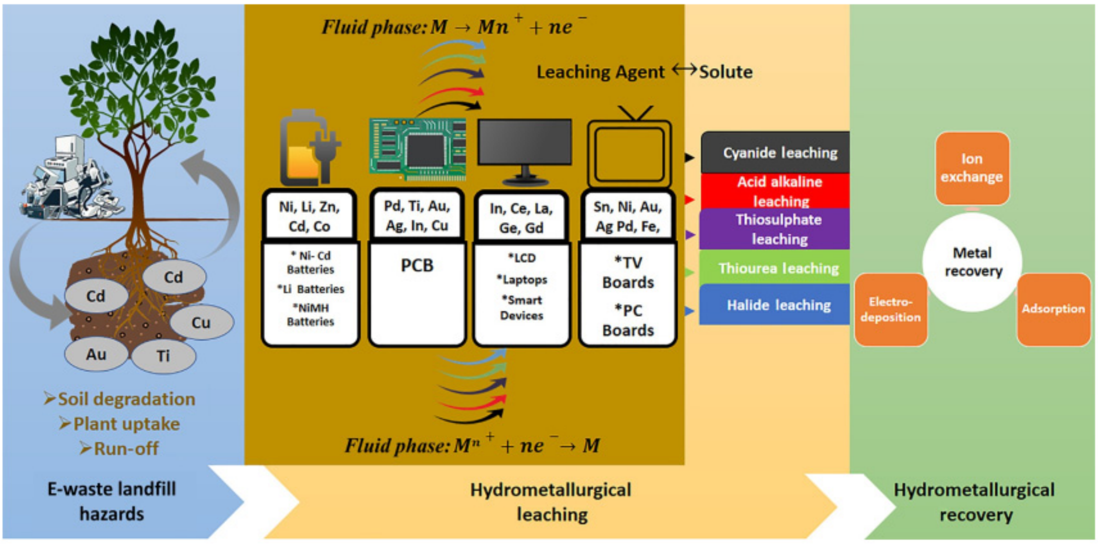

Fig. 1. E-waste from landfills to resource recovery (Ashiq et al., 2019)

E-waste from such equipment contains many toxic elements such as lead, mercury, cadmium, nickel, chromium, etc., which has an adverse impact on our environment. Moreover, e-waste also contains many valuable metals, such as gold, silver, platinum, and palladium (Tripathi et al., 2012). The proper management of discarded electronic devices is an emerging issue for solid waste professionals throughout the world because of the large growth of the waste stream, and the content of toxic metals in them, most notably heavy metals such as lead (Jang and Townsend, 2006). Harmful effects of various metals present in the electronic waste on human health are summarized in Table 2.

Table 2. Hazardous substances and their possible adverse effects (Kaya, 2016)

Substances	Occurrence in WEEE	Possible adverse effects
Lead (Pb)	CRT screens, batteries, PCBs	Vomiting, diarrhea, convulsions, coma or even death, appetite loss, abdominal pain, constipation, fatigue, sleeplessness, irritability, and headache
Mercury (Hg)	Fluorescent lamps, some alkaline batteries, switches	Brain and liver damage
Chromium VI (Cr^6)	Data tapes, floppy-discs	Irritating to eyes, skin and mucous membranes, DNA
Barium (Ba)	Getters in CRT	Brain swelling, muscle weakness, damage to the heart, liver, and spleen
Cadmium (Cd)	NiCd batteries, fluorescent layer (CRT screens), printer inks and toners	Symptoms of poisoning (weakness, fever, headache, chills, sweating and muscle pain), lung cancer and kidney damage
Arsenic (As)	Gallium arsenide in light-emitting diodes (LED)	Skin diseases, decrease nerve conduction velocity, lung cancer
Americium (Am)	Smoke detectors	Radioactive element
Antimony (Sb)	Flame retardants in plastics	Carcinogenic potential
Chlorofluoro carbon (CFC)	Cooling units, insulation foams	The deleterious effect on the ozone layer, increased incidence of skin cancer and/or genetic damages
Polychlorinated biphenyls (PCB)	Condensers, transformers	Cancer, effects on the immune systems, reproductive system, nervous system, endocrine system, and other health effects
PBDEs, PBBs	Flame retardants in plastics	Hormonal effects, under thermal treatment possible formation of dioxins and furans

Currently, e-waste recycling focuses mainly on mechanical approaches, pyro-metallurgy, bio-metallurgy, and hydro-metallurgy (Hsu et al., 2019; Liu et al., 2019). The reason for preference of hydro-metallurgy over pyro-metallurgy is because of low or no gas emission compared to pyro process which releases toxic gases (dioxins/furans) and volatile metals, dust, Cl_2, Br_2, SO_2 and CO_2 together with others Pb, Hg, Cr^{6+}, Cd, flame retardants. No dust or low dust generation, low energy consumption, high recovery rate, no slag generation except few plastics, and easy working conditions (Ni et al., 2013; Tue et al., 2013; Zhang et al., 2012). According to these studies (Andrews et al., 2000; Cui and Zhang, 2008), hydro-metallurgy could be preferred over pyro-metallurgy for the recovery of precious metals such as gold, silver, and platinum.

Table 3. Development of global silver demand by sectors (2011 - 2019) (The Silver Institute and The Materials Focus, 2020)

Metric t	2011	2012	2013	2014	2015	2016	2017	2018	2019
Industrial	15804	14012	14332	13984	14189	15250	16087	15909	15891
…of which photovoltaics	2127	1711	1571	1505	1683	2914	3166	2877	3070
Photography	1916	1633	1425	1356	1281	1176	1092	1064	1048
Jewellery	5045	4952	5819	6018	6302	5885	6106	6317	6261
Silverware	1291	1247	1421	1630	1760	1627	1795	2034	1860
Net physical investment	8460	7490	9334	8790	9654	6653	4858	5154	5788
TOTAL	32515	30590	33246	31775	33187	30963	30005	30739	30848

Table 4 shows the development in global silver supply by the sources During the last decade (2011 – 2019). Global recycling edged higher last year (2019), up 1.3 % to 5,284t. Volumes from industrial end-uses, the biggest source of scrap, rose 2 % to the highest level this decade (The Silver Institute, 2020).

Table 4. Development of global silver supply by sources (2011 - 2019) (The Silver Institute and The Materials Focus, 2020)

Metric t	2011	2012	2013	2014	2015	2016	2017	2018	2019
Mine production	23642	24656	26136	27293	27772	27753	26855	26369	26018
Recycling	7244	6718	5994	5440	5179	5113	5216	5216	5284
Net hedging supply	370	-	-	333	68	-	-	-	488
TOTAL	31405	31489	32183	33100	33050	32901	32105	31626	31822

Spent electronic equipment consists of several components in the form of metals and multicomponent elements. The base metals include iron, aluminum, nickel, zinc, selenium, indium, and gallium. The noble metals can be divided into copper, palladium, or gold, silver. Hazardous substances that can be found in spent electronic equipment include mercury, beryllium, lead, arsenic, cadmium, antimony and plastics, glass, and ceramics. Depending on many factors, such as the age of the device, manufacturer, or the type of equipment, the content of the individual electronic component in the waste is mixed (Fornalczyk et al., 2013). Spent electronic equipment consists of several components in the form of metals and multicomponent elements. The base metals include iron, aluminum, nickel, zinc, selenium, indium, and gallium. The noble metals can be divided into copper, palladium, or gold, silver. Hazardous substances that can be found in spent electronic equipment include mercury, beryllium, lead, arsenic, cadmium, antimony, and plastics (Fornalczyk et al., 2013). Table 2 shows the selected material composition of electronic devices. A decisive impact on the value of electronic scrap has the content of precious metals, although iron and plastic are dominant components, and a seemingly small content of precious metals in different electronic devices (<0.5 %).

Table 5. Composition of metals from different e-waste samples (Cui and Zhang, 2008)

E-waste	Weight [%]					Weight [ppm]		
	Fe	Cu	Al	Pb	Ni	Ag	Au	Pd
TV board scrap	28	10	10	1.0	0.3	280	20	10
PC board scrap	7	20	5	1.5	1	1000	250	110
Mobile phone scrap	5	13	1	0.3	0.1	1380	350	210
Portable audio scrap	23	21	1	0.14	0.03	150	10	4
DVD player scrap	62	5	2	0.3	0.05	115	15	4
Calculator scrap	4	3	5	0.1	0.5	260	50	5
PC mainboard scrap	4.5	14.3	2.8	2.5	1.1	639	566	124
Printed circuit boards	12	10	7	1.2	0.85	280	110	-
Printed circuit boards	5.3	26.8	1.9	-	0.47	3300	80	-

Although iron and plastic are dominant components, in terms of weight, a seemingly small content of precious metals in different electronic devices (<0.5 %), constitutes about the electronic scrap value (Table 4) (Fornalczyk and Saternus, 2013). Analysing only computer equipment and mobile phones, this share is 3 % of the world's production for Ag, 4 % for Au, and 16 % for Pd. In 2019 the global silver demand was 30848 metric tonnes (Table 3). The highest demand is in long-termed achieved in the industry, which also includes the electronics and IT sector.

More than ten times higher purity of precious metals in waste printed circuit boards compared to the rich ore content attract the attention to extract noble metal from e-waste. Hence, the extraction of noble metals (Au, Pt, Pd, Ta, Te, Ge, Se) from e-waste should be given major priorities. However, the realization of recycling should be the basis of maximum recovery and minimum negative impact on the environment (Islam et al., 2020). This paper discusses the extraction of silver from used electronic relays via a simple hydrometallurgical process. The objective was to determine the relative amount of Ag recoverable from this type of waste.

Material and Methods

Chemical leaching (Fig. 2) involves leaching either by using acid or ligand supported complexation. Chemical leaching of metals from E-waste can also be done by utilizing various inorganic-acids.

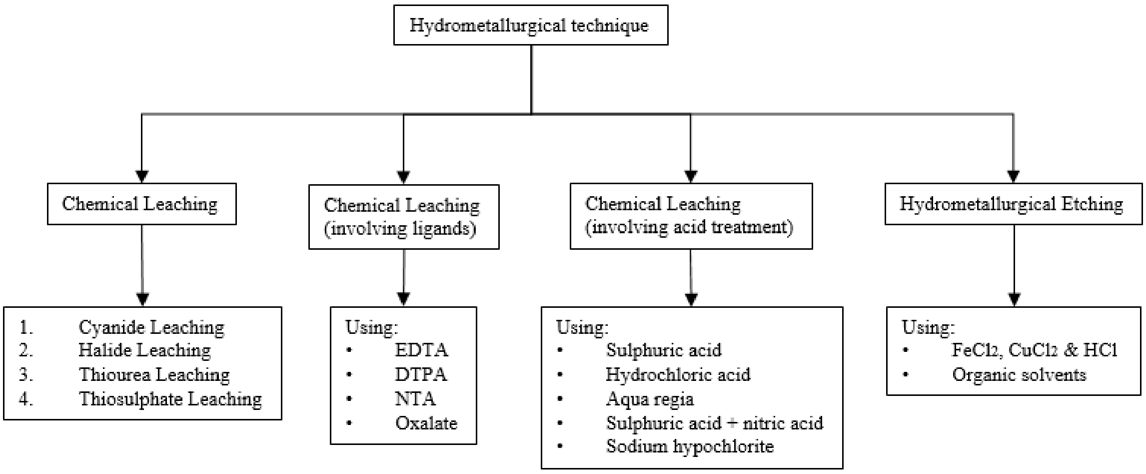

Fig. 2. Types of hydrometallurgical techniques

In this paper, two sets of electrical relays were used to extract silver by hydrometallurgical acidic techniques. The difference in the two sets was in the used precipitation of the silver from the pregnant leach solution.

The first set consisted of seven commercially used electrical relays (Allen-Bradley 700-HA33Z2-3) containing nine silver contacts made of silver, copper, nickel, and aluminum. The weight of the whole relay was 86.74 grams. The experimental procedure consisted of six main steps. All of the used chemicals were purchased from CentralChem s.r.o. The used chemicals were of analytical grade. After collecting the raw material, the relays were manually disassembled, and the silver-containing contacts were collected in a beaker. To remove all of the base and redundant metals except silver, the contacts were treated by concentrated hydrochloride acid + 35 % hydrogen peroxide (100 ml + 5 ml). The beaker was placed on a heating plate to accelerate the reaction of metals removal. Chemicals were added and heated until no visible signs of reaction were observed, and only silvery metal was present. The contacts were then washed three times with distilled water, and in the next step, concentrated nitric acid with distilled water (50 ml + 50 ml) were added to the beaker with the contacts. After two hours, the contacts were completely dissolved in the solution in the form of silver(I) nitrate ($AgNO_3$). To precipitate the silver(I) nitrate from the solution, a concentrated hydrochloric acid was used to produce AgCl (silver(I) chloride). After three washings with boiling distilled water, sodium hydroxide (NaOH) was added to convert AgCl to silver(II) oxide (Ag_2O). As a final step, the silver oxide dust was placed into a melting dish and melted at a temperature of 980 °C to form a single bead of silver using a muffle furnace. Analysis of the metal was performed using a scanning electron microscope (SEM) and energy dispersive spectrum (EDS) analysis. The main individual steps and corresponding reactions of the procedure are shown in Table 6.

Table 6. Main steps of the silver extraction from electrical relays (1st set)

NR.	OPERATION	MAIN REACTION
1.	Disassembly of relays	–
2.	Removal of redundant metals by hydrochloride acid + hydrogen peroxide	$H_2O_2 + Cu + 2\,HCl \rightarrow CuCl_2 + 2\,H_2O$ $H_2O_2 + Ni + 2HCl \rightarrow NiCl_2 + 2H_2O$ $3\,H_2O_2 + 2\,Al + 6\,HCl \rightarrow 2\,AlCl_3 + 6\,H_2O$
3.	Dissolving in nitric acid	$Ag + 2HNO_3 \rightarrow AgNO_3 + NO_2 + H_2O$
4.	Precipitation with hydrochloric acid	$AgNO_3 + HCl \rightarrow AgCl + HNO_3$
5.	Conversion with sodium hydroxide	$2AgCl + 2NaOH \rightarrow Ag_2O + H_2O + 2NaCl$
6.	Melting	$2Ag_2O \xrightarrow{t°C} 4Ag + O_2$

In the second stage of the research, ten electrical relays, each containing nine contacts made of silver, copper, nickel, and aluminum were used. The weight of the whole relay was 86.74 grams. The experimental procedure consisted of four main steps. All chemicals (analytical grade) were purchased from CentralChem s.r.o. Contacts were mechanically trimmed from relays, put in a beaker, and treated by a mixture of concentrated HCl and 35 % H_2O_2 (100 ml + 5 ml) to remove all the base metals. The solution was heated by a heating plate to increase the reaction speed. After the removal of all metals, the residual silver coatings were washed by distilled water. In the next step, concentrated HNO_3 with distilled water (ratio 1:1) was used to dissolve the silver. After two hours, all silver was completely dissolved, forming silver(I) nitrate ($AgNO_3$). In this case, pure metallic silver was obtained from the solution by cementing on a solid copper cylinder. Obtained silver was washed by hot distilled water three times and subsequently melted into one bead. The main individual steps and corresponding reactions of the procedure are shown in Table 7.

Table 7. Main steps and corresponding reactions used to extract silver from electrical relays (2nd set)

Nr.	Operation	Main reaction
1.	Mechanical separation of contacts	–
2.	Removal of redundant metals by HCl + 35 % H_2O_2	$H_2O_2 + Cu + 2\ HCl \rightarrow CuCl_2 + 2\ H_2O$ $H_2O_2 + Ni + 2HCl \rightarrow NiCl_2 + 2H_2O$ $3\ H_2O_2 + 2\ Al + 6\ HCl \rightarrow 2\ AlCl_3 + 6\ H_2O$
3.	Dissolving in nitric acid	$Ag + 2HNO_3 \rightarrow AgNO_3 + NO_2 + H_2O$
4.	Cementing on the copper cylinder	$AgNO_3 + Cu0 \rightarrow Ag0 + CuNO_3$

The summarised flowchart of the processes is shown in the Figure 4.

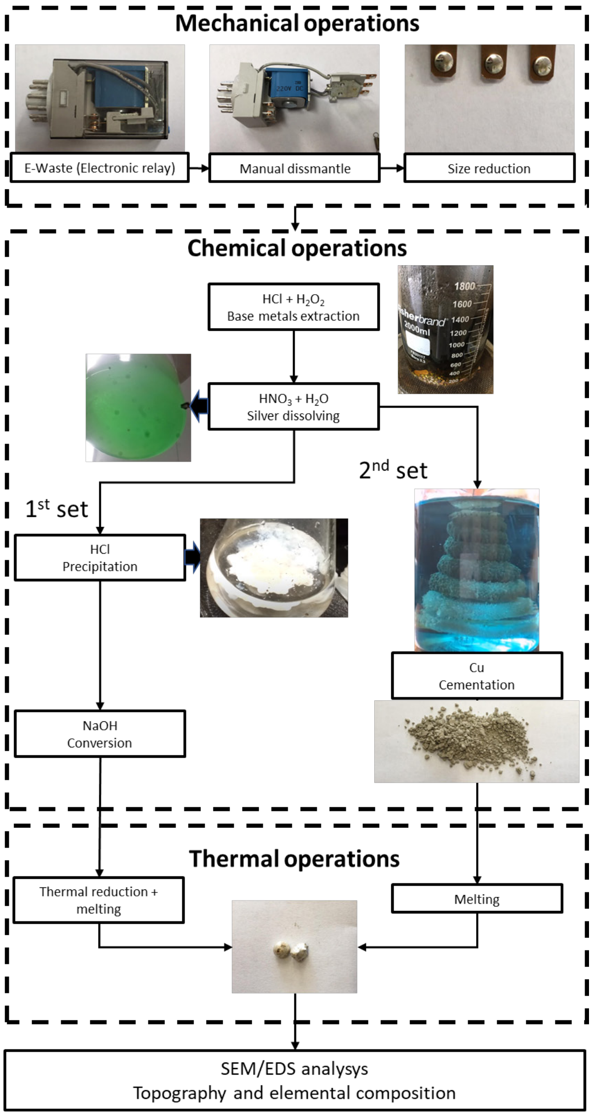

Fig. 3. Flowchart of the experiments

Results and Discussion

Researchers have indicated that effective recovery of precious metals from e-waste is feasible (Ficeriová et al., 2011, 2005; Ficeriová and Baláž, 2010). To illustrate, printed circuit board (PCB) of a PC can contain up to 20 % Cu and 250 g/ton Au, which are significantly high, i.e. 25–250-fold for gold and 20–40-fold for copper when compared with gold ores (1 – 10 g/ton Au) and copper ores (0.5–1 % Cu), respectively. Recycling turns WEEE into a secondary resource allowing the recovery and reuse of metals and non-metals contained and mitigating the environmental impact of WEEE (Cui and Zhang, 2008; Havlík et al., 2010; Yazici et al., 2010).

The recovery yield of silver obtained from the first set of electrical relays reached 0.44 %. In each of seven electrical relays, there are nine silver-containing contacts made of silver, copper, nickel, and aluminum. The total weight of one whole relay was 86.744 g (seven relays weight 607.21 g). After mechanical removal of the nine silver-bearing contacts, its weight was 2.892 g (63 pieces of contacts weight 182.196 g). After acid – peroxide bath, the contacts weighed 3.981 g. In total, 2.667 g of silver was extracted from the material by this process. Electrical relay mainly consists of circuitry, plastic, and base metals, which makes it easily recyclable e-waste. This kind of e-waste becomes a valuable material for further processing of basic mechanical separation. Therefore, an estimated concentration of silver in this type of relay is 4400 g/t.

The recovery yield of silver obtained from the second set of electrical relays reached 0.54 %. The total weight of ten relays was 921.35 g. The total weight of separated contacts (90 pieces) was approximately 25.4 g. In total, 4.79 g of silver was extracted from the material by this process, which is 5200 g/t (from the total weight).

Cui et al. (2008) determined the amount of Ag in different e-waste samples to be comparable or lower than in keyboards. Li et al. (2019), reported that CPU sockets also contain silver (431 g/t) with a lower yield. For the mining sector, the silver reserves are divided into known reserves and hidden reserves and stratified into four levels of ore quality: 1. Rich silver is labeled as extra high quality (10,000 – 6000 g/t), 2. High grade (1100 – 800 g/t), 3. Low grade (100 – 80 g/t) and 4. Ultra-low grade (below 10 – 8 g/t), which means this type of e-waste could be considered to be an extra high-quality source of silver (Sverdrup et al., 2014). As shown in Table 8, copper and precious metals contribute invariably and extensively to the economic potential of all WEEE.

Table 8. Composition of metals from different e-waste samples

Type of e-waste	Content (% or g/ton) and contribution to economic potential (%) (in brackets)								
	Fe (%)	Cu (%)	Al (%)	Pb (%)	Sn (%)	Ni (%)	Au (g/ton)	Ag (g/ton)	Pd (g/ton)
Price ($/ton)[a]	525	9211	2298	242	25.900	24.180	$4.9x10^7$	$1.06x10^6$	$2.68x10^7$
PC boards	7 (0)	20 (10)	5 (1)	1.5 (0)	2,9 (4)	1 (1)	250 (64)	1000 (5)	110 (15)
PC boards	2.1 (1)	18.5 (10)	1.3 (0)	2.7 (0)	4.9 (7)	0.4 (1)	86 (26)	694 (4)	309 (51)
TV boards[b]	0.04 (0)	9.2 (61)	0.75 (1)	0.003 (0)	0.72 (13)	0.01 (0)	3 (11)	86 (7)	3.7 (7)
TV boards	28 (5)	10 (28)	10 (7)	1 (1)	1.4 (10)	0.3 (2)	20 (30)	280 (9)	10 (8)
Mobile phones (1999)	5 (0)	13 (5)	1 (0)	0.3 (0)	0.5 (0)	0.1 (0)	350 (67)	1380 (6)	210 (22)
Typical ore grades	25	0.5	30	5	0.5	0.5	1	-	-

[a] *Metal prices are from London Metal Office (LME) official prices for cash seller and settlement (December 14th, 2010)*
[b] *Manufacturer waste without components*

Analysis of the metal beads was performed using a scanning electron microscope (SEM) and energy dispersive spectrum (EDS) analysis (Figure 5). EDS (Energy Dispersive Spectrum) analysis was used to determine the chemical composition and concentration of individual elements. It was performed by the energy-dispersive X-ray spectroscopy analyzer, which was a part of the scanning electron microscope of JEOL JSM 7600 Ftype. The topography of silver beads was observed at an accelerating voltage of 20 kV, current 2 nA, and a working distance of approximately 15 mm. The chemical composition of silver bead was investigated by software INCA.

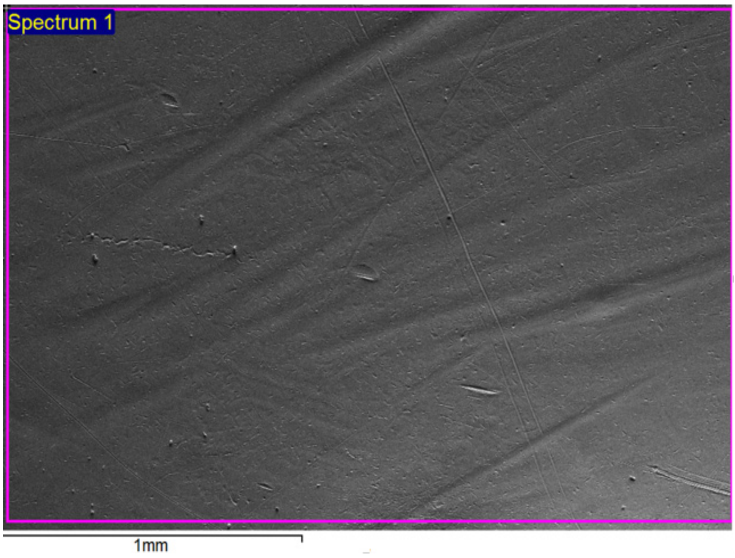

Fig. 4. SEM image of the resulting silver sample (1st set)

Table 9 shows the results of EDS analysis. Elemental analysis showed that the purity of obtained silver beads was 88.45 % (1st set) and 95.65 %) (2nd set). Because only the surface of the sample is analyzed by this method, it is possible that the sample has a higher purity under the top layer. The presence of oxygen may be caused by the formation of silver oxide, which is produced under normal conditions when silver reacts with the oxygen present in the air. The presence of carbon may be explained by the impurities on the melting cupel from the previous melting. The magnesium also comes from the cupel, which is made of pure and compressed magnesium oxide (MgO).

Table 9. EDS analysis of the silver bead

	Element content (%)					
	C	O	Mg	Si	Ag	Total
Bead 1	4.53	6.43	0.32	0.27	88.45	100.00
Bead 2	3.78	0.34	0.23	-	95.65	100.00

The waste solution containing dissolved metals from the process was cemented according to the electronegativity series, and as a result, almost zero waste was produced during the whole extraction process.

Conclusion

At present mechanical and hydrometallurgical separation technologies has a relatively high recovery rate of precious metals, although these methods have not been adopted by countries with low GDP because of its complexity and high economic cost. Hence, recycling this kind of e-waste can both decrease the pressure on natural resources and reduce environmental contamination. This paper presented a simple silver extracting method from electrical relays and determined the quantity of recoverable precious metal. EDS analyses showed the purity of the obtained metal. The advantages of the presented hydrometallurgical method were its cost-effectiveness, environmental friendliness, and time-efficiency. We demonstrated that discarded electrical relays contain an appreciable quantity of silver with high economic potential. Using this method, it is possible to extract 4400 g/t –5200 g/t of silver from commercially used electrical relays (Allen-Bradley 700-HA33Z2-3) with 88.45 % purity (1st set) and 95.65 % purity (2nd set). The procedure should be further studied for different aspects and for different e-wastes to help with negative impacts on the environment.

References

Akcil, A., Erust, C., Gahan, C.S., Ozgun, M., Sahin, M., Tuncuk, A., 2015. Precious metal recovery from waste printed circuit boards using cyanide and non-cyanide lixiviants – A review. Waste Manag. 45, 258–271. https://doi.org/https://doi.org/10.1016/j.wasman.2015.01.017

Andrews, D., Raychaudhuri, A., Frías, C., 2000. Environmentally sound technologies for recycling secondary lead. J. Power Sources 88, 124–129. https://doi.org/https://doi.org/10.1016/S0378-7753(99)00520-0

Ashiq, A., Kulkarni, J., Vithanage, M., 2019. Hydrometallurgical Recovery of Metals From E-waste. pp. 225–246. https://doi.org/10.1016/B978-0-12-816190-6.00010-8
Bialy W, Sovin V.E, Zatsepina V.I, Zatsepin E.P, Shachnev O.Ya.: 2019. „Ensuring efficient operation of electromechanical systems with frequency regulation with periodic voltage sags”. E3S Web of Conferences, Volume 124, 2019. International Scientific and Technical Conference Smart Energy Systems 2019 (SES-2019) Article Number 05059, Number of page(s) 5.
Bialy W, Stepanova E.M., Zatsepina V.I, Zatsepin E.P, Skomorokhov P.I.: 2019a. „Improving the relability of operation of electromechanical devices by means of ionistor-battery backup”. E3S Web of Conferences, Volume 124, 2019. International Scientific and Technical Conference Smart Energy Systems 2019 (SES-2019) Article Number 05064, Number of page(s) 5.
Behnamfard, A., Salarirad, M.M., Veglio, F., 2013. Process development for recovery of copper and precious metals from waste printed circuit boards with emphasize on palladium and gold leaching and precipitation. Waste Manag. 33, 2354–2363. https://doi.org/https://doi.org/10.1016/j.wasman.2013.07.017
Cui, J., Zhang, L., 2008. Metallurgical recovery of metals from electronic waste: A review. J. Hazard. Mater. 158, 228–256. https://doi.org/https://doi.org/10.1016/j.jhazmat.2008.02.001
Drechsel, C., 2006. Mechanical processes for recycling waste electric and electronic equipment with the rotorshredder and rotor impact mill 47, 4–14.
Ficeriová, J., Baláž, P., 2010. Leaching of gold from a mechanically and mechanochemically activated waste. Acta Montan. Slovaca 15.
Ficeriová, J., Baláž, P., Gock, E., 2011. Leaching of gold, silver and accompanying metals from circuit boards (PCBs) waste. Acta Montan. Slovaca 16.
Ficeriová, J., Baláž, P., Gock, E., 2005. A processing method of the goldsmith’s and electronic Au-Ag-containing wastes. Acta Montan. Slovaca 10.
Fornalczyk, A., Saternus, M., 2013. Platinum recovery from used auto catalytic converters in electrorefining process. Metal. -Sisak then Zagreb. 52, 219–222.
Fornalczyk, A., Willner, J., Francuz, K., Cebulski, J., 2013. E-waste as a source of valuable metals. Arch. Mater. Sci. Eng. 63, 87–92.
Gramatyka, P., Nowosielski, R., Sakiewicz, P., 2007. Recycling of waste electrical and electronic equipment. J. Achiev. Mater. Manuf. Eng. 20.
Havlík, T., Orac, D., Petrániková, M., Miskufova, A., Kukurugya, F., Takáčová, Z., 2010. Leaching of copper and tin from used printed circuit boards after thermal treatment. J. Hazard. Mater. 183, 866–873. https://doi.org/https://doi.org/10.1016/j.jhazmat.2010.07.107
Hsu, E., Barmak, K., West, A., Park, A.-H., 2019. Advancements in the Treatment and Processing of Electronic Waste with Sustainability: A Review of Metal Extraction and Recovery Technologies. Green Chem. 21. https://doi.org/10.1039/C8GC03688H
Islam, A., Ahmed, T., Awual, M.R., Rahman, A., Sultana, M., Aziz, A.A., Monir, M.U., Teo, S.H., Hasan, M., 2020. Advances in sustainable approaches to recover metals from e-waste-A review. J. Clean. Prod. 244, 118815. https://doi.org/https://doi.org/10.1016/j.jclepro.2019.118815
Ivanova T.N., Korshunov A.I., Soldán M., Novokshonov D.N., Bialy W., Baranov M.N.: The Efficiency of Use of Heating Cables in Wells of Complicated Stock. Acta Montanistica Slovaca. ISSN 1335-1788. Volume 23 (2018), number 2, pp. 153-162.
Jang, Y.-C., Townsend, T., 2006. LEACHING OF LEAD FROM DISCARDED NOTEBOOK COMPUTERS USING THE SCALE-UP TCLP AND OTHER STANDARD LEACHING TESTS. Environ. Eng. Res. 11. https://doi.org/10.4491/eer.2006.11.1.014
Kaya, M., 2016. Recovery of metals and non-metals from electronic waste by physical and chemical recycling processes. Waste Manag. 57, 64–90. https://doi.org/https://doi.org/10.1016/j.wasman.2016.08.004
Li, F., Chen, M., Shu, J., Shirvani, M., Li, Y., Sun, Z., Sun, S., Xu, Z., Fu, K., Chen, S., 2019. Copper and gold recovery from CPU sockets by one-step slurry electrolysis. J. Clean. Prod. 213, 673–679. https://doi.org/https://doi.org/10.1016/j.jclepro.2018.12.161
Liu, W., Ford, P., Uvegi, H., Margarido, F., Santos, E., Ferrão, P., Olivetti, E., 2019. Economics of materials in mobile phone preprocessing, focus on non-printed circuit board materials. Waste Manag. 87, 78–85. https://doi.org/https://doi.org/10.1016/j.wasman.2019.01.044
Ni, K., Wang, T., Gosens, J., Xu, L., Li, Q., Wang, L., Liu, S., 2013. A review of human exposure to polybrominated diphenyl ethers (PBDEs) in China. Int. J. Hyg. Environ. Health 216. https://doi.org/10.1016/j.ijheh.2013.02.002
Otto, S., Kibbe, A., Henn, L., Hentschke, L., Kaiser, F.G., 2018. The economy of E-waste collection at the individual level: A practice oriented approach of categorizing determinants of E-waste collection into behavioral costs and motivation. J. Clean. Prod. 204, 33–40. https://doi.org/https://doi.org/10.1016/j.jclepro.2018.08.293
Petraniková, M., 2008. Treatment of End of Life Computers. Technical University of Košice.

Qu, Y., Wang, W., Liu, Y., Zhu, Q., 2019. Understanding residents' preferences for e-waste collection in China - A case study of waste mobile phones. J. Clean. Prod. 228. https://doi.org/10.1016/j.jclepro.2019.04.216

Romaric, O.E., Ogundiran, M., Sangodoyin, A., Babalola, B., 2019. Ecological Risk and Human Health Implications of Heavy Metals Contamination of Surface Soil in E-Waste Recycling Sites in Douala, Cameroun. J. Heal. Pollut. 9, 190310. https://doi.org/10.5696/2156-9614-9.21.190310

Sverdrup, H., Koca, D., Ragnarsdottir, K.V., 2014. Investigating the sustainability of the global silver supply, reserves, stocks in society and market price using different approaches. Resour. Conserv. Recycl. 83, 121–140. https://doi.org/https://doi.org/10.1016/j.resconrec.2013.12.008

Sviatskii V., Bialy W., Sentyakov K., Repko A.: "Estimation of Quality Indicators of Ecological Thermoplastic Fiber Materials" Acta Montanistica Slovaca. ISSN 1335-1788. Volume 25 (2019), number 1, pp. 14-23.

The Silver Institute, The Materials Focus, 2020. World Silver Survey 2020.

Tripathi, A., Kumar, M., Sau, D., Agrawal, A., Chakravarty, S., Mankhand, T., 2012. Leaching of Gold from the Waste Mobile Phone Printed Circuit Boards (PCBs) with Ammonium Thiosulphate. Int. J. Metall. Eng. 1, 17–21. https://doi.org/10.5923/j.ijmee.20120102.02

Tue, N., Takahashi, S., Annamalai, S., Sakai, S., Tajima, Y., 2013. Environmental contamination and human exposure to dioxin-related compounds in e-waste recycling sites of developing countries. Environ. Sci. Process. Impacts 15, 1326–1331. https://doi.org/10.1039/c3em00086a

Widmer, R., Oswald-Krapf, H., Sinha-Khetriwal, D., Schnellmann, M., Böni, H., 2005. Global perspectives on e-waste. Environ. Impact Assess. Rev. 25, 436–458. https://doi.org/10.1016/j.eiar.2005.04.001

Yazici, E., Deveci, H., Alp, I., Akcil, A., Yazici, R., 2010. Characterisation of Computer Printed Circuit Boards for Hazardous Properties and Beneficiation Studies, XXV International Mineral Processing Congress 2010, IMPC 2010.

Zhang, Y., Liu, S., Xie, H., Zeng, X., Li, J., 2012. Current Status on Leaching Precious Metals from Waste Printed Circuit Boards. Procedia Environ. Sci. 16, 560–568. https://doi.org/https://doi.org/10.1016/j.proenv.2012.10.077

Acta Montanistica Slovaca
ISSN 1335-1788
actamont.tuke.sk

Load-Bearing Capacity Modelling and Testing of Single-Stranded Wire Rope

Michal LESŇÁK[1,2], *Pavel MARŠÁLEK*[3]**, *Petr HORYL*[3] and *Jaromír PIŠTORA*[1,2]

Authors' affiliations and addresses:
[1] Nanotechnology Centre, VŠB – Technical University of Ostrava, 17. listopadu 2172/15, 708 00 Ostrava, Czech Republic

[2] Modelling for Nanotechnologies Lab, VŠB – Technical University of Ostrava, 17. listopadu 2172/15, 708 00 Ostrava, Czech Republic
e-mail: michal.lesnak@vsb.cz
e-mail: jaromir.pistora@vsb.cz

[3] Department of Applied Mechanics, Faculty of Mechanical Engineering, VŠB – Technical University of Ostrava, 17. listopadu 2172/15, 708 00 Ostrava, Czech Republic
e-mail: pavel.marsalek@vsb.cz
e-mail: petr.horyl@vsb.cz

***Correspondence:**
Pavel Maršálek, Department of Applied Mechanics, Faculty of Mechanical Engineering, VŠB – Technical University of Ostrava, 17. listopadu 2172/15, 708 00 Ostrava, Czech Republic
tel: +420 597 324 351
e-mail: pavel.marsalek@vsb.cz

Funding information:
The Technology Agency of the Czech Republic TN01000024 National Competence, Center-Cybernetics and Artificial Intelligence Structural Funds of the European Union within the project Innovative and additive manufacturing technology – new technological solutions for 3D printing of metals and composite materials, CZ.02.1.01/0.0/0.0/17_049/0008407 European Regional Development Fund in the IT4Innovations national supercomputing center - path to exascale project, project number EF16_013/0001791 within the Operational Programme Research, Development and Education.

Acknowledgment:
This work was supported by The Ministry of Education, Youth and Sports of the Czech Republic from the Specific Research Project SP2020/23

How to cite this article:
Lesňák, M., Maršálek, P., Horyl, P. and Pištora, J. (2020). Load-Bearing Capacity Modelling and Testing of Single-Stranded Wire Rope. *Acta Montanistica Slovaca,* Volume 25 (2), 192-200

DOI:
https://doi.org/10.46544/AMS.v25i2.6

Abstract
The load-bearing capacity of the wire rope is an extremely important factor for the precise rope design. This value mainly depends on the rope cross-section and the strength class. The nominal value of the load-bearing capacity can be found in the standards. However, this value is on the side of safety. For new rope constructions or improvements in production technology, it is suitable to determine the real value of load-bearing capacity. In this paper, we present two approaches, how to determine the real value of the load-bearing capacity related to the single-stranded wire rope. The first approach is based on a simplified experiment using a tensile test. This phase of the research is divided into two separate experiments. The first experiment is focused on tests of individual wires forming the rope. The second experiment is designed to test the entire wire rope.
Finally, the second approach uses the finite element method to create a computer model is presented. Since the rope tensile test is a strongly non-linear task, the solver LS-DYNA with an explicit time integration technique is used for simulation of the experiment. The results from both presented approaches are compared
With the nominal value. Designed experiment for testing the whole rope and computer modeling method is created based on the practical requirements from industry, and the obtained results will be reflected in the design of new types of wire ropes.

Keywords
wire, rope, single-stranded, load-bearing capacity, tensile test, fem, ls-dyna, explicit

Introduction

The wire ropes are important technical elements in transport, construction, raw material mining, etc. (Straka et al., 2018). The ropes are made of patented steel wire of higher strength, which guarantees a high load-bearing capacity of the rope, relatively small weight, and sufficient flexibility. In particular, their high strength, which allows the construction of small diameter wires and low weight, meets required properties (especially stiffness and load-bearing capacity). During operation, many negative phenomena affect the ropes, which decrease their service life (Costello, 1997; and Ivanco, Kmet and Fedorko, 2016). A detailed analysis of the technical risk of steel wire ropes showed two main factors that most affect its reliability.

The first main factor is mechanical rope wear and corrosion. Especially the corrosion of internal wires (Molnar et al., 2017), which cannot be detected during visual inspections, is particularly dangerous. Damaged or corroded ropes, whose load-bearing capacity is under the prescribed limits, must be discarded immediately. In our former papers related to steel ropes, we focused on the inspection of magnetic field analysis around magnetized ropes with mechanical defects (Pistora et al., 2019). The non-reciprocity of magneto-optical (MO)-surface plasmon resonance (SPR) reflection response observed by polarity change of the external magnetic field has been studied for sensor applications aimed at magnetic defectoscopy (Pistora et al., 2010; Vlcek et al., 2013).

The second main factor is the load-bearing capacity, which can be determined by experiment (Utting and Jones, 1987) or calculation. Using the theory of elasticity and strength, many authors have taken an analytical calculation approach to give this relationship between rope geometry and load-bearing capacity (Velinsky, 1985; Ghoreishi et al., 2007; Usabiaga and Pagalday, 2008). However, during the last decade, the deployment of the computer modeling method has been intensively studied (Nawrocki and Labrosse, 2000; Jiang, Henshall and Walton, 2000; Stanova et al., 2011; Yu et al., 2014; Fontanari, Benedetti and Monelli, 2015; Foti and di Roseto, 2016). The computer modeling method allows taking into account all important influences during the tensile test of wire ropes. In (Wang et al., 2015), the authors described a parametric computer model of the wire ropes for fast indeterminate contact analysis statically and dynamically. The local model of the wire rope has been implemented. The aims of the local model are to link the global quantities, namely tension and rope curvature, to local quantities that govern the fatigue damage at the wire level (Bussolati et al., 2018). The slipping and crushing behaviors of a steel wire rope during a tensile test using a curve-type clamping mechanism to realize safe and reliable clamping during safety testing have been studied (Song et al., 2019). The experimental results show that the improved clamping mechanism can effectively clamp the wire rope for tensile testing and meet test requirements. The breaking failure characteristics of hoist ropes with different wear scars were investigated by the breaking tensile test (Chang et al., 2019). The finite element method was used to simulate the mechanical properties of the wear-out strands subjected to tensile load. Results show that the severe plastic deformation and obvious temperature rise occur in the wear scar region. The wear-out outer wires fracture earlier than the internal wires, and the wires with irregular wear scar always fracture along the sliding wear direction at the location with the maximum wear depth.

In the frame industrial practice, the application of single-stranded wire rope is often used. For this reason, the modeling and experimental testing of the load-bearing capacity related is very important. The authors of the article have extensive experience with modeling load-bearing capacity of steel arch yielding supports (Horyl, Snuparek nad Marsalek, 2014; Horyl et al., 2016, 2017, 2019; Marsalek and Horyl, 2017).

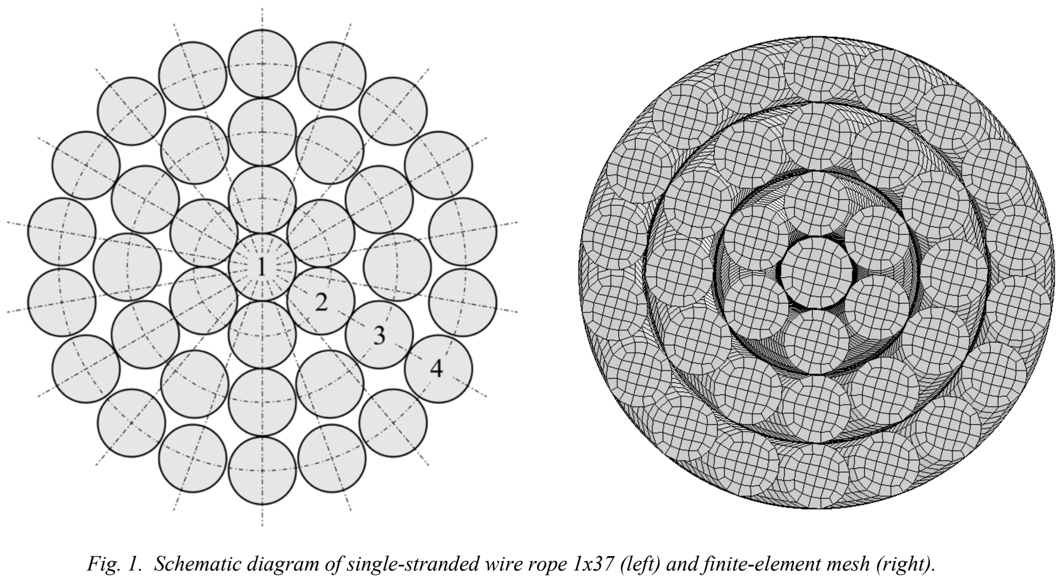

Fig. 1. Schematic diagram of single-stranded wire rope 1x37 (left) and finite-element mesh (right).

The aim of work is to create a simple experiment determining the real value of the load-bearing capacity of the wire rope. Using this experiment, a computer model describing the failure of steel ropes is created and validated. For these purposes, a single-strand steel wire rope - labeled 1x37 is chosen. Fig. 1 gives the cross-section of this rope. The rope is made up of 37 wires with the construction of 1+6+12+18 wires in individual layers. The rope with an outer diameter of d = 8.00 mm is used during the tests with declared rope strength class σ_r = 1,570 MPa. The rope wires have been galvanized. The nominal rope cross-section is S_n = 37.30 mm^2. The nominal load-bearing capacity of the rope is F_n = 51.50 kN declared by a manufacturer. The rope complies with Standard (CSN EN 12385-4, 2008) and (Standard DIN 3054, 1972). The measured wire diameters are given in Tab. 1. The real rope cross-section S_r = 39.77 mm^2 is calculated from the measured diameters of each wire.

Tab. 1. Wire diameters for each rope layer

Rope layer i [-]	1 (inner layer)	2	3	4 (outer layer)
Wire diameter di [mm]	1.27	1.15	1.20	1.15

Material and Methods

Experiment

This phase of the research was divided into two separate experiments that were conducted using a tensile test on the TESTOMETRIC M500-50CT. The first experiment was focused on tests of individual wires forming the rope. The aim was to obtain the wire behavior needed for the computer modeling of the entire rope. Another goal is to calculate the load-bearing capacity of the rope F_w using the load-bearing capacity of individual rope wires F_{wi}. The wire tensile test results are given in Fig. 2. and measured load-bearing capacities for individual wires in the rope layer are summarized in Tab. 2. The load-bearing capacity calculated from individual wire measurement F_w = 66.67 kN is determined as the sum of the measured load-bearing capacities of individual wires (see Tab. 2).

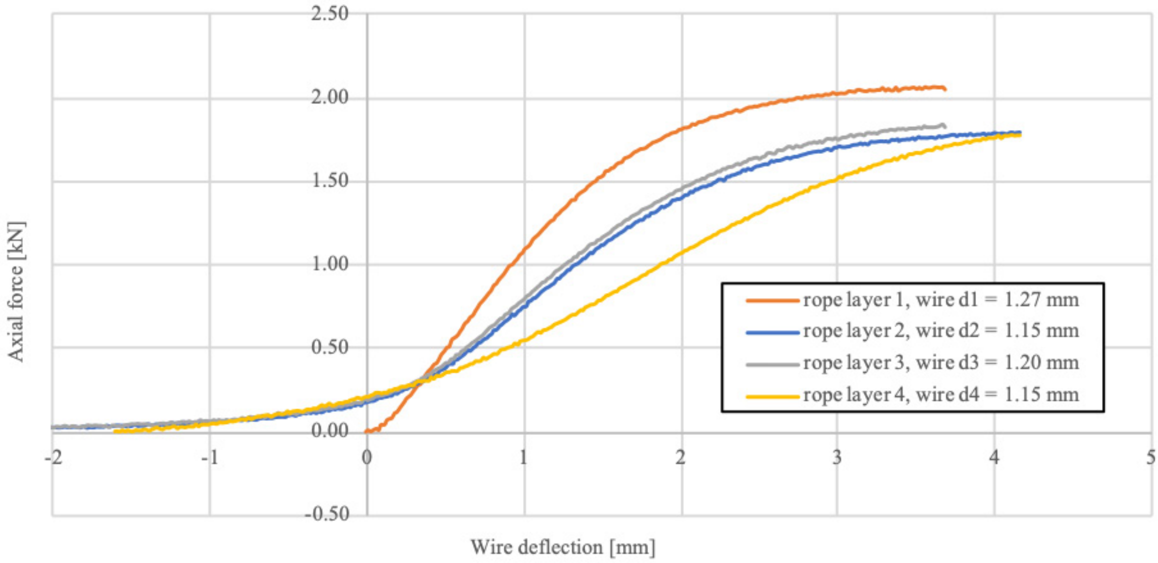

Fig. 2. Tensile test of individual wires in the rope layer.

Tab. 2. The measured load-bearing capacity of individual wires in the rope layer

Rope layer i [-]	1 (inner layer)	2	3	4 (outer layer)
The measured load-bearing capacity of wire Fwi [kN]	2.05	1.83	1.80	1.78

The second experiment was designed to test the entire wire rope (the distance between the jaws was l = 150 mm). During rope tests, it was found that the testing samples were poorly attached to the machine's jaws. The inner wires were not sufficiently pressed together (not fully gripped) and then pulled the axial forces were not transferred to the individual rope layers (especially to the inner layer). Thus, only the outer rope layers experienced excess loading. When more axial force was applied with the jaws, the wires near the grip cracked, and the core of the rope was not stressed. For this reason, both ends of the test sample were welded. The measurements were repeated using samples with the ends welded. The experiments confirmed the expediency of this approach. The results of these experiments are shown in Fig. 3. The load-bearing capacities of the welded samples obtained from the tests are listed in Tab. 3.

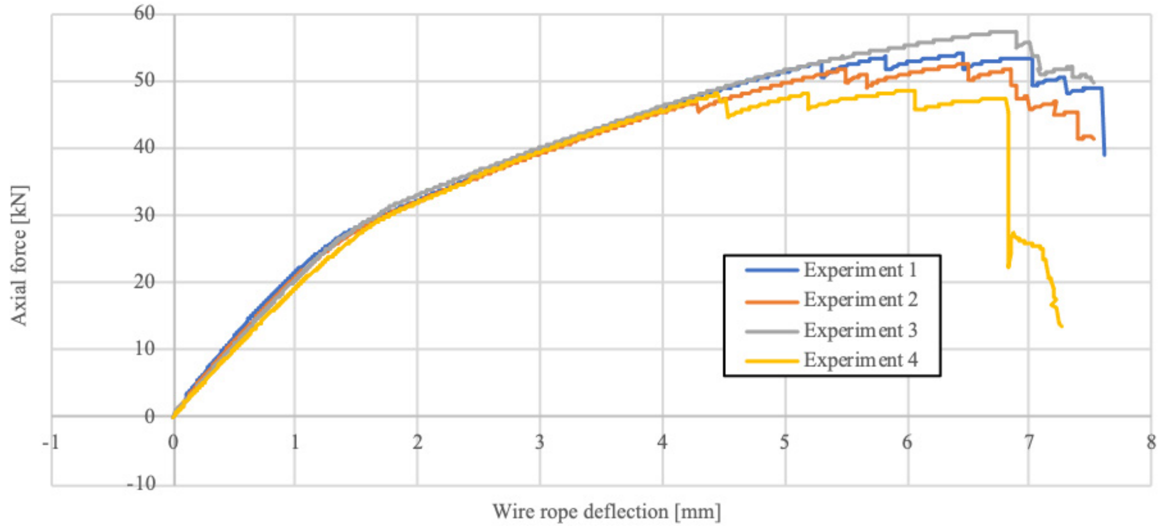

Fig. 3. Tensile test of the entire rope.

Tab. 3. The measured load-bearing capacity of the entire rope

Experiment	1	2	3	4
Measure the load-bearing capacity of rope F_r [kN]	54.00	52.55	57.45	48.67

Computer modeling

The finite element method was used to create a computer model for the experiments described above. The LS-DYNA R7.1 solver was applied to solve the tasks (Judge et al., 2012). In the initial research, test tasks were carried out to make the computer model more accurate. Here, a quasi-static implicit solution of the spatial task was considered with all kinds of nonlinearities (material model, frictional contact between all wires, large displacements, and deformations). The static solution converged to overcome frictional forces between layers. Consequently, the divergence has been registered, and it was not possible to successfully complete the task even when the stabilization has been applied (in the form of damping and numerical stabilization). Subsequently, the task was formulated as an implicit dynamic. Unfortunately, this approach did not lead to success. Therefore, the solution of the problem was chosen to be explicitly dynamic (Cech, Horyl and Marsalek, 2016; Marsalek et al., 2017; Klemenc et al., 2017) based on the fact that after overcoming the frictional forces between the wires, there is a dynamic realignment of the wires.

Geometric Model. The geometric model for the wire rope has been produced by pulling the cross-sections of the individual wires along the helix (50 mm gradient per one turn). The rope cut geometry was obtained from (Standard CSN 02 4313, 2004); and wire diameters are specified in Tab. 1. Wires inside the rope touch tangentially. There is no penetration or looseness. Initial geometry is ideal, without the curvature effect caused by manufacturing technology. The initial state is characterized by zero stress in all the rope wires. The model geometry can be considered consistent with the test sample.

Finite Element Mesh. The finite element mesh was created by a controlled generation using SW Altair Hypermesh. Element drag along a curved wire axis was used to establish a mapped mesh consisting of 8 node hexahedral elements with full integration. The element edge is between 0.20 mm and 0.25 mm. Mesh fineness was chosen concerning the task's time step, and its statistics are specified in Tab. 4. Mass scaling was used to adjust the time step to $\Delta t = 2.80 \cdot 10^{-5}$ ms.

Tab. 4. Finite element mesh statistics

Nodes	860,000
Elements	630,000

Material Model. The same material model was chosen for all wires. It is high-strength steel, which is further strengthened by the wire production technology. Based on the experiments, an elastoplastic material model with kinematic hardening (*MAT_003) was preferred. The material constants given in Tab. 5 were subtracted based on the averaged results of the first single-wire experiment (see Section 1). There are two variants of calculation, where the influence of the defects defined by the failure strain fs is analyzed. The failure strain is prescribed for rope volume in the distance e = 20 mm from the jaws.

Tab. 5. Material model parameters

Material model parameter	Value
Young's modulus E [GPa]	200.0
Poisson ratio μ [-]	0.300
Yielding Stress σ_y [GPa]	1.300
Tangent modulus E_t [GPa]	22.20
Density ρ [kg m^{-3}]	7,800
Failure strain f_s [-]	0.025 and 0.031

Boundary and Initial Conditions. The definition of the computer model's marginal conditions is chosen concerning the second experiment (tensile test of the entire rope). The effect of compressing the ends of the rope by the grips is not considered. One end of the rope is fixed. The other end is rotated during blocking and feeding. Only the jaw velocity v = 5.00 ms^{-1} in the pull direction is prescribed.

A robust *CONTACT_AUTOMATIC_SINGLE_SURFACE friction contact with a Coulomb friction model was used for the numerical description of the contacts between the wires (Benson and Hallquist, 1990). This formulation automatically seeks out contact between the wire surfaces. The friction coefficient chosen to describe the magnitude of the frictional forces was f = 0.10. Several values of the friction coefficient (f = 0.10 to 0.50) were tested with no significant effect on the result (Sun et al., 2005; Chen et al., 2017).

Results

Many calculations modeling real tensile tests were realized. The results correspond to real experiments and are shown in Fig. 3 (comparison with Fig. 4). To compare the data obtained, the calculated rope shift is normalized by u = 0.30 mm. This shift corresponds to the wires limiting during the tensile test simulation, which arises due to the idealization of the rope's geometric model.

Calculated dependences - green corresponding to failure strain f_s = 0.031 and light blue corresponding to failure strain f_s = 0.025 - are compared with measured data (remaining curves). When using explicit time integration to calculate the load-bearing capacity, the noise is generated as a result of discretization and the absence of damping. In fact, during the tensile test, the jaws' velocity is very low, therefore the response given in Fig. 3 is smooth. It is necessary to use a low pass filter to determine the load-bearing capacity of the entire rope, as it eliminates the effect of high frequencies on the calculated response. Based on previous experience, the SAE J211-600 Hz two-pole filter is applied. The calculated load-bearing capacities for both values of entire rope failure strain (f_s = 0.025 and f_s = 0.031) are given in Tab. 6. The wire break pattern (Fig. 5) copies the actual experiment.

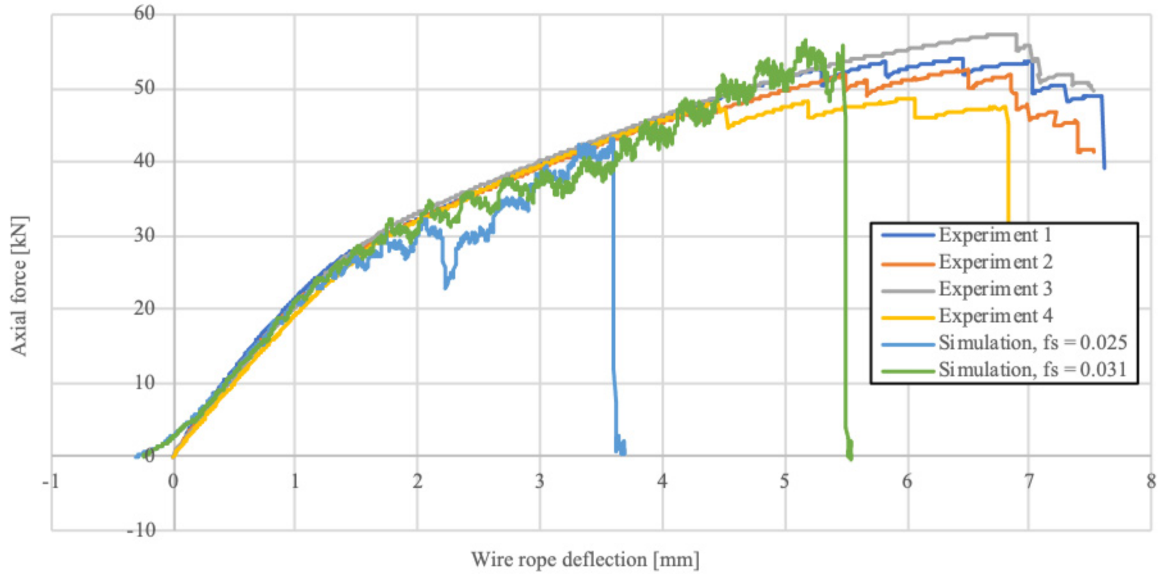

Fig. 4. Comparison of calculated results with measured data for the entire rope.

Tab. 6. Rope load capacity obtained by the computer model

Failure strain f_s [-]	0.025	0.031
Load-bearing capacity F_c [kN] (SAE 600 Hz Filter)	43.93	55.79

The load-bearing capacity of the rope (F_c = 55.79 kN) determined by the computer modeling method (Tab. 6) is very sensitive to the failure strain (plastic deformation) – as is the measured load-bearing capacity of the rope (Tab. 3) specified by the tensile test.

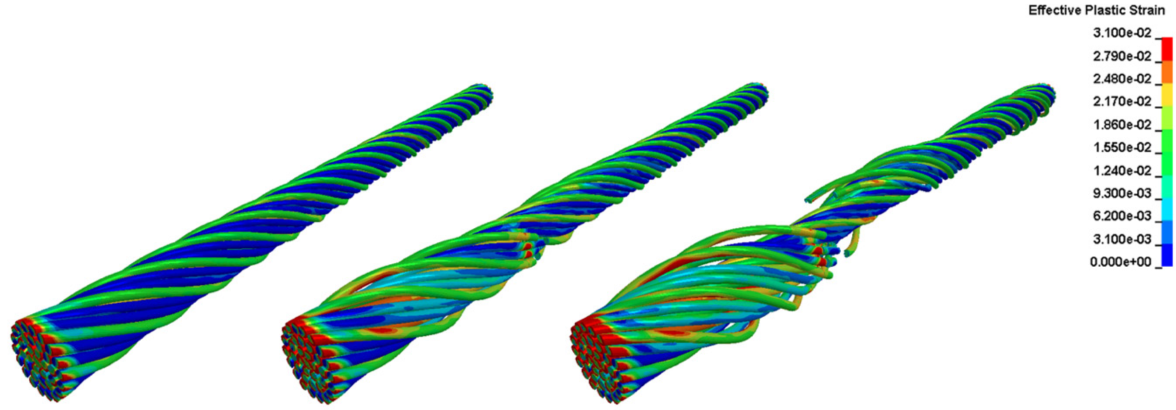

Fig. 5. Animation of rope break for failure strain f_s = 0.031 corresponds to calculated load-bearing capacity F_c = 55.79 kN.

Discussion

The load-bearing capacity of wire ropes presents an important parameter for wire design. During the study of data from both presented experiments, we create a computer model using the finite element method that determines the load-bearing capacity with sufficient accuracy.

To determine the real load-bearing capacity value using the computer modeling method, the creation of an accurate geometric model is necessary. It is necessary to note that only from a detailed comparison of the nominal rope cross-section is S_n = 37.30 mm^2 with the real rope cross-section S_r = 39.77 mm^2. The difference between values is 6.6 %, see Tab. 1.

However, another key factor is the material model and the determination of the material constants. Based on the performed calculations, it was found that the load-bearing capacity is very sensitive to the failure strain value f_s and the chosen method of response filtering.

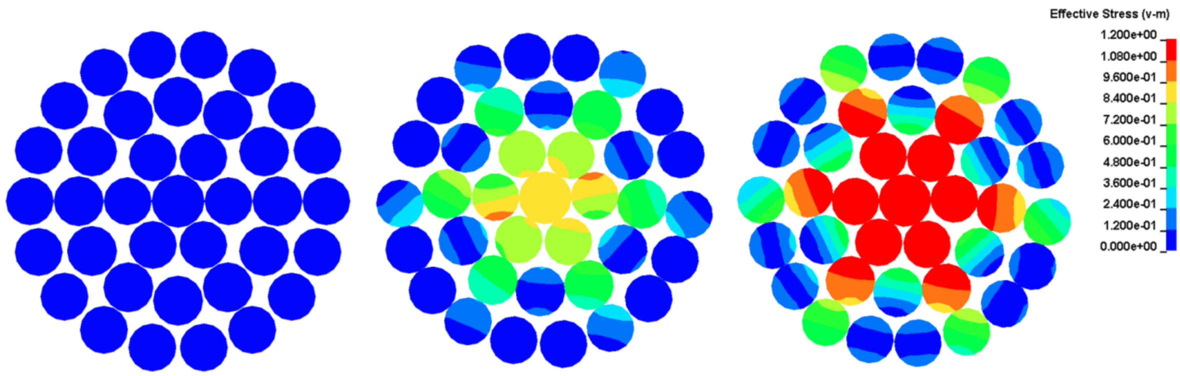

Fig. 6. Cross-section of tested rope sample for axial force F = 0 kN, 10 kN, and 20 kN - von Mises stress.

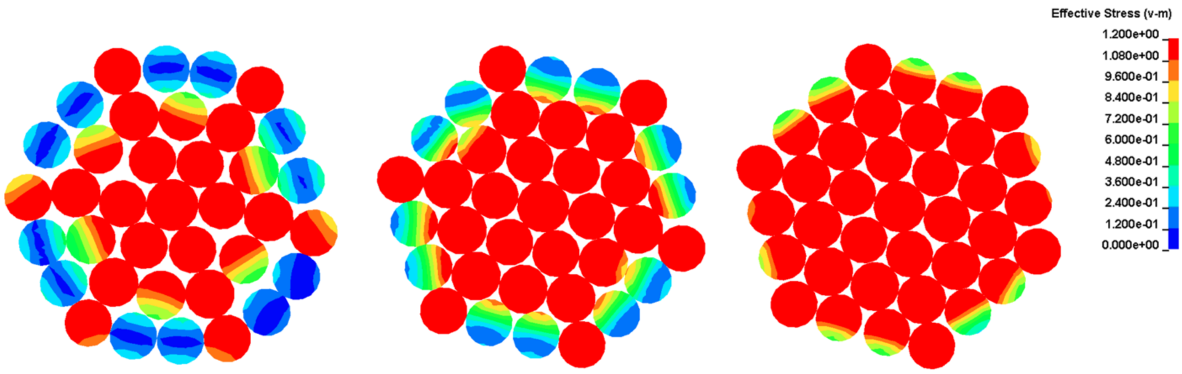

Fig. 7. Cross-section of tested rope sample for axial F = 30 kN, 40 kN, and 50 kN - von Mises stress.

In Fig. 6 and Fig. 7, a cross-section of the analyzed wire rope during loading is illustrated. Fig. 6 and Fig. 7 show a noticeable effect of significant load on the internal wires, where plastic deformation occurs from axial force F = 12.50 kN have been observed. In addition, the overall deformation of the rope under load is clearly visible. Using a stress distribution obtained by the presented computer model, the ideal rope cross-section (including the shape of individual wires) can be designed.

Using linear regression of the data measured, the stiffness of the entire rope k_c in the length l = 150 mm was specified. The stiffness of the entire rope k_c is 2.6 times smaller than the stiffness of the solid steel bar of cross-section S_r = 39.77 mm^2 with equivalent length, see Tab. 7. This rope property is very important for computer modeling of large structures containing wire ropes (mining towers, suspension bridges, etc.).

Tab. 7. Comparison of entire rope stiffness

Parameter	Value
Stiffness of the entire rope k_c [kN/mm]	20.40
Stiffness of a solid steel bar k_b [kN/mm]	53.03

Conclusion

The safety factor of the wire rope is given by the ratio between the load-bearing capacity of the rope and its maximum design load. For wire ropes that have not been subjected to the required tests, the nominal load-bearing capacity F_n is used. The nominal value is on the safe side, as well as the nominal cross-section. If we would like to specify the real value of the load-bearing capacity, it is necessary to experiment with the subjected rope or its wires. In this work, a simple experiment was designed, and a corresponding computer model was created, which can be used to accurately determine the real value of the load-bearing capacity of the wire rope.

In the first part of the work, the individual wires were tested, followed by testing the entire rope. For these purposes, a single-strand steel wire - labeled 1x37 was chosen. Steel rope is made up of 37 wires with the construction of 1+6+12+18 wires in individual layers. Ropes with an outer diameter of d = 8.00 mm were used during the tests with declared rope strength σ_r = 1,570 MPa. Based on the performed research work, three values of load-bearing capacity were determined (Tab. 8).

Tab. 8. Comparison of obtained load-bearing capacity values

Experiment	Value
Nominal load-bearing capacity F_n [kN] (Standard CSN 02 4313, 2004)	51.50
Load-bearing capacity calculated from each wire measurement F_w [kN]	66.67
Load-bearing capacity calculated from the entire rope measurement F_r [kN]	53.16
Load-bearing capacity obtained from the presented computer model F_c [kN]	55.79

In the first phase, the load-bearing capacity calculated from individual wire measurement F_w = 66.67 kN is determined as the sum of the measured load-bearing capacities of individual wires (see Tab. 2). This estimated value is only theoretical. The load-bearing capacity calculated from individual wire according to the result of the experiment is about 29.5 % higher than the nominal value F_n = 51.50 kN. The use of this method is not suitable due to the uneven distribution of wire due to their different stiffness. The result does not appear to be accurate. To determine the real load-bearing capacity, it is necessary to use the testing of the entire wire rope. This was performed in the second phase of the work. Load-bearing capacity calculated from the entire rope measurement F_r = 53.16 kN is determined by testing the wire rope in the length l = 150 mm. The value given in Tab. 8 is calculated using the arithmetic mean of testing 4 samples, see Tab. 3. According to the results of the entire rope experiment, this value is 3.2 % higher than the nominal value. The results obtained with this procedure show high accuracy of the measurement. The last phase describes the load-bearing capacity obtained from the presented computer model F_c = 55.79 kN, which was validated based on the experiment. This value is 8.3% higher than the nominal value.

Designed experiment for testing the whole rope and computer modeling method is suitable for practical purposes in industrial practice. It is necessary to keep in mind that the safety of a wire rope is negatively affected by many operating factors. Not only the rope construction but also pulley diameter, rope lubrication, suitable groove shape, rope load, corrosion plays an import role.

References

Bussolati, F., Allix, O., Guidault, P., Guiton, M. and Poirette, Y. (2018). Toward a two-scale modeling of spiral strand wire rope for floating offshore wind turbine to predict fatigue damages: possibilities and difficulties in using a legacy code. *Contact Mechanics International Symposium 2018*, Biella.

Benson, D. J. and Hallquist, J. O. (1990). A single surface-contact algorithm for the post-buckling analyses of shell structures. *Computer Methods in Applied Mechanics and Engineering*, 78(2).

Cech, R., Horyl, P. and Marsalek, P. (2016). Modelling of two-seat connection to the frame of rail wagon in terms of resistance at impact test. *Strojnicky Casopis*, 66(2).

Chang, X. D., Peng, Y. X., Zhu, Z. C., Gong, X. S., Yu, Z. F., Mi, Z. T. and Xu, C. M. (2019). Breaking failure analysis and finite element simulation of wear-out winding hoist wire rope. *Engineering Failure Analysis*, 95.

Chen, Y., P., Meng, F. M. and Gong, X. S. (2017). Study on performance of bended spiral strand with interwire frictional contact. *International Journal of Mechanical Sciences*, 128.

Costello G. A. (1997). Theory of Wire Rope. Springer, New York.

Fontanari, V., Benedetti, M. and Monelli, B. D. (2015). Elasto-plastic behavior of a Warrington-Seale rope: Experimental analysis and finite element modeling. *Engineering Structures*, 82.

Foti, F. and di Roseto, A. D. (2016). Analytical and finite element modelling of the elastic-plastic behaviour of metallic strands under axial-torsional loads. *International Journal of Mechanical Sciences*, 115.

Ghoreishi, S. R., Messager, T., Cartraud, P. and Davies, P. (2007). Validity and limitations of linear analytical models for steel wire strands under axial loading, using a 3D FE model. *International Journal of Mechanical Sciences*, 49(11).

Horyl, P., Marsalek, P., Snuparek, R. and Paczesniowski, K. (2016). Total load-bearing capacity of yielding steel arch supports. *Rock Mechanics and Rock Engineering: From the Past to the Future*, Cappadocia.

Horyl, P., Snuparek, R. and Marsalek, P. (2014). Behaviour of frictional joints in steel arch yielding supports. *Archives of Mining Sciences*, 59(3).

Horyl, P., Snuparek, R., Marsalek, P. and Paczesniowski, K. (2017). Simulation of laboratory tests of steel arch support. *Archives of Mining Sciences*, 62(1).

Horyl, P., Snuparek, R., Marsalek, P., Poruba, Z. and Paczesniowski, K. (2019). Parametric studies of total load-bearing capacity of steel arch supports. *Acta Montanistica Slovaca*, 24(3).

Ivanco, V., Kmet, S. and Fedorko, G. (2016). Finite element simulation of creep of spiral strands. *Engineering Structures*, 117.

Jiang, W. G., Henshall, J. L. and Walton, J. M. (2000). Concise finite element model for three-layered straight wire rope strand. *International Journal of Mechanical Sciences*, 42(1).

Judge, R., Yang, Z., Jones, S. W. and Beattie, G. (2012). Full 3D finite element modelling of spiral strand cables. *Construction and Building Materials*, 35.

Klemenc, M., Markopoulos, A. and Marsalek, P. (2017). Analysing of critical force effect of aircraft seat belt using truss elements. *International Conference of Numerical Analysis and Applied Mathematics 2016*, Rhodes.

Marsalek, P. and Horyl, P. (2017). Modelling of bolted connection with flexible yokes used in mining industry. *International Conference of Numerical Analysis and Applied Mathematics 2016*, Rhodes.

Marsalek, P., Horyl, P., Karasek, T. and Ferfecki, P. (2017). Influence of seat pitch on passenger injury criteria in regional railway traffic. *International Conference of Numerical Analysis and Applied Mathematics 2016*, Rhodes.

Molnar, V., Fedorko, G., Kresak, J., Peterka, P. and Fabianova, J. (2017). The influence of corrosion on the life of steel ropes and prediction of their decommissioning. *Engineering Failure Analysis*, 74.

Nawrocki, A. and Labrosse, M. (2000). Finite element model for simple straight wire rope strands. *Computers and Structures*, 77(4).

Pistora, J., Lesnak, M., Valicek, J., Harnicarová, M. and Vrabko, V. (2019). Magnetic Field Distribution Around Magnetized Steel Ropes and Its Modulation by Rope Defects. *Engineering Design Applications*, 72.
Pistora, J., Lesnak, M., Vlasin, O. and Cada, M. (2010). Surface plasmon resonance sensor with magneto-optical structure. *Optica Applicata*, 40(4).
Song, B., Wang, H., Cui, W., Zhang, J. and Liu, H. (2019). Dynamic simulation and optimization of clamping mechanism of online tension testing machine for wire ropes. *Engineering Failure Analysis*, 95.
Standard CSN 02 4313 (2004). Ocelova lana - Ocelova lana jednopramenna, 37 dratu - Rozmery (in Czech).
Standard CSN EN 12385-4 (2008). Ocelova dratena lana - Bezpecnost - Cast 4: Pramenna lana pro vseobecne zdvihaci ucely (in Czech).
Standard DIN 3054 (1972). *Drahtseile aus Stahldrahten, Spiralseil 1×37* (in Deutch).
Stanova, E., Fedorko, G., Fabian, M. and Kmet, S. (2011). Computer modelling of wire strands and ropes Part I: Theory and computer implementation. *Advances in Engineering Software*, 42(6).
Straka, M., Rosova, A., Lenort, R., Besta, P. and Saderova, J. (2018). Principles of computer simulation design fot the needs of improvement of the raw materials combined transport system. *Acta Montanistica Slovaca*, 23(2).
Sun, J. F., Wang, G. L. and Zhang, H. O. (2005). Elasto-plastic contact problem of laying wire rope using FE analysis. *International Journal of Advanced Manufacturing Technology*, 26(1-2).
Usabiaga, H. and Pagalday, J. M. (2008). Analytical procedure for modelling recursively and wire by wire stranded ropes subjected to traction and torsion loads. *International Journal of Solids and Structures*, 45(21).
Utting, W. S. and Jones, N. (1987). The response of wire rope strands to axial tensile loads-Part I. Experimental results and theoretical predictions. *International Journal of Mechanical Sciences*, 29(9).
Utting, W. S. and Jones, N. (1987). The response of wire rope strands to axial tensile loads-Part II. Comparison of experimental results and theoretical predictions. International Journal of Mechanical Sciences 29(9).
Velinsky, S. A. (1985). General non-linear theory for complex wire rope. *International Journal of Mechanical Sciences*, 27(7-8).
Vlcek, J., Lesnak, M., Pistora, J. and Zivotsky O. (2013). Magneto-optical sensing of magnetic field. *Optics Communications*, 286.
Yu, Y. J., Chen, Z. H., Liu, H. B. and Wang, X. D. (2014). Finite element study of behavior and interface force conditions of seven-wire strand under axial and lateral loading. *Construction and Buckling Materials*, 66.
Wang, X. Y., Meng, X. B., Wang, J. X., Sun, Y. H. and Gao, K. (2015). Mathematical modeling and geometric analysis for wire rope strands. *Applied Mathematical Modelling*, 39(3-4).

Acta Montanistica Slovaca
ISSN 1335-1788
actamont.tuke.sk

The Dynamic Nonlinear Effect of Urban Intensity on Natural Resources in Indonesia: Evidence from Asymmetric ARDL and Causality Approaches

***Muhammad HASEEB*[1], *Beata ŚLUSARCZYK*[2]*, *Hafezali Iqbal HUSSAIN*[3], *Kittisak JERMSITTIPARSERT*[4] and *Paweł SOBCZAK*[5]**

Authors' affiliations and addresses:
[1] Taylor's Business School, Taylor's University, Lakeside Campus, 1 Jalan Taylors, 47500 Subang Jaya, Malaysia
e-mail: muhammad.haseeb@taylors.edu.my

[2] The Management Faculty, Czestochowa University of Technology, Al. Armii Krajowej 19B, 42-201 Czestochowa, Poland
e-mail: beata.slusarczyk@wz.pcz.pl

[3] Taylor's Business School, Taylor's University, Lakeside Campus, 1 Jalan Taylors, 47500 Subang Jaya, Malaysia
University of Economics and Human Sciences in Warsaw, Okopowa 59, 01-043 Warsaw, Poland.
e-mail: hafezali.iqbalhussain@taylors.edu.my

[4] Informetrics Research Group, Ton Duc Thang University, Ho Chi Minh City, Vietnam;
Faculty of Social Sciences and Humanities, Ton Duc Thang University, Ho Chi Minh City, Vietnam
e-mail: kittisak.jermsittiparsert@tdtu.edu.vn

[5] Faculty of Applied Sciences, WSB University, Cieplaka Street 1c, 41-300 Dąbrowa Górnicza, Poland
e-mail: psobczak@wsb.edu.pl

***Correspondence:**
Beata Ślusarczyk, The Management Faculty, Czestochowa University of Technology, Al. Armii Krajowej 19B, 42-201 Czestochowa, Poland
tel.: +48 34 3250 309
e-mail: beata.slusarczyk@wz.pcz.pl

How to cite this article:
Haseeb, M., Ślusarczyk, B., Hussain, H. I., Jermsittiparsert, K. and Sobczak, P. (2020). The Dynamic Nonlinear Effect of Urban Intensity on Natural Resources in Indonesia: Evidence from Asymmetric ARDL and Causality Approaches. *Acta Montanistica Slovaca,* Volume 25 (2), 201-212

DOI:
https://doi.org/10.46544/AMS.v25i2.7

Abstract
The aim of this study is to explore the role of urbanization and economic growth in natural resources using a time series data from 1971 to 2018. The current study applied a novel methodology of nonlinear ARDL proposed by Shin et al. (2014). This methodology is ideal to answer the asymmetric effect on the independent variable on the dependent variable. Furthermore, we also applied asymmetric Granger causality introduced by Hatemi-J (2012) to confirm the causal relationship between the variables. The results of NARDL affirmed that all the variables have a significant impact on natural resources rent. The findings confirm that negative shocks of urban intensity decrease the natural resources rents; however, the positive shocks increase the rents of natural resources. On the one hand, the positive and negative shocks of GDP increase the natural resources though, the magnitude of positive shocks are significantly different from the negative shocks. On the other hand, the results of asymmetric Granger causality confirm that positive and negative shock of urban intensity does granger cause positive shocks of natural resources. Whereas, positive shocks of natural resources (economic growth) have a causal connection with positive and negative shocks of economic growth (natural resources) in Indonesia.

Keywords
Urban intensity, natural resources management, Indonesia, NARDL.

Introduction

The term urbanization becomes a global subject which is considered as the outcome of consistent gradual revolutions in the industry based on technical, modern and technological advancements (Ding & Peng 2018; Bertinelli & Black, 2004; Fujii, 1968). Moreover, urbanization is said to be the outcome of development, industrialization and economic acceleration (Bakirtas & Akpolat, 2018), whereby manufacturing organizations explore new and efficient ways of usage, extraction, transformation, and consumption of the natural resources into the products in order to meet the market demand (Ding & Peng 2018; Bakirtas & Akpolat, 2018; Nurwanda & Honjo, 2020). Nevertheless, urbanization results in an ultimate change in resource extraction and utilization, which is also considered as the evaluating criteria for economic development (Ding & Peng 2018).

It has been reported that while comparing developing countries with developed countries, developing countries are found to be more affected by urbanization (Henderson, 2002). This is because of many reasons including the potential of the economic growth, a rapid increase in the population of the existing residents and due to immigrants shifting from the rural areas to comparatively developed cities (Elmqvist et al., 2013; Yuan, Sawaya, Loeffelholz, & Bauer, 2005; Meyer & Meyer, 2016). This leads to the speculation that most of the possible development due to urbanization can happen in medium and small-sized cities (Elmqvist et al., 2013). As mentioned earlier, one of the reasons of the urbanization is consistent growth in the population whereby it was found that in 2015, the expected population to live in the urban cities are found to be 54% whereas they are expected to grow up to 74% of the world's total population by the year 2050 (UN-Habitat, 2016). Moreover, as more people will be living in urban cities, therefore it is also expected that the general lifestyle of the residents will also change (Jones, 2017).

Urbanization leads to several potential challenges to the economy of a country that needs to be taken care of (Jones, 2017). Urbanization results in altering the supply of the basic need and services, which needed to be expanded as per the ratio of urbanization (Ding & Peng, 2018). Urbanization also results in the potential challenge of housing and land surface usage that need to improve accordingly (Jones, 2017). In addition to this, due to urbanization, the planning related to education, health, employment opportunities also affected that also need to grow in parallel to the urbanization so that the economy can be efficiently managed (Elmqvist et al., 2013). However, the most important challenge of urbanization is the usage and depletion of the natural resources that lead to a potential threat to the ecological health of the country United Nations General Assembly (2017).

The efficient consumption of natural resources significantly contributes to the country's economic growth (Hassan, Xia, Huang, Khan, Iqbal, 2019). Moreover, researchers agree that the natural resources tend to accelerate the economic health of an economy (Miao et al., 2017) and hence results in an accelerated economic growth (Hassan et al., 2018). In addition to this, depletion of natural resources either due to consumption or due to adverse ecological conditions and environmental degradation, has become one of the most important issue mankind is facing globally (Ding & Peng 2018; Jones, 2017). For instance, it has been reported that mountains, that account for 25% in terms of the usage of land surface and accommodates one-tenth of the entire global population (Löffler et al., 2011), houses nearly half of the world's total biodiversity (Payne, Warrington, Bennett, 2002) is also the source of resources that have been extracted from it including minerals, water, energy, food and others (Blyth, Groombridge, Lysenko, Miles, & Newton, 2002; Sabishchenko, Rębilas, Sczygiol & Urbański, 2020). Therefore, urbanization needed to be done in a way that it has the least adverse effects on natural resources, and hence there is a need to have more environment sustainable urbanization (Tomlinson, Chapman, Thornes, & Baker, 2011; Ding & Peng 2018). This leads to the emergence of a new agenda named "New Urban Agenda" which is a roadmap for sustainable urbanization signed by more than 170 countries for the next 25 years (Jones, 2017).

Indonesia is a country situated in the Southeast Asia region and is known as the world's largest country in terms of islands with a number of more than 16 thousand islands (The Jakarta Post, 2017). With an area spread over 1,904,569 km2, makes Indonesia 14th largest country in the world (Seeking Alpha, 2017). In terms of population, Indonesia ranks at fort among the most populous counties in the world, with people more than 267 million. According to the World Bank (2016), Indonesia is found to be the most fasting country in Asia in terms of urbanization in which the country is showing a radical transformation from being a rural-based economy to an urban-based. Moreover, it is estimated that by the year 2025, nearly 68% of the total population of Indonesia will be living in cities as the cities are growing at a pace of 4.1% annually. In terms of population density, the country requires more sophisticated urban planning and investments in the infrastructure, which are currently not in accordance with the population and the urbanization (Nurwanda & Honjo, 2020; Jones, 2017).

Despite being the highest in terms of urbanization, it is estimated that the 1% urbanization of the county leads to only 4% of economic growth, which is very low as compared to the other countries in the same region (The World Bank, 2016). Such low economic growth raises serious concern on the rate of urbanization and development (Yan, 2020). When the country urbanization is the fastest of the region, and the population is accordingly increasing, which leads to the more consumption of natural resources, energy utilization, bio-diversity mitigation, possible spreading of the population to house more land space, thus urbanizing at the cost of the natural resources where the economic growth is not in accordance with the aforementioned facts (Nurwanda & Honjo, 2020; Jones, 2017). This leads to the serious concerns of the researchers to identify and explore the relationship between urbanization at the cost of natural resources (Ma and Hao, 2020).

In light of the aforementioned discussion, it is evident that though Indonesia is progressing in terms of urbanization; however, the rate of urbanization is not providing sufficient benefits in terms of economic growth. Hence this leads to the motivation of the present study, whereby researchers aim to explore the rate of urbanization at the cost of consumption of natural resources, so that if the empirical results are not good, then the possible implications can be suggested in order to improve the consumption and utilization of the natural resources so that the outcome can be maximized which potentially contribute in the economic growth of the country n the best possible way.

The following sections include discussion related to relevant literature of the urbanization and consumption of the natural resources, followed by the methodology where the operationalization of the present study is discussed. After that, estimations and results are reported, and policy recommendations are discussed based on the findings and results.

Literature Review

Natural resources are considered as the backbone of an economy since they provide the fundamental advantageous factor of land for the development and progress along with its constituents of minerals, metals, forest, water, etc. In this regard, the theoretical aspects of Natural Resource based theory by Hart (1995) also stated that the efficient utilization of natural resources is considered to cause an increase in firm-level competence. From the macro aspect, assuming the significance of natural resources in an economy, several studies also identified the positive impact of natural resources on country's growth and development (Bunte, Desai, Gbala, Parks & Runfola, 2018; Sanusi, Meyer & Ślusarczyk, 2017; Havranek, Horvath & Zeynalov, 2016; Hao, 2007). However, with increasing trends of industrialization and globalization, there exists a continuous decline in the level of earth's natural resources (Sharif, Afshan and Qureshi, 2019; Gilberthorpe & Hilson 2016; Popp, Oláh, Fekete, Lakner, & Máté, 2018; Pegg, 2003).

Moreover, in many recent studies, urbanization has been identified as the major cause of natural resource depletion. For instance, concentrating on urbanization gradients, Parsons et al. (2019) stated that urban development acted as a carnivore commotion for natural habit and act as a major threat to environmental stability and natural resources sustenance. Similarly, in Pakistan, Rashid et al. (2018) also examined the ecological impact of urbanization in the city of Rawalpindi. The findings elaborated that only the two major urban colonies dispersed in the area of 15. 5 global hectares are utilizing the resources much greater than the bio-capacity of the entire country. On the other hand, Hassan, Xia, Huang, Khan and Iqbal (2019) studied the causal link between urbanization and natural resources. The results found that in the short run, urbanization has a significant causal effect on natural resources. However, in the long run, there existed no causal link between urbanization and natural resources in Pakistan.

Focusing on the natural resource of coal, Kurniawan and Managi (2018) investigated the relationship between coal usage and urban development in Indonesia between 1970 to 2015. The results of the study found that urbanization is significant to impact coal consumption in the country. Specifically, the findings suggested that a rise in urbanization further enhances the utilization of coal in the Indonesian economy. Similar results were reported by Guo, Zhang, Zhao, Wang and Xi (2018) while examining the Shanxi province of China from 1978 to 2014, and Wang (2018) while studying the coal-urbanization link in twenty-nine provinces of China from the period of 2006 to 2015. In Bangladesh, Arfanuzzaman and Rahman (2017) also found that urban intensity without proper planning in the current age of industrialization has resulted in increased pressure on resources such as power, land, and water. The study found the population to be the major factor in causing increased demand for natural resources. Stressing on the negative effects of increased dependence on fossil fuel in terms of damaging environment and resource depletion, Siddique, Majeed and Ahmad (2016) found that urbanization resulted in increased degradation of natural habitat.

In another study of Indonesia, Remondi, Burlando and Vollmer (2016) analyzed the hydrological impact of urbanization in Jakarta. The study established that as a result of an increase in urban intensity, the tropical river catchments face the challenge in water resources. The study also found the detrimental effects of speedy drastic land utilization as an outcome of urbanization in Indonesia. Similarly, studying the West Java province of Indonesia from the period of 1997 to 2014, Agaton, Setiawan and Effendi (2016) stated that Citarum Watershed is severely endangered by the increase in urbanization and deforestation. Moreover, examining the landscape variation in Indonesia, Arifin and Nakagoshi (2011) also stated that a fast-paced rise in urbanization, especially in a developing country such as Indonesia, contained a detrimental effect on bio-capacity of the country.

In China, Shen, Cheng, Gunson and Wan (2005) examined the relationship between urban development and power and natural resources utilization. In doing so, the authors utilized the data from the period of 1952 to 1999. The study found that urban development is a crucial factor in natural resource depletion. Specifically, the findings revealed that predicted that the resource of steel, coal, cement, aluminum, along with timber, are significant to influence the rate of urban intensity. The study also predicted that the trends of urbanization are likely to augment in the future, thereby poses a stronger threat of the extended resource scarcity in the country. Similarly, Ducrot, Le-Page, Bommel and Kuper (2004) also reported that an increase in urban intensity amplified the conflicts for natural resources utilization, hence required the need for advanced management of water and land consumption. Also, Hassan, Xia, Khan and Shah (2019) also studied the role of urbanization in disrupting eco-services. Specifically, the study assessed how the increase in urbanization is associated with the ecological footprint of Pakistan. The authors found that urbanization has a significant negative effect on the demand for natural resources, land, water, etc.

Applying the panel estimations, Bilgili, Koçak, Bulut and Kuloğlu (2017) examined the role of urbanization in affecting energy intensity in Indonesia, Malaysia, China, Nepal, Philippines, Bangladesh, South Korea, Vietnam, India, and Thailand between 1990 to 2014. Similar to Ma (2015) and Hussain, Slusarczyk, Kamarudin, Thaker and Szczepańska-Woszczyna (2020), the study also found the significant positive role of urbanization in increasing energy intensity in the selected Asian economies. In another panel investigation, Bao and Chen (2017) analyzed the factors contributing to water efficiency in thirty-one provinces of China. The findings of the study stated that urbanization reduces the efficiency of water consumption in Chinese provinces. Similarly, Gao and He (2017), while examining the association between urbanization and water consumption in China, also stated that an increase in urbanization enhanced water usage in the country. For India, Raj (2016) also reported that an increase in globalization has resulted in a water supply shortage in Bangalore City.

Moreover, Ma (2015) examined the impact of urbanization on coal and energy intensity. For this, the authors analyzed the data of the Chinese economy from 1986 to 2011. The results of the study found that urban intensity is significantly linked to energy intensity, stating that the rise in urbanization enhanced energy intensity. However, the results failed to find the impact of urbanization on coal intensity in China. Moreover, focusing on wood consumption in the form of timber, Delphin, Escobedo, Abd-Elrahman and Cropper (2016) investigated the impact of urbanization on forestry. In doing so, the study gathered information on the United States economy for the time period of 57 years. The results found that timber volume is largely reduced as a result of urbanization in the state of Florida. Similar results were reported in the study of Zhang and Nagubadi (2005), establishing that urban intensity decreases forestry timbers.

In another study, Ding and Peng (2018) examined the role of urbanization and resource consumption in the mountainous region of Dali Prefecture. The study stated that urban intensity had amplified the impact of people on natural resources. Specifically, the authors found that urban development has greatly affected arable land and thus enhanced the ecological footprint challenges. Similarly, Wu, Li and Li (2018), while analyzing the levels of natural resources in China, stated that Fees of resources are a crucial aspect for the country's growth. However, urbanization, industrialization, and poor usage of natural resources are detrimental to the country's resource sustenance. Similarly, in the case of metal resources, Ma et al. (2016) reported that an increase in urban intensity resulted in contamination and enrichment of metals into the atmosphere. Likewise, in southern Finland, Virkanen (1998) also found that urbanization led to enhance metal deposition in the country.

Furthermore, Wan et al. (2015) stressed on the concept of ecosystem services in the presence of urban growth. For this, the author utilized the data of the Chinese economy from the period of 1990 to 2011. The study defined ecosystem services as the utilization of natural resources and related assets for the endurance of the population. The investigation found the inverted U-curved association among the variables of interest, indicating that with the increase in urbanization, the level of eco-services also enhanced, however with the growth in urban intensity, the country faces a decline in the level of natural resources and assets. For Brazil, Costa and Monte-Mór (2015) also found that an increase in urban intensity causes a decline in the management and endurance of natural resources, especially the poor exploitation of land, vegetation, and water resulted in augmented expenditures of sustainable policies. Emphasizing on energy usage from both renewable and non-renewable resources, Kwakwa (2019) examined the contributing factors of enhanced power utilization in Tunisia from the period of 1971 to 2014. Contrarily to earlier findings on resource consumption, the study found that urban development reduces energy utilization in Tunisia.

Methodology

As discussed earlier, the present study empirically investigates the association between urbanization and consumption of natural resources in the context of Indonesia. Hence in order to meet the objective of the present study, Nonlinear ARDL (NARDL) technique is applied. Moreover, in order to compute the said association and to apply the NARDL, in the present study, the annual data of time series from 1971 to 2018 has been used. In addition to this, the proxy to represent the urban intensity is the total number of urban population (measured in % of total populations), whereas, for the consumption of natural resources, total natural resources rent (measured in % of GDP) is used as a proxy. Moreover, we used economic growth as a control variable as it is one of the main reasons to increase natural resources in the Indonesia economy. The data for GDP is measured in per capita of

GDP. Lastly, the employed data was extracted from the database of the World Bank, which is considered as one of the most reliable time-series data based. Therefore, for the present study, the following empirical equation is being proposed:

$$ln\,\mathrm{NAR_t} = \mathrm{f}\,(ln\,\mathrm{URB_t},\ ln\,\mathrm{GDP_t}) \qquad (1)$$

The linear form of equation 1 is stated below:

$$ln\,\mathrm{NAR_t} = \beta + \beta_1\, ln\,\mathrm{URB_t} + \beta_2\ ln\,\mathrm{GDP_t} + \mu_t \qquad (2)$$

In econometrics, while evaluating the long-run relationship between two or more variables, there are three different approaches available to the researchers. These are Granger Causality, ECM, and ARDL approach (Fareed, Meo, Zulfiqar, Shahzad & Wang, 2018; Hussain, Grabara, Razimi & Sharif, 2019). By applying any of these approaches, the asymmetric aspect of the time series data employed is accounted for. In addition to this, the linear aspect of the relationship among variables can be evaluated by linear regression. However, linear regression has the limitation to account for and to handle the nonlinear relationships among the variables. Therefore, Shin et al. (2014) advance the earlier ARDL approaches, which were proposed by Pesaran, Shin and Smith (1999; 2001) to account for the nonlinear aspect of the relationships of the variables. By such advancements, the extended framework has the capability to explain the short term-based volatilities and the asymmetric aspect, which are termed as the structural breaks in the time-series data. Therefore, the long-run equation to account for the asymmetric aspect is mentioned below:

$$\mathrm{NAR_t} = \alpha_0 + \alpha_1\mathrm{URB_t^+} + \alpha_2\mathrm{URB_t^-} + \alpha_3\mathrm{GDP_t^+} + \alpha_4\mathrm{GDP_t^-} + \varepsilon_t \qquad (3)$$

In equation 3, natural resources are represented by NAR, whereas $\alpha = (\alpha_0, \alpha_1, \alpha_3, \alpha_4)$ represents the co-integrating vector that needs to be calculated. Moreover, $\mathrm{URB_t^+}$, $\mathrm{URB_t^-}$, $\mathrm{GDP_t^+}$, $\mathrm{GDP_t^-}$ represents the partial sums of the possible positive and negative changes in natural resources by the urban intensity and economic growth, as shown below.

$$\mathrm{URB_t^+} = \sum_{t=1}^{t} \Delta\mathrm{URB_t^+} = \sum_{t=1}^{t} max(\Delta\mathrm{URB_i}, 0). \qquad (4)$$

$$\mathrm{URB^-} = \sum_{t=1}^{t} \Delta\mathrm{URB_t^-} = \sum_{t=1}^{t} min(\Delta\mathrm{URB_i}, 0). \qquad (5)$$

$$\mathrm{GDP_t^+} = \sum_{t=1}^{t} \Delta\mathrm{GDP_t^+} = \sum_{t=1}^{t} max(\Delta\mathrm{GDP_i}, 0). \qquad (6)$$

$$\mathrm{GDP_t^-} = \sum_{t=1}^{t} \Delta\mathrm{GDP_t^-} = \sum_{t=1}^{t} min(\Delta\mathrm{GDP_i}, 0). \qquad (7)$$

Referring to equation 2, the extended asymmetric ARDL framework, which is proposed by Shin et al. (2014) is shown below:

$$\Delta\mathrm{NAR_t} = \beta_0 + \beta_1\mathrm{NAR_{t-1}} + \beta_2\mathrm{URB_{t-1}^+} + \beta_3\mathrm{URB_{t-1}^-} + \beta_4\mathrm{GDP_{t-1}^+} + \beta_5\mathrm{GDP_{t-1}^-} + \sum_{i=1}^{m} \delta_{1i}\Delta\mathrm{NAR_{t-1}}$$
$$+ \sum_{i=0}^{n} \delta_{2i}\Delta\mathrm{URB_{t-i}^+} + \sum_{i=0}^{p} \delta_{3i}\Delta\mathrm{URB_{t-i}^-} + \sum_{i=0}^{q} \delta_{4i}\Delta\mathrm{GDP_{t-i}^+} + \sum_{i=0}^{r} \delta_{5i}\Delta\mathrm{GDP_{t-i}^-}$$
$$+ u_i \qquad (8)$$

Referring to equation 8, lags orders are represented by *m*, *n*, *p*, *q* and *r*, whereas $\beta_1, \beta_2, \beta_3, \beta_4, \beta_5$ represents the positive and negative long term shock effects and $\sum_{i=0}^{n}\delta_{2i}, \sum_{i=0}^{p}\delta_{3i}, \sum_{i=0}^{q}\delta_{4i}, \sum_{i=0}^{r}\delta_{5i}$ represents the potential positive and negative short term on natural resources caused by the urban intensity and economic growth respectively. In the present study, by employing NRDL, the nonlinear based relationship among the variables are being studied and evaluated.

On the other hand, the asymmetric ARDL framework is applied as per the steps discussed by (Fareed, Meo, Zulfiqar, Shahzad & Wang, 2018). Firstly, all of the variables are evaluated, whether they are stationary or not. Such evaluation is performed by augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) unit root tests. Though the evaluation of stationery is not compulsory when approach like ARDL is applied, and ARDL can be employed when the variables are found stationary at either 1(0), 1(1) or the combination of 1(1) and (0). However, Ibrahim (2015) has discussed that ARDL has the limitation that when the 1(2) series is present, the model cannot proceed. Therefore, in order to avoid and eliminate the potential risk associated with the deceptive, tempered, or ambiguous findings, the stationary test was applied. Secondly, referring to Equation 8, the model is estimated through the ordinary least-squares method. In addition to this, following the guidelines by Katrakilidis and Trachanas (2012), the general to specific approach and SIC information criterion is also followed. Thirdly, the existence of cointegration was evaluated by employing bounds test just to ensure the presence or absence of cointegration. When the presence of cointegration is confirmed, the asymmetric ARDL framework is applied. At this stage, the derivation of the asymmetric cumulative dynamic multiplier effects lead by 1% change is studied in URB^{+}_{t-1}, URB^{-}_{t-1}, GDP^{+}_{t-1}, GDP^{-}_{t-1} accordingly. These are shown in the following equations:

$$s_h^{+}(URB) = \sum_{j=0}^{h} \frac{\partial NAR_{t+i}}{\partial URB^{+}_{t-1}} \quad (9)$$

$$s_h^{-}(URB) = \sum_{j=0}^{h} \frac{\partial NAR_{t+i}}{\partial URB^{-}_{t-1}} \quad (10)$$

$$s_h^{+}(GDP) = \sum_{j=0}^{h} \frac{\partial NAR_{t+i}}{\partial GDP^{+}_{t-1}} \quad (11)$$

$$s_h^{-}(GDP) = \sum_{j=0}^{h} \frac{\partial NAR_{t+i}}{\partial GDP^{-}_{t-1}} \quad (12)$$

Based on the aforementioned discussion, which states the step by step application of NARDL, the objective of the present study is studied and evaluated. The empirical findings of the tests applied, and results are discussed in the next section.

Data Analysis and Interpretation

Initially, we applied descriptive statistics for all the three variables used in this research. The findings of descriptive statistics are reported in Table 1. It contains mean value, minimum, maximum, standard deviation value along with the Jarque-Bera test, which confirms that whether our variables are linear or nonlinear. The findings confirm that the mean of all the variables is positive. The mean value of natural resources is 10.167, with a minimum value of 3.059 and a maximum value of 33.658. In addition, the mean value of urban intensity is 35.763, with a minimum value of 17.338 and a maximum value of 55.325. Moreover, the mean value of economic growth is 2118.153, with a minimum value of 804.724 and a maximum value of 4284.653. In addition, the standard deviation for natural resources, economic growth, and urban intensity are 6.022, 966.081, and 12.382. Furthermore, we applied the Jarque-Bera test to confirm the normality in the selected variables. The results of the JB test confirm the rejection of the null hypothesis at a 1% level of significance, which means all the variables are non-normally distributed. The results of further confirm that there is an indication of nonlinearity in all the selected variables (Troster et al., 2018; Shahbaz et al., 2018; Sharif et al., 2019; Arain et al., 2019).

Tab.1. Results of Descriptive Statistics

	GDP	NAR	URB
Mean	2118.153	10.167	35.763
Maximum	4284.653	33.658	55.325
Minimum	804.724	3.059	17.338
Std. Dev.	966.081	6.022	12.382
Skewness	0.585	1.848	0.035
Kurtosis	2.383	7.152	1.585
Jarque-Bera	34.500	61.786	42.017
Probability	0.000	0.000	0.000

Source: Authors' Estimations

There is one significant requirement of utilizing ARDL bound testing methodology that all of the aeries ought to be stationary at I (0) or I (1) but not I(2). As indicated by Ouattara (2004), the findings of ARDL will be invalid if any of the I (2) factors are considered for the model. Thusly, it is fundamental to decide the stationarity of the dataset. In doing so, we used ADF and PP unit root tests, and the outcomes of the two tests are introduced in Table 2. The unit root test outcomes indicated that natural resources rents, urban intensity, and economic growth are showing not stationary features at the level and then become stationary at the first differential series. Moreover, we likewise utilized Zivot and Andrews' (1992) unit root test, which reflects breaks as contended by

Perron (1989) that the basic stationary tests give bogus results within sight of breaks to dismiss the null of unit root test. Thinking about the issue of the break in the time series, utilizing Zivot and Andrews (1992) unit root test, we additionally observed that all the factors are stationary at I (1), not I (2) (Table 3). Subsequently, it is affirmed that we can apply ARDL methodology as all the series are not I (2).

Tab. 2. Results of Unit root test

Variables	ADF Unit root test				PP unit root test			
	I(0)		I(1)		I(0)		I(1)	
	C	C&T	C	C&T	C	C&T	C	C&T
GDP	0.438	0.392	-5.382	-5.024	0.391	0.401	-5.658	-5.33
NAR	-0.214	-0.195	-4.137	-4.372	-0.227	-0.254	-4.282	-4.039
URB	-0.827	-0.785	-3.486	-3.773	-0.754	-0.795	-3.435	-3.238
Note: GDP explains the per capita of gross domestic product, NAR represents the natural resources rents, and URB describes the urban population. ***, ** & * represents level of significance at 1%, 5% and 10% respectively.								

Source: Authors' Estimations

Tab. 3. Zivot-Andrews Structural Break Trended Unit Root Test

Variable	At Level		At 1st Difference	
	T- Statistics	Time Break	T- Statistics	Time Break
GDP	-0.346 (1)	2004	-5.483 (1)***	2002
NAR	-1.048 (1)	2010	-5.049 (1)***	2000
URB	-0.893 (1)	1999	-7.724 (1)***	2015
Note: Lag order shown in parenthesis.				
* Represents significance at 1% level.				

Source: Authors' Estimations

Moreover, Sharif, Afshan & Shahzad (2018) asserted that long-term connections rely upon maximum lags, and Stock and Watson (2012) additionally affirmed that utilizing an excessive number of lags or utilizing less lags can avoid most significant information of the framework or may reason worthless valuation. Hence, thinking about the significance of ideal lags, we utilized just 1 lag as ideal after Schwarz Info Criteria (SIC). The results of bound testing, along with nonlinear specifications, are reported in Table 4. The value of F-stats is higher than the upper limits at a 5% significance level, which affirms the nonlinear long-run relationship between urban intensity, natural resources, and economic growth in Indonesia. In this manner, we can push ahead to estimate nonlinear ARDL coefficients.

Tab. 4. Results of Bond test cointegration in the asymmetric specification

Model	F-Statistics	Upper Bond	Lower Bond
ln NAR / (ln URB_POS, ln URB_NEG, ln GDP_POS, ln GDP_NEG)	32.548		
Critical Values			
10%		4.463	1.735
5%		5.433	2.231
1%		6.873	2.802
Note: The combine null of no long-run relationship is p=o+ = o-=0. Moreover, the critical values are depending on Narayan (2005), the sample period.			

Source: Authors' Estimations

In the next step, we evaluated equation 8 by utilizing the general approach utilizing $p=q=1$ as an ideal lag selection. The leading investigation of Shin et al. (2014) additionally pursued this way to deal with the final description of the nonlinear ARDL framework. Here, we did not use all the lag regressors, which are insignificant, as indicated by the general approach since Katrakilidis and Trachanas (2012) proposed expelling unimportant lag regressors is vital as insignificant lag regressors can make clamor in the graphical plot multipliers. Moreover, we likewise checked other significant issues of NARDL, for example, heteroskedasticity utilizing the BPG test, serial correlation utilizing the LM test, and specification of the model using the Ramsey RESET test. The findings of the diagnostic test are reported in table 7. The results affirmed that the framework is not experiencing any of the previously mentioned problems; along these lines, we can push toward a novel estimation of the NARDL approach. The NARDL estimation findings are reported in Table 5.

Tab. 5. Estimations using NARDL Approach

Variables	Coeff.	t-stats	Prob.
C	2.048	3.088	0.005
ln NAR (-1)	0.384	5.372	0.000
ln URB_NEG	0.284	4.684	0.000
ln URB_POS	0.176	3.785	0.000
ln GDP_NEG (-1)	-0.133	-1.960	0.050
ln GDP_POS (-1)	0.295	4.547	0.000
DlnURB_NEG (-1)	0.216	4.628	0.000
DlnURB_POS (-1)	0.149	3.957	0.000
DlnGDP_NEG (-1)	0.206	-4.515	0.000
DlnGDP_POS (-1)	0.124	2.019	0.050
Note: _POS & NEG reflects to partial sum of positive and negative			

Source: Authors' Estimations

The present study investigates the asymmetric effect of urban intensity and economic growth on natural resources in Indonesia. The results of long-run asymmetric ARDL is reported in Table-6. The results affirmed that there is a presence of an asymmetric connection between urban intensity and natural resources and economic growth and natural resources in the Indonesian economy. The results further suggested that due to the negative shocks of urban intensity, the natural resources rents decreased by 20.4%. However, because of the positive shocks of urban intensity, the natural resources rents increase by 35.5%. The signs of both shocks are different, which affirm a nonlinear relationship between urban intensity and natural resources. The findings are very logical and justifiable as the number of people increases in urban areas; the needs of natural resources increase as compared if people live in rural areas. On the other hand, the effect of economic growth on natural resources is also significant and asymmetric in nature. The negative shocks in GDP increase the natural resources rent by 18.3%. However, the positive shocks in GDP increase the natural resources by 38.5%. The signs of both shocks are the same, but the magnitudes are different, which suggested that there is an asymmetric relationship between economic growth and natural resources. This means that, as the economic growth increase of decrease, it will increase the needs of natural resources with a different magnitude as low growth increase natural resources rent significantly lower in comparison with higher growth in the Indonesia economy.

Tab. 6. Results of Long-run asymmetric using NARDL Approach

Variables	Coeff.	t-stats	Prob.
ln URB_NEG	-0.204	4.548	0.000
ln URB_POS	0.353	4.968	0.000
ln GDP_NEG	0.183	2.904	0.004
ln GDP_POS	0.385	5.411	0.000
Dependent Variable: Natural resources rent			

Source: Authors' Estimations

Next, the results of the diagnostic test of the NARDL approach are reported in Table 7. Here, the significance value of LM and Breusch-Pagan-Godfrey is greater than 0.100 (10%), which confirms that the model is independent of serial correlation and heteroscedasticity issues. In addition, we reported the p-value of the Ramsay RESET test, which is also more than 0.100, suggesting that the current model is suitably specified. Finally, we reported the variance inflation factor value, which is 4.583, suggesting that there is no problem of multicollinearity in our model.

Tab. 7. Results of Diagnostic Test

Diagnostic Test	Problem	P-value	Status
LM test	Serial Correlation	0.148	No serial correlation
Breusch-Pagan-Godfrey	Heteroscedasticity	0.227	No heteroscedasticity
Ramsey RESET test	Model specification	0.583	Model is correct
VIF	Multicollinearity	4.582	No multicollinearity

Source: Authors' Estimations

In the final step, we applied the asymmetric Granger causality, which is proposed by Hatemi-j (2012). We used asymmetric causality to examine the causal connection between the positive and negative shocks natural resources, urban intensity, and economic growth in the Indonesia economy. The results are reported in Table-8. The results suggested a unidirectional causal relationship from negative shocks of urban intensity and positive shocks o natural resources. Moreover, the results further suggested a unidirectional causal connection from the positive shock of urban intensity to positive shocks of natural resources. On the other hand, the causal connection between economic growth and natural resources rent is significant. We found a bidirectional causal connection between positive shocks of natural resources to positive and negative shocks of economic growth and positive shocks of economic growth to positive and negative shocks of natural resources rents in the Indonesian economy. However, we do not find any causal connection from negative shocks of natural resources rents to the positive and negative shock of urban intensity and economic growth.

Tab. 8. Results of Asymmetric Granger Causality

Null hypothesis	Wald Test	Bstrap 1%	Bstrap 5%	Bstrap 10%
NAR^- does not Granger cause URB^-	4.483	19.372	14.472	9.372
NAR^- does not Granger cause URB^+	2.048	8.483	6.613	4.874
NAR^+ does not Granger cause URB^-	0.483	10.746	8.313	5.382
NAR^+ does not Granger cause URB^+	1.484	24.584	19.485	16.897
URB^- does not Granger cause NAR^-	3.694	7.692	6.039	4.593
URB^- does not Granger cause NAR^+	26.483***	14.483	11.962	9.493
URB^+ does not Granger cause NAR^-	4.932	9.766	7.491	5.882
URB^+ does not Granger cause NAR^+	19.496***	9.521	7.804	6.087
NAR^- does not Granger cause GDP^-	0.483	15.584	11.421	8.572
NAR^- does not Granger cause GDP^+	4.797	19.385	10.096	7.381
NAR^+ does not Granger cause GDP^-	53.390***	23.584	18.009	15.882
NAR^+ does not Granger cause GDP^+	38.511***	16.900	13.548	10.596
GDP^- does not Granger cause NAR^-	4.583	18.795	12.001	9.593
GDP^- does not Granger cause NAR^+	0.427	14.778	9.493	7.842
GDP^+ does not Granger cause NAR^-	9.584***	7.483	4.583	1.484
GDP^+ does not Granger cause NAR^+	46.651***	19.584	14.642	10.037
Note: *, ** and *** indicate statistical significance at 10, 5 and 1% level respectively. Critical values are obtained from 10000 bootstrap replications.				

Note: *, ** and *** indicate statistical significance at 10, 5 and 1% level respectively. Critical values are obtained from 10000 bootstrap replications.

Discussion and Conclusion

Urbanization also results in the potential challenge of housing and land surface usage that need to improve accordingly. In addition to this, due to urban intensity, the planning related to education, health, employment opportunities also affected that also need to grow in parallel to the urbanization so that the economy can be efficiently managed. However, the most important challenge of urbanization is the usage and depletion of the natural resources that lead to a potential threat to ecological health. In doing so, the aim of this study is to explore the rate of urbanization at the cost of consumption of natural resources. The current study applied a novel methodology of nonlinear ARDL proposed by Shin et al. (2014). This methodology is ideal to answer the asymmetric effect on the independent variable on the dependent variable. Furthermore, we also applied asymmetric Granger causality introduced by Hatemi-J (2012) to confirm the causal relationship between the variables. The results of NARDL affirmed that all the variables have a significant impact on natural resources rent. The findings confirm that negative shocks of urban intensity decrease the natural resources rents; however, the positive shocks increase the rents of natural resources. On the one hand, the positive and negative shocks of GDP increase the natural resources though, the magnitude of positive shocks are significantly different from the negative shocks. On the other hand, the results of asymmetric Granger causality confirm that positive and negative shock of urban intensity does granger cause positive shocks of natural resources. Whereas, positive shocks of natural resources (economic growth) have a causal connection with positive and negative shocks of economic growth (natural resources) in Indonesia. The current study recommends that the Indonesia government and policymakers need to provide a better life and earning opportunities in the rural areas, so the people do not travel more towards urban areas, which ultimately helps to reduce natural resources.

References

Agaton, M., Setiawan, Y., & Effendi, H. (2016). Land use/land cover change detection in an urban watershed: a case study of upper Citarum Watershed, West Java Province, Indonesia. *Procedia Environmental Sciences*, *33*, 654-660, doi: 10.1016/j.proenv.2016.03.120

Arain, H., Han, L., Sharif, A., & Meo, M. S. (2019). Investigating the effect of inbound tourism on FDI: The importance of quantile estimations. *Tourism Economics*, DOI: 10.1177/1354816619859695

Arfanuzzaman, M., & Rahman, A. A. (2017). Sustainable water demand management in the face of rapid urbanization and ground water depletion for social–ecological resilience building. *Global Ecology and Conservation*, *10*, 9-22, https://doi.org/10.1016/j.gecco.2017.01.005

Arifin, H. S., & Nakagoshi, N. (2011). Landscape ecology and urban biodiversity in tropical Indonesian cities. *Landscape and ecological engineering*, *7*(1), 33-43, DOI 10.1007/s11355-010-0145-9

Bahmani-Oskooee, M., & Bohl, M. T. (2000). German monetary unification and the stability of the German M3 money demand function. *Economics letters*, *66*(2), 203-208, https://doi.org/10.1016/S0165-1765(99)00223-2

Bakirtas, T., & Akpolat, A. G. (2018). The relationship between energy consumption, urbanization, and economic growth in new emerging-market countries. *Energy*, *147*, 110-121, https://doi.org/10.1016/j.energy.2018.01.011

Bao, C., & Chen, X. (2017). Spatial econometric analysis on influencing factors of water consumption efficiency in urbanizing China. *Journal of Geographical Sciences*, *27*(12), 1450-1462, https://doi.org/10.1007/s11442-017-1446-9

Bertinelli, L., & Black, D. (2004). Urbanization and growth. *Journal of Urban Economics*, *56*(1), 80-96.

Bilgili, F., Koçak, E., Bulut, Ü., & Kuloğlu, A. (2017). The impact of urbanization on energy intensity: Panel data evidence considering cross-sectional dependence and heterogeneity. *Energy*, *133*, 242-256, https://doi.org/10.1016/j.energy.2017.05.121

Blyth, S.; Groombridge, B.; Lysenko, I.; Miles, L.; Newton, A. (2002). Mountain Watch, Environmental Change and Sustainable Development in Mountains; UNEP-WCMC: Cambridge, UK; p. 11.

Bunte, J. B., Desai, H., Gbala, K., Parks, B., & Runfola, D. M. (2018). Natural resource sector FDI, government policy, and economic growth: Quasi-experimental evidence from Liberia. *World Development*, *107*, 151-162, https://doi.org/10.1016/j.worlddev.2018.02.034

Costa, H. S., & Monte-Mór, R. L. (2015). Urbanization & Environment: trends and patterns in contemporary Brazil. *Livros*, 125-146.

Delphin, S., Escobedo, F. J., Abd-Elrahman, A., & Cropper, W. P. (2016). Urbanization as a land use change driver of forest ecosystem services. *Land Use Policy*, *54*, 188-199, https://doi.org/10.1016/j.landusepol.2016.02.006

Ding, Y., & Peng, J. (2018). Impacts of urbanization of mountainous areas on resources and environment: Based on ecological footprint model. *Sustainability*, *10*(3), 765, https://doi.org/10.3390/su10030765

Ducrot, R., Le Page, C., Bommel, P., & Kuper, M. (2004). Articulating land and water dynamics with urbanization: an attempt to model natural resources management at the urban edge. *Computers, Environment and Urban Systems*, *28*(1-2), 85-106, https://doi.org/10.1016/S0198-9715(02)00066-2

Elmqvist, T., Fragkias, M., Goodness, J., Güneralp, B., Marcotullio, P. J., McDonald, R. I., ... & Wilkinson, C. (Eds.). (2013). *Urbanization, biodiversity and ecosystem services: challenges and opportunities: a global assessment*. Springer.

Fareed, Z., Meo, M. S., Zulfiqar, B., Shahzad, F., & Wang, N. (2018). Nexus of tourism, terrorism, and economic growth in Thailand: new evidence from asymmetric ARDL cointegration approach. *Asia Pacific Journal of Tourism Research*, *23*(12), 1129-1141, https://doi.org/10.1080/10941665.2018.1528289

Fujii, T. (1966). Industrization, urbanization and economic growth. *Econ. Rev. 17*, 368–372.

Gao, S., & He, Y. (2017). The Effect of Urbanization and Economic Performance on Metropolitan Water Consumption: Theoretic Model and Evidence from Guangzhou of China. *Applied Economics and Finance*, *4*(2), 163-171, https://doi.org/10.11114/aef.v4i2.2076

Gilberthorpe, E., & Hilson, G. (Eds.). (2016). *Natural resource extraction and indigenous livelihoods: Development challenges in an era of globalization*. Routledge.

Guo, X., Zhang, Z., Zhao, R., Wang, G., & Xi, J. (2018). Association between coal consumption and urbanization in a coal-based region: a multivariate path analysis. *Environmental Science and Pollution Research*, *25*(1), 533-540, https://doi.org/10.1007/s11356-017-0436-x

Hao, L. (2007). Natural Resource and Economic Growth: Resource Bottleneck and its Solution [J]. *Economic Research Journal*, *6*, 142-153,

Hatemi-j, A. (2012). Asymmetric causality tests with an application. *Empirical Economics*, *43*(1), 447-456, https://doi.org/10.1007/s00181-011-0484-x

Hart, S. L. (1995). A natural-resource-based view of the firm. *Academy of management review*, *20*(4), 986-1014.

Hassan, S. T., Xia, E., Huang, J., Khan, N. H., & Iqbal, K. (2019). Natural resources, globalization, and economic growth: evidence from Pakistan. *Environmental Science and Pollution Research*, *26*(15), 15527-15534, https://doi.org/10.1007/s11356-019-04890-z

Hassan, S. T., Xia, E., Khan, N. H., & Shah, S. M. A. (2019). Economic growth, natural resources, and ecological footprints: evidence from Pakistan. *Environmental Science and Pollution Research*, *26*(3), 2929-2938, https://doi.org/10.1007/s11356-018-3803-3

Havranek, T., Horvath, R., & Zeynalov, A. (2016). Natural resources and economic growth: a meta-analysis. *World Development*, *88*, 134-151, https://doi.org/10.1016/j.worlddev.2016.07.016

Henderson, V. (2002). Urbanization in developing countries. *The World Bank Research Observer, 17*(1), 89–112. https://doi.org/10.1093/wbro/17.1.89.

Hussain, H.I., Grabara, J., Razimi, M.S.A., & Sharif, S.P. (2019) Sustainability of Leverage Levels in Response to Shocks in Equity Prices: Islamic Finance as a Socially Responsible Investment, *Sustainability*, 11 (12), 3260. https://doi.org/10.3390/su11123260.

Hussain, H.I., Slusarczyk, B., Kamarudin, F., Thaker, H.M.T., Szczepańska-Woszczyna, K. (2020) An investigation of an adaptive neuro-fuzzy inference system to predict the relationship among energy intensity, globalization, and financial development in major ASEAN economies. *Energies*, 13 (4), art. no. 850. doi: 10.3390/en13040850

Ibrahim, M. H. (2015). Oil and food prices in Malaysia: a nonlinear ARDL analysis. *Agricultural and Food Economics*, *3*(1), 1-14, https://doi.org/10.1186/s40100-014-0020-3

Katrakilidis, C., & Trachanas, E. (2012). What drives housing price dynamics in Greece: New evidence from asymmetric ARDL cointegration. *Economic Modelling*, *29*(4), 1064-1069, https://doi.org/10.1016/j.econmod.2012.03.029

Kurniawan, R., & Managi, S. (2018). Coal consumption, urbanization, and trade openness linkage in Indonesia. *Energy policy*, *121*, 576-583, https://doi.org/10.1016/j.enpol.2018.07.023

Kwakwa, P. A. (2019). Towards Sustainable Energy: What Have Natural Resource Extraction, Political Regime and Urbanization Got to Do With it?. *Parameters*, *1*, 1; DOI: 10.22109/JEMT.2019.152097.1132

Löffler, J.; Anschlag, K.; Baker, B.; Finch, O.-D.; Wundram, D.; Diekkrüger, B.; Schröder, B.; Pape, R.; Lundberg, A. (2011). Mountain ecosystem response to global change. Erdkunde, 6, 189–213, DOI: 10.3112/erdkunde.2011.02.06

Ma, B. (2015). Does urbanization affect energy intensities across provinces in China? Long-run elasticities estimation using dynamic panels with heterogeneous slopes. *Energy Economics*, *49*, 390-401, https://doi.org/10.1016/j.eneco.2015.03.012

Ma, Y. & Hao, Q. (2020) Innovation of Economic Management under Economic Globalization based on Cognitive and Behavioral Sciences, *Revista Argentina de Clínica Psicológica*, 29 (2), 846 – 853.

Ma, J., Liu, Y., Yu, G., Li, H., Yu, S., Jiang, Y., ... & Lin, J. (2016). Temporal dynamics of urbanization-driven environmental changes explored by metal contamination in surface sediments in a restoring urban wetland park. *Journal of hazardous materials*, *309*, 228-235, https://doi.org/10.1016/j.jhazmat.2016.02.017

Meyer, D.F., Meyer, N. (2016). A comparative analysis of the perceptions of business chambers in rural and urban South Africa on the developmental role of local government. *Polish Journal of Management Studies*, 14(1), 152-162, DOI: 10.17512/pjms.2016.14.1.14

Miao, C., Fang, D., Sun, L., & Luo, Q. (2017). Natural resources utilization efficiency under the influence of green technological innovation. *Resources, Conservation and Recycling*, *126*, 153-161, https://doi.org/10.1016/j.resconrec.2017.07.019

Nurwanda, A., & Honjo, T. (2020). The prediction of city expansion and land surface temperature in Bogor City, Indonesia. *Sustainable Cities and Society*, *52*, 101772, https://doi.org/10.1016/j.scs.2019.101772

Ouattara, B. (2004). Modelling the long run determinants of private investment in Senegal. The School of Economics Discussion Paper Series 0413. *Economics, The University of Manchester*.

Parsons, A. W., Rota, C. T., Forrester, T., Baker-Whatton, M. C., McShea, W. J., Schuttler, S. G., ... & Kays, R. (2019). Urbanization focuses carnivore activity in remaining natural habitats, increasing species interactions. *Journal of Applied Ecology*, 56(8), 1894-1904, https://doi.org/10.1111/1365-2664.13385

Payne, K.;Warrington, S.; Bennett, O. (2002). High Stakes: The Future for Mountain Societies; London England Panos Institute: London, UK.

Pegg, S. (2003). Globalization and natural-resource conflicts. *Naval War College Review*, *56*(4), 82-96.

Perron, P. (1989). The great crash, the oil price shock, and the unit root hypothesis. *Econometrica: Journal of the Econometric Society*, 57(6), 1361-1401, DOI: 10.2307/1913712

Pesaran, M. H., Shin, Y., & Smith, R. J. (2001). Bounds testing approaches to the analysis of level relationships. *Journal of applied econometrics*, *16*(3), 289-326, https://doi.org/10.1002/jae.616

Pesaran, M. H., Shin, Y., & Smith, R. P. (1999). Pooled mean group estimation of dynamic heterogeneous panels. *Journal of the American Statistical Association*, *94*(446), 621-634.

Popp, J., Oláh, J., Fekete, M.F., Lakner, Z., & Máté, D. (2018) The relationship between prices of various metals, oil and scarcity. *Energies,* 11(9), art. no. 2392, https://doi.org/10.3390/en11092392

Raj, K. (2016). Urbanization and Water Supply: An Analysis of Unreliable Water Supply in Bangalore City, India. In *Nature, Economy and Society* (pp. 113-132). Springer, New Delhi.

Remondi, F., Burlando, P., & Vollmer, D. (2016). Exploring the hydrological impact of increasing urbanisation on a tropical river catchment of the metropolitan Jakarta, Indonesia. *Sustainable Cities and Society*, *20*, 210-221, https://doi.org/10.1016/j.scs.2015.10.001

Sanusi, K.A., Meyer, D., Ślusarczyk, B. (2017). The relationship between changes in inflation and financial development. *Polish Journal of Management Studies*, 16(2), 253-265, DOI: 10.17512/pjms.2017.16.2.22

Seeking Alpha (2017). "Indonesia – The Next Major Oil Importer?". Archived from the original on 6 February 2017. Retrieved 6 February 2017.

Shahbaz, M., Zakaria, M., Shahzad, S. J. H., & Mahalik, M. K. (2018). The energy consumption and economic growth nexus in top ten energy-consuming countries: Fresh evidence from using the quantile-on-quantile approach. *Energy Economics*, *71*, 282-301, https://doi.org/10.1016/j.eneco.2018.02.023

Sharif, A., Afshan, S., & Khan, B. S. (2018). Does democracy embolden economic growth in Pakistan? Evidence from ARDL bound testing and rolling window analysis. *International Journal of Economics and Business Research*, *15*(2), 180-203, https://doi.org/10.1504/IJEBR.2018.089684

Sharif, A., Afshan, S., & Qureshi, M. A. (2019). Idolization and ramification between globalization and ecological footprints: evidence from quantile-on-quantile approach. *Environmental Science and Pollution Research*, *26*(11), 11191-11211, https://doi.org/10.1007/s11356-019-04351-7

Shen, L., Cheng, S., Gunson, A. J., & Wan, H. (2005). Urbanization, sustainability and the utilization of energy and mineral resources in China. *Cities*, *22*(4), 287-302, https://doi.org/10.1016/j.cities.2005.05.007

Shin, Y., Yu, B., & Greenwood-Nimmo, M. (2014). Modelling asymmetric cointegration and dynamic multipliers in a nonlinear ARDL framework. In *Festschrift in honor of Peter Schmidt* (pp. 281-314). Springer, New York, NY.

Siddique, H. M. A., Majeed, M. T., & Ahmad, H. K. (2016). The Impact of Urbanization and Energy Consumption on CO 2 Emissions in South Asia. *South Asian Studies (1026-678X)*, *31*(2).

Sabishchenko, O., Rębilas, R., Sczygiol, N., Urbański, M. (2020). Ukraine energy sector management using hybrid renewable energy systems. *Energies*, 13 (7), art. no. 1776, doi: 10.3390/en13071776

Stock, J., & Watson, M. (2012). Disentangling the channels of the 2007–2009 recession (WP no. 18094). Cambridge, MA: NBER. doi:10.3386/w18094

The Jakarta Post. (2017). 16,000 Indonesian islands registered at UN". 21 August 2017. Archived from the original on 30 November 2018. Retrieved 3 December 2018.

The World Bank (2016). Retrieved from: https://www.worldbank.org/en/news/feature/2016/06/14/indonesia-urban-story

Tomlinson, C. J., Chapman, L., Thornes, J. E., & Baker, C. J. (2011). Including the urban heat island in spatial heat health risk assessment strategies: a case study for Birmingham, UK. *International journal of health geographics*, *10*(1), 42, https://doi.org/10.1186/1476-072X-10-42

Troster, V., Shahbaz, M., & Uddin, G. S. (2018). Renewable energy, oil prices, and economic activity: A Granger-causality in quantiles analysis. *Energy Economics*, *70*, 440-452, https://doi.org/10.1016/j.eneco.2018.01.029

UN-Habitat. (2016). Urbanization and Development: Emerging Futures. World Cities Report. Nairobi, Africa. Available online: https://unhabitat.org/wp-content/uploads/2014/03/WCR-%20Full-Report-2016.pdf (accessed on 30 May 2017).

United Nations General Assembly (2017). New Urban Agenda. Available online: http://habitat3.org/the-newurban-agenda/

Virkanen, J. (1998). Effect of urbanization on metal deposition in the bay of Töölönlahti, Southern Finland. *Marine Pollution Bulletin*, *36*(9), 729-738, https://doi.org/10.1016/S0025-326X(98)00053-8

Wan, L., Ye, X., Lee, J., Lu, X., Zheng, L., & Wu, K. (2015). Effects of urbanization on ecosystem service values in a mineral resource-based city. *Habitat International*, *46*, 54-63, https://doi.org/10.1016/j.habitatint.2014.10.020

Wang, S. (2018). *Impact of Urbanization of Coal Consumption in China*. Retrieved from https://repository.library.georgetown.edu/handle/10822/1050875

Wu, S., Li, L., & Li, S. (2018). Natural resource abundance, natural resource-oriented industry dependence, and economic growth: Evidence from the provincial level in China. *Resources, Conservation and Recycling*, *139*, 163-171, https://doi.org/10.1016/j.resconrec.2018.08.012

Yan, W. (2020) Multi-Factor Check-and-Balance Mechanism of the Spread of Urban Financial Emergencies and Public Psychological Acceptance, *Revista Argentina de Clínica Psicológica*, 29 (2), 200 – 206.

Yuan, F., Sawaya, K. E., Loeffelholz, B. C., & Bauer, M. E. (2005). Land cover classification and change analysis of the Twin Cities (Minnesota) Metropolitan Area by multi temporal Landsat remote sensing. *Remote sensing of Environment*, *98*(2-3), 317-328, https://doi.org/10.1016/j.rse.2005.08.006

Zhang, D., & Nagubadi, R. V. (2005). The influence of urbanization on timberland use by forest type in the Southern United States. *Forest Policy and Economics*, *7*(5), 721-731, https://doi.org/10.1016/j.forpol.2005.03.002

Zivot, E., & Andrews, D. W. K. (1992). Further evidence on the great crash, the oil-price shock, and the unit-root hypothesis. *Journal of business & economic statistics*, *20*(1), 25-44.

Acta Montanistica Slovaca
ISSN 1335-1788
actamont.tuke.sk

The Destructive Impact of Burned Peatlands to Physical and Chemical Properties of Soil

***Deasy ARISANTY*[1], *Karol JĘDRASIAK*[2], *Ismi RAJIANI*[3]* *and Janusz GRABARA*[4]**

Authors' affiliations and addresses:
[1] Lambung Mangkurat University, Jl. Brigjend H. Hasan Basry, Banjarmasin 70123, Indonesia
e-mail: deasyarisanty@ulm.ac.id

[2] Faculty of Applied Sciences, Department of Transport and IT, WSB University, Zygmunta Cieplaka 1c, 41-300 Dąbrowa Górnicza, Poland
e-mail: jedrasiak.karol@gmail.com

[3] Lambung Mangkurat University, Jl. Brigjend H. Hasan Basry, Banjarmasin 70123, Indonesia
e-mail: rajiani@ulm.ac.id

[4] The Management Faculty, Czestochowa University of Technology, Armii Krajowej 19B, 42-201 Częstochowa, Poland and Al-Farabi Kazakh National University, Kazakhstan
e-mail: janusz@grabara.eu

***Correspondence:**
Ismi Rajiani, Lambung Mangkurat University, Jl. Brigjend H. Hasan Basry, Banjarmasin 70123, Indonesia
tel.: +62812342322298
e-mail: rajiani@ulm.ac.id

How to cite this article:
Arisanty, D., Jędrasiak, K., Rajiani, I. and Grabara, J. (2020). The Destructive Impact of Burned Peatlands to Physical and Chemical Properties of Soil. *Acta Montanistica Slovaca,* Volume 25 (2), 213-223

DOI:
https://doi.org/10.46544/AMS.v25i2.8

Abstract
Peatland fires occur every year in the South Kalimantan Province Indonesia, particularly affecting soil characteristics. The purposes of this study are to analyse the physical aspects of soil (colour and soil texture) caused by fires and to investigate the chemical characteristics of soil (pH, Fe^{2+}, P_2O_5, and K_2O). This study used measurements in the field based on a map of peatland fires in the region and laboratory results. There were 24 samples in this study; they were taken in October 2018, which was about a month after the fire, and in January 2019, which was about four months after the burning. The samples were analysed regarding the soil colour, texture, pH, $Fe^{2+,}$ P_2O_5, and K_2O. The results of the study indicated that the characteristics of the soil on burned land in October 2018 had higher pH, P_2O_5, and K_2O levels than in January 2019. Fires occurred in soil brought changes to the soil physical and chemical properties. The added combustion ash affected the physical and chemical properties of the land, such as soil colour, texture, pH, P_2O_5, K_2O, and Fe^{2+}.

Keywords
Peatland, land burning, soil characteristics

Introduction

Land fires in Indonesia are regional and global disasters. They do not only bring impacts to Indonesia, but gas emission from the combustion also affect neighbouring countries (Nugroho, 2017). Fires in Indonesia occur not only on dry land but also on wetlands (Cahyono et al., 2015; Rauf, 2016). In wetlands, they often burn on deep organic soils that accumulate in this ecosystem. Fires can occur on high-frequency wetlands that will increase in the future (Brown et al., 2015; Watts & Kobziar, 2013), one of which is on peatland.

Peatlands in Indonesia are estimated at 20.6 million hectares or around 10.8% of Indonesia's land area. Peatland fire in Indonesia regularly occurs in the dry season. The dry season is compounded by the number of dry days within the dry season or the El Niño, and the drainage system of peatland (Novitasari et al., 2019; Nugroho, 2017). In the reaction of peatland burning, the Indonesian government has propelled an activity to reestablish more than 2 million ha of peatland between presently and 2020 for Kalimantan, Sumatra, and Papua Islands (Hansson & Dargusch, 2017).

Kalimantan peatland area reaches 5.7 ha, or 27.8% of the island (Wahyunto & Suparto, 2004) and this area becomes the main location of Reducing Emissions from Deforestation and forest Degradation (REDD+) which is a project of sustainable management of forests and enhancement of forest carbon stocks in developing countries (Rajiani & Pypłacz, 2018). Peatland in South Kalimantan is always burned every year (Arisanty et al., 2019; Vetrita & Cochrane, 2020). The area burned in South Kalimantan Province has increased in the last 3 years. The burned area reached 2,331.96 Ha in 2016; 8,290.34 Ha in 2017 and raised to 98,637.99 Ha in 2018. Most of the peatlands in South Kalimantan Indonesia are at risk of experiencing fires. In January 1st to September 14th, 2018, 552 land fires were causing the area to burn up to thousands of hectares. The most burned land area occurred in Banjarbaru, which reached 467.03 hectares and mostly located on peatland (Kumparan, 2018).

Peatlands in South Kalimantan are classified as thin and medium peat soils (Wahyunto & Suparto, 2004). Fires every year occurred on peatlands increasingly cause degraded soil conditions in South Kalimantan. Research on the impact of peat fires on the physical and chemical characteristics of soils in Indonesia is still limited, especially in South Kalimantan, although fires continue to occur every year in the South Kalimantan region.

Literature Review

Burned Peatland

Peatlands are lands rich in organic material with organic C > 18% and a minimum thickness of 50 cm. Natural materials on peat soil are formed from undecayed plant remnants and are often found in swampy areas or poorly drained basins. Peat soils are generally formed in water-saturated and nutrient-poor conditions (Agus et al., 2019; Xu et al., 2018). They consist of at least 30% of dead organic matter’s dry mass. Peatlands can have vegetation and no peat on its surface (Joosten, 2009). In general, the minimum thickness of peat in a bog is 30 cm (Joosten et al., 2012).

Peatlands play critical economic and ecological roles (Saputra, 2019) and are crucial for the life of human culture (Xu et al., 2018). Human interference in peatland management causes damage. Problems occurring in peatlands are fire, deforestation, land subsidence (Saputra, 2019), and agricultural land clearing (Frolking et al., 2011). The inventory of peatland potential is still shallow due to the problematic interpretation of satellite imagery and the low data obtained through field measurements (Joosten, 2009). It is crucial to conserve peatland ecosystems since they have essential functions, which are the preservation of water resources, flood suppression, prevention of seawater intrusion, supporting various life/biodiversity, and climate control as it is one of the carbon supplies (Wahyunto & Suparto, 2004; Wiri et al., 2017).

Human is the highest factor in causing the damage (Prayoto et al., 2017; Tacconi, 2003); for instance, community's lack of the attention to peatlands, forest conversion on a peatland such as land clearing and plantations with inappropriate trenching and peatland fires (Prayoto et al., 2017). However, drying as a result of climate alter and human action brings down the water table in peatlands and increments the recurrence and degree of peat fires (Turetsky et al., 2015).

Cultivated peatlands are more vulnerable to fires than conserved ones (Prayoto et al., 2017). The vulnerability is best characterised as a total degree of human welfare that integrates a natural, social, financial and political introduction to a run of potential hurtful annoyances (Blistanova et al., 2016). Burning peatlands is considered the easiest way to clear them; the community also deems it can increase soil fertility (Wiri et al., 2017; Zulkifli & Kamarubayana, 2017). Fires on peatlands are more difficult to extinguish than the others. Areas with extensive and deep peatland will take years to ensure that the fires have been completely extinguished (Jones, 2005). The dynamics of peat fires are caused by the exploitation of large-scale agricultural and plantation activities. These activities are followed by forest clearing and peatland drainage so that it made the peatland dry; if accompanied by a long dry season, everything can increase the danger level of fires (Page, 2016). Conversion of secondary forests by cutting down and burning organic matter that converted into available nutrients will increase the pH of the soil at the surface of the soil. However, these nutrients are easily dissolved by high rainfall. Land becomes degraded over a long period of time and flammable during the dry season (Agus et al., 2020). To make it worst, burned peat forests need 27 to 47 years to recover, depending on the environment in which the vegetation grows (Marlier et al., 2019).

Effect of fire for soil characteristics

Combustion of peatlands can cause damage to peat soil. The soil physical nature determines the land quality because land with excellent physical properties will provide good environmental quality (Susandi et al., 2015). The peat characteristics affected by open-fire have undergone extreme changes (Kŏnŏnen et al., 2015). Peat soil burned has decreased water content, water binding power, porosity, and permeability while Bulk Density (BD) and Particle Density (PD) has increased, compared to non-burning peat soil. Fire decreases total carbon (TC), total nitrogen (TN), and organic phosphorus (P_o), but fire increases inorganic phosphorus (P_i) and total calcium (TCa) (Smith et al., 2001). The microbial abundance and phosphatase movement within the burned soils substantially diminished compared to those of the unburned soil (Sazawa et al., 2018).

Peat fires also affect soil temperature, structure, and ability to absorb water. Damage to the structure and reduced pore will cause increased soil fill weight — fires' open' the soil due to loss of litter, understorey, and canopy. The open ground will increase temperature, evaporation rate, loss of organic matter and decreased water content available (Lubis, 2016). In areas with low topography, peatland fires can change the volume, height, and water storage in wetlands after fires (Watts & Kobziar, 2013).

Based on background, the purposes of this research are (1) to analyse the physical characteristics of soil (colour and soil texture) caused by fires in Banjarbaru, Indonesia (2) to investigate the chemical characteristics of soil (pH, dissolved Fe^{2+}, P_2O_5, and K_2O) caused by fires.

Materials and Methods

This research was conducted in Banjarbaru, South Kalimantan Province, Indonesia. The city of Banjarbaru is geographically located between 3 ° 25'40 "-3 ° 28 '37" LS and 114 ° 41'22 "-114 ° 54'25" BT (BPS, 2018). Soil samples were measured based on the location of peatland fires in Banjarbaru, obtained from the data of Sipongi hotspot points (SiPongi, 2018). There were 24 samples in total: 12 samples in October 2018 and 12 samples in January 2019 taken in the same location; they were taken based on fire occurrence on peatland in Banjarbaru, Indonesia. The sampling map is shown in Figure 1. The fires occurred around September 2018 in the research area. The samples were taken in October 2018, which was about one month after the fire; and in January 2019, which was about 4 months after the fire. One month after the fire, the land was still dry because the burning vegetation had not grown back. In January 2019, the land was wet and inundated because it was the rainy season, and the vegetation began to grow again. The land cover at the research location was shrubs. The location of research in the field can be seen in Figure 1 and Figure 2.

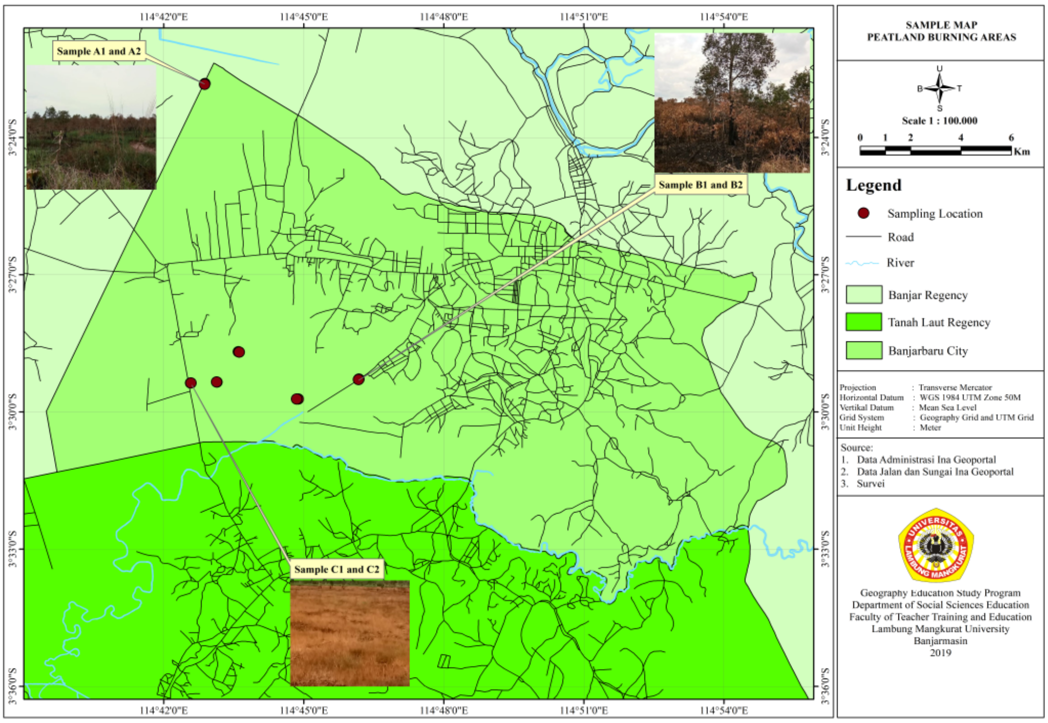

Fig. 1. Research location

The sampling utilised a peat soil drill. The drilling depth was 1 meter. The fire has an impact on peat depth. The peat in the research area included shallow/thin peat types with an average thickness of about 50-100 cm and medium peat with a diameter of 100-200 cm based on the map of peat in Kalimantan (Wahyunto & Suparto, 2004). In location, peat only has the depth about 10 cm-15 cm because of peat degradation due to fire. The extent of peat burned has a relationship with the fire recurrence (Wijedasa, 2016).

The samples were analysed regarding colour, pH, texture, dissolved Fe^{2+}, P_2O_5, and K_2O. Soil colour and pH were identified directly in the field. The soil colour was identified using Munsell's soil book; the soil pH was determined using Soil pH meter. The dissolved Fe^{2+}, P_2O_5, and K_2O were identified through laboratory tests.

Fig. 2. Research location (a) One month after the fire (October 2018); and (b) Four months after the fire (January 2019)

Results

Physical Characteristics of Soil in Burned Peatland
Soil Color

The colour characteristics of the soil at one month after the fire and 4 months after the fire are presented in Table 1.

Tab. 1. The colour of soil on burned land

Samples No.	X	Y	Soil colour 1 month after the fire		Soil colour 4 months after the fire	
A1	244795.8	9627240	7.5 YR 3/1	Very Dark Grey	7.5 YR3/2	Dark Brown
A2	244786.0	9627210	7.5 YR 3/2	Dark Brown	7.5 YR3/2	Dark Brown
B1	245542.4	9613998	7.5 YR 3/2	Dark Brown	7.5 YR3/2	Dark Brown
B2	245551.7	9613996	7.5 YR3/2	Dark Brown	7.5 YR3/2	Dark Brown
C1	246582.6	9614035	7.5 YR3/2	Dark Brown	7.5 YR 3/2	Dark Brown
C2	246573.0	9614040	7.5 YR3/2	Dark Brown	7.5 YR3/2	Dark Brown
D1	247435.5	9615259	7.5 YR3/2	Dark Brown	7.5 YR3/2	Dark Brown
D2	247466.1	9615244	7.5 YR3/1	Very Dark Grey	7.5 YR3/2	Dark Brown
E1	252218.8	9614169	7.5 YR3/2	Dark Brown	7.5 YR3/2	Dark Brown
E2	252203.1	9614150	7.5 YR3/2	Dark Brown	7.5 YR3/2	Dark Brown
F1	249811.4	9613362	7.5 YR3/1	Very Dark Grey	7.5 YR3/2	Dark Brown
F2	249750.6	9613357	7.5 YR3/1	Very Dark Grey	7.5 YR3/2	Dark Brown

The fire caused the colour to be very dark grey in within one month after the land burning. Moreover, fire locations at points A1, D2, F1, and F2 had very dark grey soil colours; the mixture of combustion ash resulted in the grey colour of the soil within a month after the fire.

Nonetheless, change in colour did not occur on all soils at the research site. Some research locations, such as points A2, B1, B2, C1, C2, D1, E1, and E2, did not experience changes in soil colour between 1-month post-fire and 4-months post-fire. There was additional rainwater inundating the land in 4 months after the fire at the locations A1, D2, F1, and F2 washing residual combustion ash on the ground, which caused the soil to become dark brown.

Soil texture

The soil texture characteristics at one month after the fire and 4 months after the fire can be seen in Table 2.

Tab. 2. The soil texture on burned land

Samples No.	X	Y	Soil Texture 1 month after the burning				Soil Texture 4 months after the burning			
			Sand (%)	Silt (%)	Clay (%)	Texture	Sand (%)	Silt (%)	Clay (%)	Texture
A1	244795.8	9627240	1.3	49.05	49.65	Silty Clay	1.74	52.62	45.64	Silty Clay
A2	244786.0	9627210	5.53	49.68	44.79	Silty Clay	1.27	13.71	85.02	Clay
B1	245542.4	9613998	0.40	62.94	36.62	Silty Clay Loam	0.92	51.25	47.83	Silty Clay
B2	245551.7	9613996	0.23	63.68	36.10	Silty Clay Loam	2.17	59.03	38.80	Silty Clay
C1	246582.6	9614035	0.15	55.11	44.74	Silty Clay	1.05	56.21	42.74	Silty Clay
C2	246573.0	9614040	3.03	53.86	43.11	Silty Clay	0.95	55.20	43.85	Silty Clay
D1	247435.5	9615259	0.01	57.32	42.67	Silty Clay	25.97	39.39	34.64	Clay Loam
D2	247466.1	9615244	10.78	54.88	34.34	Silty Clay Loam	27.77	41.03	31.19	Clay Loam
E1	252218.8	9614169	30.47	37.30	32.23	Clay Loam	19.57	33.63	46.80	Clay
E2	252203.1	9614150	36.49	36.07	27.44	Clay Loam	21.34	29.25	49.42	Clay
F1	249811.4	9613362	7.01	57.36	35.63	Silty Clay Loam	2.80	56.85	40.35	Silty Clay
F2	249750.6	9613357	2.98	59.03	37.98	Silty Clay Loam	3.64	56.69	39.67	Silty Clay

The soil texture was dominated by excellent size material such as silt and clay. At one month after the fire, the silt content dominated the surface compared to sand and clay. Minimum of sand content at 1 month was 0.01, while the maximum of sand content at 1 month was 36.49. Besides, minimum of silt content at 1 month was 36.07, while the maximum of silt content at 1 month was 63.68. Further, the minimum of clay content at 1 month was 27.44, while the maximum of clay content at 1 month was 49.65. Range of sand at 1 month was 36.48. Range of silt was 27.61. Range of clay was 22.21. In the other hand, the mean of sand was 9.1733 with the standard deviation were 12.18556 and variance was 148.488. Mean of silt was 53.0233, with the standard deviation were 8.81815 and variance was 77.760 and mean of clay was 38.7750 with the standard deviation were 6.30513 and variance was 39.755.

The material content at 4 months was dominated by clay. Minimum of sand at 4 months was 0.92, while the maximum of sand was 27.77. Minimum of silt was 13.71, while the maximum of silt was 59.03. Minimum of clay was 31.19, while the maximum of clay was 85.02. Range of sand, silt and clay contents were 26.85, 45.32, and 53.83. Means of sand, silt and clay contents were 9.0992, 45.4050, and 45.4958. Standard deviations of sand, silt and clay contents were 10.96999, 14.14991, and 13.56061. Variances of sand, silt and clay contents were 120.341, 200.220, and 183.890. Descriptive statistics of sand, silt and clay contents were presented in Table 3.

Tab. 3. Descriptive statistics of sand, silt, and clay contents

	N	Range	Minimum	Maximum	Mean		Std. Deviation	Variance
	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Statistic
1month_Sand	12	36.48	.01	36.49	9.1733	3.51767	12.18556	148.488
1 month_Silt	12	27.61	36.07	63.68	53.0233	2.54558	8.81815	77.760
1 month_Clay	12	22.21	27.44	49.65	38.7750	1.82013	6.30513	39.755
4 months Sand	12	26.85	.92	27.77	9.0992	3.16676	10.96999	120.341
4 months Silt	12	45.32	13.71	59.03	45.4050	4.08473	14.14991	200.220
4 months Clay	12	53.83	31.19	85.02	45.4958	3.91461	13.56061	183.890
Valid N (listwise)	12							

The silt content was also higher in one month after the fire, compared to 4 months after. The clay content was also higher in 4 months than one month. The soil texture in one month after the fire was dominated by silty clay and silty clay loam, while the soil texture in 4 months after the fire was silty clay and clay loam. The fire created new ash on the ground so that the silt content in one month after the fire was higher than 4 months after. The rainwater in 4 months after the fire washed the residual combustion ash on the ground causing the soil texture to be dominated by silty clay.

Chemical Characteristics of Soil in Peatland

pH

The pH at one month after the fire and 4 months after the fire are displayed in Table 4.

Tab. 4. The characteristics of pH on burned land

Samples No.	X	Y	pH 1 month after the fire	pH 4 months after the fire
A1	244795.8	9627240	6	4
A2	244786.0	9627210	4	4
B1	245542.4	9613998	4	4
B2	245551.7	9613996	5	4
C1	246582.6	9614035	5	4
C2	246573.0	9614040	5	4
D1	247435.5	9615259	5	4
D2	247466.1	9615244	3	4
E1	252218.8	9614169	5	4
E2	252203.1	9614150	4	4
F1	249811.4	9613362	6	4
F2	249750.6	9613357	5	4

The soil pH a month after the fire ranged from 3-6, while the soil pH 4 months after the fire was 4. Mean of pH a month after the fire is pH 4 month is 4. The standard deviation of 1 month is 0.866, while the standard deviation of 4 months is 0. The average pH condition decreased. The peatland was dry in one month after the fire and was flooded after 4 months due to additional water from the rain and from canals around the peatland. Descriptive statistic of pH is presented in Table 5.

Tab. 5. Descriptive statistics of pH

	N	Range	Minimum	Maximum	Mean		Std. Deviation	Variance
	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Statistic
1 month	12	3	3	6	4.75	.250	.866	.750
4 months	12	0	4	4	4.00	.000	.000	.000
Valid N (listwise)	12							

Fires added minerals from ash or charcoal to the soil, increasing the pH level of the soil within a month after the fire. Alkaline oxides from the ash remaining combustion added at the time of the fire increased the pH levels. The pH level decreased along with the inundation of peatlands during the rainy season. The dissolution of residual combustion ash in stagnant soil caused the pH levels to drop.

Fe Dissolved (Fe^{2+})

The characteristics of Fe^{2+} at one month after a fire and after 4 months of fire are presented in Table 6.

The level of Fe^{2+} in one month of fire was lower than 4 months after, except at points A1, A2, E1, and E2. The highest Fe^{2+} at one month after the fire was 268.78 ppm, while the lowest was 18.18 ppm. Range of Fe^{2+} was 250.60 and the mean of Fe^{2+} at one month was 94.2592. Standard deviation at one month was 77.92506.

Tab. 6. Fe^{2+} in burned land

Samples No.	X	Y	Fe^{2+} 1 month after the fire (ppm)	Fe^{2+} 4 months after the fire (ppm)
A1	244795.8	9627240	125.53	30.39
A2	244786.0	9627210	268.78	105.36
B1	245542.4	9613998	71.67	150.11
B2	245551.7	9613996	77.87	2200.74
C1	246582.6	9614035	57.30	265.45
C2	246573.0	9614040	48.82	305.89
D1	247435.5	9615259	18.18	332.53
D2	247466.1	9615244	76.89	344.78
E1	252218.8	9614169	88.68	30.39
E2	252203.1	9614150	227.75	105.36
F1	249811.4	9613362	43.30	150.11
F2	249750.6	9613357	26.34	2200.74

Furthermore, the highest Fe^{2+} at 4 months after the fire was 2200.74 ppm, while the lowest was 30.39 ppm. The Fe monthly concentration was lost due to the combustion process. After 4 months of the fire, rainwater inundated the peatland and caused a reduction condition increasing Fe^{2+}. Range of Fe^{2+} was 2170.35, and the mean of Fe^{2+} at 4 months was 518.4875, with the standard deviation at 4 months of 793.33348. Descriptive statistics of Fe^{2+} was presented in Table 7.

Tab. 7. Descriptive statistics of Fe^{2+}

	N	Range	Minimum	Maximum	Mean		Std. Deviation	Variance
	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Statistic
1 month	12	250.60	18.18	268.78	94.2592	22.49503	77.92506	6072.315
4 months	12	2170.35	30.39	2200.74	518.4875	229.01565	793.33348	629378.007
Valid N (listwise)	12							

P_2O_5 Content

The characteristics of P_2O_5 levels at one month after the fire and after 4 months of fire can be seen in Table 8.

Tab. 8. P_2O_5 levels in burned land

Samples No.	X	Y	P_2O_5 1 month after the fire (mg/100 g)	P_2O_5 4 months after the fire (mg/100 g)
A1	244795.8	9627240	14.50	2.89
A2	244786.0	9627210	10.56	1.70
B1	245542.4	9613998	14.61	2.03
B2	245551.7	9613996	4.88	2.31
C1	246582.6	9614035	4.45	2.40
C2	246573.0	9614040	56.94	2.88
D1	247435.5	9615259	2.99	3.19
D2	247466.1	9615244	15.38	1.71
E1	252218.8	9614169	26.11	3.27
E2	252203.1	9614150	12.70	2.47
F1	249811.4	9613362	10.79	7.33
F2	249750.6	9613357	9.92	1.99

P_2O_5 concentrations were higher one month after the fire and then decreased at 4 months after the fire. The highest P_2O_5 level at one month after the fire was 56.94 mg/100 g, while the lowest was 2.99 mg/100 g. The highest P_2O_5 level at 4 months after the fire was 7.33 mg/100 g; while the lowest was 1.70 mg/100 g. Range of P_2O_5 at 1 month was 53.95, while the range of P_2O_5 at 4 months was 5.63. Mean of P_2O_5 at 1 month was 15.3192, while the mean of P_2O_5 at 4 months was 2.8475. Standard deviation at 1 month was 14.48576, while standard deviation at 4 months was 1.50868. Variance value at 1 month was 209.837, while variance at 4 months was 2.276. Descriptive statistics of P_2O_5 was presented in Table 9.

Tab. 9. Descriptive statistics of P_2O_5 levels

	N	Range	Minimum	Maximum	Mean		Std. Deviation	Variance
	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Statistic
1 month	12	53.95	2.99	56.94	15.3192	4.18168	14.48576	209.837
4 months	12	5.63	1.70	7.33	2.8475	.43552	1.50868	2.276
Valid N (listwise)	12							

P_2O_5 levels increased at one month after the fire due to the burning of organic matter and mineralisation caused by high temperatures. At 4 months after the fire, P_2O_5 levels decreased; this was resulted from the rainwater on peatland, causing loss of P_2O_5 levels in the soil since it dissolved in water inundating the peatlands.

K_2O Content

Characteristics of K_2O levels at one month after the fire and 4 months after the fire are displayed in Table 10.

Tab. 10. K_2O levels in burned land

Samples No.	X	Y	K_2O 1 month after the fire (mg/100 g)	K_2O 4 months after the fire (mg/100 g)
A1	244795.8	9627240	9.37	8.40
A2	244786.0	9627210	8.95	4.81
B1	245542,4	9613998	8.01	6.97
B2	245551.7	9613996	7.66	6.87
C1	246582.6	9614035	8.46	10.67
C2	246573.0	9614040	8.05	9.67
D1	247435.5	9615259	7.25	5.96
D2	247466.1	9615244	7.82	5.28
E1	252218.8	9614169	7.85	6.52
E2	252203.1	9614150	7.87	3.18
F1	249811.4	9613362	7.51	3.29
F2	249750.6	9613357	7.68	2.56

K_2O levels were almost the same as P_2O_5 levels. One month after the fire, K_2O levels were higher than 4 months after. The highest K_2O level one month after the fire was 9.37 mg/100 g, while the lowest was 7.25 mg/100 g. The highest K_2O level at 4 months after the fire was 10.67 mg/100 g, and the lowest was 2.56 mg/100 g. Range of K_2O level at 1 month was 2.12, and the range of K_2O level at 4 months was 8.11. Mean of K_2O level at 1 month was 8.0400, while the mean of K_2O level at 4 months was 6.1817. The standard deviation at 1 month was 0.60804, while standard deviation at 4 months was 2.55265. Variance at 1 month was 0.370. Variance at 4 months was 6.516. K_2O levels were higher at one month after a fire due to the burning of organic matter and mineralisation caused by high temperatures. At 4 months after the fire, K_2O levels decreased at almost all samples except at C1 and C2. The cause of decreased K_2O was rainwater inundating peatlands. The flooded peatlands washed K elements in the soil and dissolved them in water. Descriptive statistics of K_2O levels were presented in Table 11.

Tab. 11. Descriptive statistics of K_2O levels

	N	Range	Minimum	Maximum	Mean		Std. Deviation	Variance
	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Statistic
1 month	12	2.12	7.25	9.37	8.0400	.17553	.60804	.370
4 months	12	8.11	2.56	10.67	6.1817	.73689	2.55265	6.516
Valid N (listwise)	12							

Discussion

Fire causes an increase in pH, P_2O_5, and K_2O levels; it also brought changes in soil colour, texture, and decreased Fe^{2+}. The residual combustion ash on the soil increased the silt, pH, of P_2O_5, and K_2O levels. Characteristic peat soil in October 2018 was soil colour was very dark grey-dark brown, the soil texture was silty clay and silty clay loam, the pH level was 3-6. Fe^{2+} was 18.18-268.78 ppm. Mean of Fe^{2+} was 94.2592 ppm. P_2O_5 content was 2.99-56.94 mg/100 g. P_2O_5 mean was 15.3192 mg/100 g. K_2O content was 7.25-9.37 mg/100 g. Mean of K_2O content was 8.0400 mg/100 g.

The pH, P_2O_5, and K_2O levels decreased along with rainwater on the peatland due to the loss of residual combustion ash on it. Fe^{2+} increased with the addition of rainwater on the peatland. The reduction reaction increased Fe^{2+}. In January 2019, characteristics of peat soil were the soil colour was dark brown, the soil texture was silty clay and clay loam, and the pH level was 4. The concentration of Fe^{2+} was 30.39-2200.74 ppm. Fe^{2+} mean was 518.4875 ppm. P_2O_5 content was 1.70-7.33 mg/100 g. Mean of P_2O_5 was 2.8475 mg/100 g. K_2O content was 2.56-10.67 mg/100 g. Mean of K_2O_5 was 6.1817 mg/100 g.

The soil in peatland is a land easily subjected to change and damage. Fires cause changes to the soil's nature. Changes in soil properties can be physical, chemical, and biological. Fires on organic soil can increase some nutrients, such as the P elements. Fires can increase pH levels, P levels, and K levels. The fire effects were limited to Fe and related to pH and organic content (Norouzi & Ramezanpour, 2013). Characteristic of soils was found that pH levels, soil fertility, and P were dissolved (Tata et al., 2018). The land fire was an increase in pH, P and K levels in the soil (Ekinci, 2006; Wasis et al., 2019). Ca also experienced a significant increase after land fires (Wasis et al., 2019). P levels increased 6 times in burned soils compared to unburned soils, especially at the surface of the soil (Sulwiński et al., 2017). Organic phosphorus (Po) decreases, but inorganic phosphorus (Pi) increases after the land fire (Wang et al., 2015).

Fires can indeed add P_2O_5 and K_2O to the soil, but they are only temporary. $P_2O_5$and K_2O will be lost due to the rainwater inundated. The damage produced by combustion is more considerable. The accumulation of ashes in wooded area peat fires impacted place right away improved pH, organic matter, humic acid content, hydrophobicity, available-N and available-K. However, their availabilities had solely been briefed as they were without difficulty diminished and washed way, which results in long-term degradation (Agus et al., 2019). Fires burning over these landscapes moreover expend surface peat, uncovering more seasoned peat strata (Sinclair et al., 2020). The impact of peat fires is not only on the ground but also affects up to 30-50 cm deep (Yustiawati et al., 2016). The fire also causes a decrease in peat soil thickness of 10-15 cm (Wasis et al., 2019). In the research location, we found the peat depth only about 10-15 cm due to land fire every year. This condition is characteristic of land degradation.

The land fire also has damaged peatland organism. Peatland fires cause 100% mortality of flora and fauna of the soil. Total microorganisms, total fungi, and soil respiration have decreased due to land fires (Wasis et al., 2019). Species are showed more significant damage at higher temperatures, with harm taking place at once after heat exposure (Noble et al., 2019). Wetland fires influence aquatic animal and plant neighbourhood structure, at least for brief intervals post-fire (Venne et al., 2016). In research, we found that warm temperature after the fire and no organism in soil, and this is the loses of land fire.

Conclusions

Fires occurred in peat soil in Banjarbaru, South Kalimantan, Indonesia brought changes to the soil physical and chemical properties, but the effect of fire is only temporary. This research recommends no land burning to prepare agriculture land, although the land burning increases pH, P_2O_5 and K_2O, due to the land fire has the highest effect on land degradation. The next research should be expanded to the other peatland in Indonesia and more of soil properties to understand the more impact of fire for peatland properties.

References

Agus, C., Azmi, F. F., Ilfana, Z. R., Wulandari, D., Rachmanadi, D., Harun, M. K., & Yuwati, T. W. (2019). *The Impact of Forest Fire on the Biodiversity and the Soil Characteristics of Tropical Peatland*: Springer. https//doi.org/10.1007/978-3-319-98681-4_18

Agus, C., Ilfana, Z., Azmi, F., Rachmanadi, D., Wulandari, D., Santosa, P., Harun, M., Yuwati, T., & Lestari, T. (2020). The effect of tropical peat land-use changes on plant diversity and soil properties. *International Journal of Environmental Science and Technology,* 17(3). https://doi.org/10.1007/s13762-019-02579-x

Arisanty, D., Adyatma, S., Muhaimin, M., & Nursaputra, A. (2019). Landsat 8 OLI TIRS Imagery Ability for Monitoring Post Forest Fire Changes. *Pertanika Journal of Science & Technology,* 27(3).

Blistanova, M., Zeleňáková, M., Blistan, P., & Ferencz, V. (2016). Assessment of flood vulnerability in Bodva river basin, Slovakia. *Acta Montanistica Slovaca,* 21(1). https://10.3390/ams21010019

BPS. (2018). *Regional Statistics of Banjarbaru City*. Banjarbaru: BPS Retrieved from https://banjarbarukota.bps.go.id/. Access date: 5 October 2019

Brown, L. E., Palmer, S. M., Johnston, K., & Holden, J. (2015). Vegetation management with fire modifies peatland soil thermal regime. *Journal of Environmental Management,* 154. https://doi.org/10.1016/j.jenvman.2015.02.037

Cahyono, S. A., Warsito, S. P., Andayani, W., & Darwanto, D. H. (2015). Faktor-faktor yang mempengaruhi kebakaran hutan di indonesia dan implikasi kebijakannya (Factors Affecting Forest Fires in Indonesia and the Policy Implications). *Jurnal Sylva Lestari,* 3(1). https://dx.doi.org/10.23960/jsl13103-112

Ekinci, H. (2006). Effect of forest fire on some physical, chemical and biological properties of soil in Çanakkale, Turkey. *International Journal of Agriculture and Biology,* 8(1).

Frolking, S., Talbot, J., Jones, M. C., Treat, C. C., Kauffman, J. B., Tuittila, E.-S., & Roulet, N. (2011). Peatlands in the Earth's 21st century climate system. *Environmental Reviews,* 19. https://doi.org/10.1139/a11-014

Hansson, A., & Dargusch, P. (2017). An estimate of the financial cost of peatland restoration in Indonesia. *Case Studies in the Environment,* 2(1). https://doi.org/10.1525/cse.2017.000695

Jones, W. (2005). Peat Fires: the dangers from a Fire Manager's point of view. *Journal of the Royal Society of Western Australia,* 88.

Joosten, H. (2009). *The Global Peatland CO2 Picture: Peatland Status and Drainage Related Emissions in All Countries of the World*. Germany: Universität Greifswald, Wetlands International.

Joosten, H., Tapio-Biström, M.-L., & Tol, S. (2012). *Peatlands: guidance for climate change mitigation through conservation, rehabilitation and sustainable use*. Germany: Food and Agriculture Organization of the United Nations

Könönen, M., Jauhiainen, J., Laiho, R., Kusin, K., & Vasander, H. (2015). Physical and chemical properties of tropical peat under stabilised land uses. *Mires and Peat,* 16(8).

Kumparan. (2018). Peatland Areas Dominate 2,005 hectares of forest and land fires in South Kalimantan. Retrieved from kumparan.com/trubus-id/kawasan-lahan-gambut-dominasi-2-005-hektare-kathutla-di-kalsel-1537065212533751796. Access date: 5 October 2019

Lubis, A. H. (2016). *Responses of Peat Soil Characteristics on Fire.* Institut Pertanian Bogor, Bogor.

Marlier, M. E., Liu, T., Yu, K., Buonocore, J. J., Koplitz, S. N., DeFries, R. S., ... & Myers, S. S. (2019). Fires, smoke exposure, and public health: An integrative framework to maximise health benefits from peatland restoration. *GeoHealth, 3*(7). https://doi.org/10.1029/2019GH000191

Noble, A., Crowle, A., Glaves, D. J., Palmer, S. M., & Holden, J. (2019). Fire temperatures and Sphagnum damage during prescribed burning on peatlands. *Ecological Indicators,* 103(-). https://10.1016/j.ecolind.2019.04.044

Norouzi, M., & Ramezanpour, H. (2013). Effect of fire on soil nutrient availability in forests of Guilan, north of Iran. *Carpathian Journal of Earth and Environmental Sciences,* 8(1).

Novitasari, N., Sujono, J., Harto, S., Maas, A., & Jayadi, R. (2019). Drought Index for Peatland Wildfire Management in Central Kalimantan, Indonesia During El Nino Phenomenon. *Journal of Disaster Research,* 14(7). https://10.20965/jdr.2019.p0939

Nugroho, Y. S. (2017). Integrating Wildland and Urban Fire Risks in Local Development Strategies in Indonesia. In Harada, Matsuyama, Himoto, Nakamura, & Wakatsuki (Eds.), *In Fire Science and Technology 2015*. Singapore: Springer. https://doi.org/10.1007/978-981-10-0376-9_4

Page, S. (2016). Understanding the Dynamics of Peatland Fires in Indonesia. Pengelolaan Lanskap Berkelanjutan*, 1(1), 4–13.*

Prayoto, T., Ishihara, M., Firdaus, R., & Nakagoshi, N. (2017). Peatland Fires in Riau, Indonesia, in Relation to Land Cover Type, Land Management, Landholder, and Spatial Management. *Journal of Environmental Protection,* 8(11). https://10.4236/jep.2017.811081

Rajiani, I., & Pypłacz, P. (2018). National culture as modality in managing the carbon economy in Southeast Asia. *Polish Journal of Management Studies,* 18. https://10.17512/pjms.2018.18.1.22

Rauf, A. (2016). Dampak Kebakaran Hutan Tanaman Kelapa Sawit terhadap Lahan Gambut di Kabupaten Aceh Barat Daya terhadap Sifat Lahan Gambut (The Impact of Oil Palm Plantation Fires on Peatlands in Southwest Aceh District on the Characteristic of Peatlands). *Jurnal Pertanian Tropik,* 3(3). https://doi.org/10.32734/jpt.v3i3.2985

Saputra, E. (2019). Beyond fires and deforestation: Tackling land subsidence in peatland areas, a case study from Riau, Indonesia. *Land,* 8(5). https://10.3390/land8050076

Sazawa, K., Wakimoto, T., Fukushima, M., Yustiawati, Y., Syawal, M. S., Hata, N., Taguchi, S., Tanaka, S., Tanaka, D., & Kuramitz, H. (2018). Impact of Peat Fire on the Soil and Export of Dissolved Organic

Carbon in Tropical Peat Soil, Central Kalimantan, Indonesia. *ACS Earth and Space Chemistry,* 2(7). https://doi.org/10.1021/acsearthspacechem.8b00018

Sinclair, A. L., Graham, L. L., Putra, E. I., Saharjo, B. H., Applegate, G., Grover, S. P., & Cochrane, M. A. (2020). Effects of distance from canal and degradation history on peat bulk density in a degraded tropical peatland. *Science of The Total Environment,* 699. https://doi.org/10.1016/j.scitotenv.2019.134199

SiPongi. (2018). Peatland fires in Banjarbaru. Retrieved 5 Oktober 2019 http://sipongi.menlhk.go.id/

Smith, S. M., Newman, S., Garrett, P. B., & Leeds, J. A. (2001). Differential effects of surface and peat fire on soil constituents in a degraded wetland of the northern Florida Everglades. *Journal of Environmental Quality,* 30(6). https://10.2134/jeq2001.1998

Sulwiński, M., Mętrak, M., & Suska-Malawska, M. (2017). Long-term fire effects of the drained open fen on organic soils. *Archives of Environmental Protection,* 43(1). https://10.1515/aep-2017-0002

Susandi, Oksana, & Arminudin, A. T. (2015). Analisis sifat fisika tanah gambut pada hutan gambut di Kecamatan Tambang Kabupaten Kampar Provinsi Riau (Analysis of Physical Characteristics of Peatlands in Peat Forests in Tambang Sub-District, Kampar District, Riau Province). *Jurnal Agroteknologi,* 5(2). https://dx.doi.org/10.24014/ja.v5i2.1351

Tacconi, L. (2003). *Fires in Indonesia: Causes, Costs and Policy Implications*. Indonesia: Center for International Forestry Research (CIFOR). https://doi.org/10.17528/cifor/001200

Tata, H. L., Narendra, B. H., & Mawazin. (2018). Forest and land fires in Pelalawan District, Riau, Indonesia: Drivers, pressures, impacts and responses. *Biodiversitas Journal of Biological Diversity,* 19(2). https://doi.org/10.13057/biodiv/d190224

Turetsky, M. R., Benscoter, B., Page, S., Rein, G., Van Der Werf, G. R., & Watts, A. (2015). Global vulnerability of peatlands to fire and carbon loss. *Nature Geoscience,* 8(1). https://doi.org/10.1038/ngeo2325

Venne, L. S., Trexler, J. C., & Frederick, P. C. (2016). Prescribed burn creates pulsed effects on a wetland aquatic community. *Hydrobiologia,* 771(1). https://10.1007/s10750-016-2640-y

Vetrita, Y., & Cochrane, M. A. (2020). Fire Frequency and Related Land-Use and Land-Cover Changes in Indonesia's Peatlands. *Remote Sensing,* 12(1). https://doi.org/10.3390/rs12010005

Wahyunto, R. S., & Suparto, S. H. (2004). *Map of peatland distribution area and carbon content in Kalimantan*. Bogor: Wetland International-Indonesia.

Wang, G., Yu, X., Bao, K., Xing, W., Gao, C., Lin, Q., & Lu, X. (2015). Effect of fire on phosphorus forms in Sphagnum moss and peat soils of ombrotrophic bogs. *Chemosphere,* 119. https://doi.org/10.1016/j.chemosphere.2014.01.084

Wasis, B., Saharjo, B. H., & Putra, E. I. (2019). Impacts of peat fire on soil flora and fauna, soil properties and environmental damage in Riau Province, Indonesia. *Biodiversitas Journal of Biological Diversity,* 20(6). https://Doi.Org/10.13057/Biodiv/D200639

Watts, A. C., & Kobziar, L. N. (2013). Smoldering Combustion and Ground Fires: Ecological Effects and Multi-Scale Significance. *Fire Ecology,* 9(1). https://10.4996/fireecology.0901124

Wijedasa, L. S. (2016). Peat soil bulk density important for estimation of peatland fire emissions. *Global change biology,* 22(9). https://doi.org/10.1111/gcb.13364

Wiri, Astiani, D., & Fernando, T. (2017). Peat Biomass Loss Due to Forest Fires. *Jurnal Hutan Lestari,* 3(2).

Xu, J., Morris, P. J., Liu, J., & Holden, J. (2018). PEATMAP: Refining estimates of global peatland distribution based on a meta-analysis. *Catena,* 160. https://10.1016/j.catena.2017.09.010.

Yustiawati, Sazawa, K., Syawal, M. S., Kuramitz, H., Saito, T., Hosokawa, T., Kurasaki, M., & Tanaka, S. (2016). Peat Fire Impact on Water Quality and Organic Matter in Peat Soil *Tropical Peatland Ecosystems* (pp. 281-296): Springer. https://doi.org/10.1007/978-4-431-55681-7_18

Zulkifli, I., & Kamarubayana, L. (2017). Studi Pengendalian Kebakaran Hutan di Wilayah Kelurahan Merdeka Kecamatan Samboja Kalimantan Timur (Study on Forest Fire Control in the Merdeka Village, Samboja Sub-District, East Kalimantan). *AGRIFOR,* 16(1). ISSN: 2503-4960

Acta Montanistica Slovaca
ISSN 1335-1788
actamont.tuke.sk

Innovative Regional Development of the Structurally Disadvantaged Industrial Region by means of the Local Currency

Aleksandr **KLJUČNİKOV**[1], *Mehmet* **CİVELEK**[2*], *Vladimír* **KRAJČÍK**[3] and *Ivana* **ONDREJMIŠKOVÁ**[4]

Authors' affiliations and addresses:
[1] Institute of Entrepreneurship and Marketing, University of Entrepreneurship and Law, Michálkovická 1810/181, 710 00 Ostrava-Slezská Ostrava, Czech Republic
e-mail: kliuchnikov@gmail.com

[2] Institute of Entrepreneurship and Marketing, University of Entrepreneurship and Law, Michálkovická 1810/181, 710 00 Ostrava-Slezská Ostrava, Czech Republic
e-mail: m_civelek@windowslive.com

[3] Department of Information Technologies and Analytical Methods, University College of Business in Prague, Spálená 76/14, 110 00 Nové Město, Prague, Czech Republic
e-mail: krajcik@vso-praha.eu

[4] Department of Safety Studies, Faculty of Political Science and International Relations, Matej Bel University in Banská Bystrica, Kuzmányho 1, 974 01 Banská Bystrica, Slovakia
e-mail: ivana.ondrejmiskova@umb.sk

***Correspondence:**
Mehmet Civelek, Institute of Entrepreneurship and Marketing, University of Entrepreneurship and Law, Michálkovická 1810/181, 710 00 Ostrava-Slezská Ostrava, Czech Republic
tel.: +420773873403
e-mail: m_civelek@windowslive.com

Funding information:
Technology Agency of the Czech Republic
Grant Number TL02000562

Acknowledgement:
This research is a part of the scientific research project "Research of the potential of local currency's implementation for sustainable regional development" funded by the Technology Agency of the Czech Republic TAČR, grant number (TL02000562).

How to cite this article:
Ključnikov, A., Civelek, M., Krajčík, V. and Ondrejmišková, I. (2020). Innovative Regional Development of the Structurally Disadvantaged Industrial Region by the Means of the Local Currency. *Acta Montanistica Slovaca,* Volume 25 (2), 224-235

DOI:
https://doi.org/10.46544/AMS.v25i2.9

Abstract
Local and community currencies have been used as a stimulating tool to increase trading activities and social interactions of geographically restricted regions. This paper aims to investigate the potential of innovative regional development of the structurally disadvantaged industrial region focused on the steel and mining industry by means of the local currency. Being the important players of local economies and regional development, SMEs have always been in the center of interest for practitioners of the local and community currencies. Therefore, our research team analyzed and explored major benefits and barriers that SMEs perceive to adopt and use local currency. In parallel with the specified aims, the researchers employed the structured questionnaire survey with open and dichotomous questions focused on SMEs with no practical experience with the acceptance and use od the local or community currencies in Cieszyn Silesia region. The results of our research show that SMEs are prone to be active members of local currency communities, and they positively perceive the support that major regional producers, service providers, and practitioners can provide for them through this instrument. Moreover, some SMEs also perceive local currencies as a marketing and promotion tool that increases product-service quality and mutual transactions of firms. According to the respondents, high participation fees and exchange rates, lack of usage by customers and coverage by national currencies, counterfeiting, and fraud, liquidity risk, taxability, accountability, legislative and technical issues, credibility and trustworthiness of practitioners have been main impediments in the adoption and usage of these currencies by SMEs. This research provides innovative solutions and suggestions for policymakers in case of the regional development of the structurally disadvantaged industrial regions to overcome the barriers of local currencies. Since local currencies can be created in digital formats, the increasing importance of local digital currencies in the Covid-19 pandemic has also been highlighted.

Keywords
SMEs, regional development, local currency, community currency, digital currency, Covid-19, benefits, obstacles, Cieszyn Silesia region.

Introduction

Regional development of the structurally disadvantaged industrial regions (Mohammadali & Abdulkhaliq, 2019) is a field that needs a new and innovative approach. This paper aims to investigate the potential of innovative regional development of the structurally disadvantaged industrial region focused on the steel and mining industry by means of the local currency. Many studies also confirm the existence of regional disparities and inequalities regarding the economic and social conditions of individuals in various regions (Maličká, 2019; Svatošová, 2012; Netrdová & Nosek, 2020).

Some indicators such as unemployment rates, and GDP per capita also differ in various regions of countries especially the regions close to capital cities, industrialized regions (Maličká, 2019; Svobodová et al., 2018) and borders (Sirohi et al., 2019; Churski & Dominiak, 2014; Gajdová & Tuleja, 2015). Sirohi et al. (2019) analyze the regions, including the locations next to the borders, and confirm that agricultural firms located to borders have lower performance levels than other regions. Similarly, Svobodová et al. (2018), Churski and Dominiak (2014), Gajdová and Tuleja (2015) state that regions that are close to borders do usually experience more economic issues and have lower economic power and conditions in comparison with other regions of nations. The border regions also face more problems to receive more income, attract more investments, and have more innovative actions (Svobodová et al., 2018). In this regard, the region that this research analyzes might be a good example. This is because Cieszyn Silesia is located in the Polish-Czech borderland, and it is a Euroregion. Moreover, this region has coal mines and carries importance for the steel industry (Olszewski, 2016).

Cieszyn Silesia region was formed by the collaboration of Stowarzyszenie Rozwoju i Współpracy Regionalnej "Olza in Poland and Regionální sdružení pro česko-polskou spolupráci Těšínského Slezska in the Czech Republic on 22 April, 1998 (Wróblewski, 2016; Olszewski, 2016). Since this region's location is at the borderland, it has some problems related to geography (Olszewski, 2016). This region is a mountainous region (Wróblewski, 2016) and, firms in the mountainous can face with some obstacles regarding transportation or cooperation (Dołzbłasz & Raczyk, 2015; Svobodová et al., 2018). Moreover, the cities located next to Poland-Czech borders also have some issues such as lack of industrialization, job opportunities, and population. These cities are located in highland regions that create a barrier to be developed, although it can provide benefits for regional tourism (Svobodová et al., 2018). Wróblewski (2016) investigates citizens of this region and find that industrialization, social policy, self-governance, and agriculture were perceived as main problems by these individuals regarding the conditions of Cieszyn Silesia. On the other hand, the lack of financial means and projects is one of the main problems experienced in this region. Although some organizations and local authorities have provided some financing opportunities for citizens and local firms, the amount of these funding options is not enough. Organizational and legal differences in these cross-border cities also create some difficulties for the development of this region (Olszewski, 2016). For these reasons, regions in Czech-Poland borders face more economic problems and have lower economic conditions than other regions in the Czech Republic and Poland (Svobodová et al., 2018; Churski & Dominiak, 2014; Gajdová & Tuleja, 2015).

To reduce these regional disparities and inequalities, some innovative implementations can be applied by local authorities, practitioners, or policymakers. In this regard, local currencies can be used as an innovative tool to overcome these issues. Local and community currencies are called as "monetary and grassroots innovations" that enable local citizens and firms to have new social and economic opportunities to reduce income inequalities (Huttunen & Joutsenvirta, 2019; Seyfang & Longhurst 2012; Benkler, 2017; Ryan-Collins, 2011; Chipere, 2018) and regional disparities by providing sustainable and regional development (Seyfang & Longhurst 2013; Fesenfeld et al., 2015; Szemerédi, 2018). This is because national currencies might cause social and economic inequalities since they are under the control of policymakers and other strong players in the market, such as multinational firms (Carroll & Bellotti, 2015). Therefore, especially in the era of economic crises, local and community currencies have been implemented by practitioners to overcome the negative impact of crises because of its influences on stabilization (Seyfang & Longhurst, 2012) and stimulating role for economic power and social equality in various regions (De Filippi, 2015). Since these currencies also circulate in digital form by using new technological tools or methods as digital currencies do, this fact is also a strong argument to confirm its innovativeness. Local currencies are also called community currencies; thus, the term of community currency will also be used in this paper to remark local currencies (Civelek et al., 2019).

Community currencies circulate in restricted regions as a payment method; thus, they differ from national currencies (Shaw, 2018; Dini & Kioupkiolis, 2019; Diniz et al., 2019; Kwon et al., 2019) and operate and are disbursed in meso-level mainly by close local citizens or firms (Dini & Kioupkiolis, 2019). These currencies also enable its users to have a closer relationship by building societies, new methods of payments and exchange, providing new solutions for individuals to survive and increase local economic activities (Dittmer, 2013) and also local tourism activities (Vu & Ngo, 2019).

With the existence of the Covid-19 pandemic, digital payments and technologies have become more popular since they have enabled people to do transactions with required social distance, no physical contacts, and stay away from crowded places. Carrying coins and banknotes and making purchases by them have become more suspicious transactions, because of people's concerns that these materials can carry viruses (Gardner, 2020; Samantha, 2020; De' et al., 2020; Kakushadze & Liew, 2020). Since digital currencies provide contactless transactions for payments, people might become more adapted to the new era's usage of these currencies. Therefore, focusing on both forms of local currency digital and paper-based makes this paper draw attention to a current topic and its importance in the Covid-19 pandemic.

Community currencies also encourage especially smaller enterprises to overcome financial issues that they face (Cannas, 2017). Dini and Kioupkiolis (2019) investigate one of the community currencies in Italy, namely, Sardex, and express that local currency provide economic and financial support for SMEs. For instance, when merchant users adopt the usage of these currencies for their sales, this fact also influences consumers' behaviors by making them perceive these currencies' usage more secure and guaranteed (Hartono et al. 2014; Roussou et al., 2019). In this case, businesses that are users of these currencies will also receive benefits by increasing the number of their customers and incomes (Roussou et al., 2019). Benefits that are provided by local currencies have also been analyzed by some researchers (Gao et al., 2016; Hur et al., 2015; Ly, 2013). However, different from these researches, this paper aims to investigate the perceptions of SMEs regarding benefits, incentives, and supports that practitioners and major local merchant users provide for users of local currencies. SMEs carry high importance for SMEs since they play a vital role in job creation (Ključnikov et al., 2019). SMEs that are analyzed by this paper are located in the specific region, which is located in Beskyd mountains, that this is a mining region of Silesia, with highly developed iron processing.

Although local currencies provide supports, incentives and other benefits for its merchant users such as SMEs, because of security issues such as fraud and counterfeiting (Gentilal et al., 2017; Abraham et al., 2019; Glaser et al., 2014; Walton & Johnston, 2018), risk (Pianese et al., 2018; Beer & Weber, 2015; Dupont & Squicciarini, 2015; Gao et al., 2016; Hur et al., 2015; Ly, 2013), trust (Abraham et al., 2019; Shahzad et al., 2018), costs of exchange and membership (Pianese et al., 2018, Diniz et al., 2016; Diniz et al., 2019), accountability (Blanc & Fare, 2013; Diniz et al., 2016; Diniz et al., 2019) and tax issues (Eisenstein, 2011; Seyfang, 2005), SMEs might become less interested in the usage of these currencies, and their adoption to the usage of these currencies might be reduced. In this regard, this paper also aims to indicate and explore major concerns of potential merchant users of local currency that might influence their adoption and usage. For these reasons, two main research questions can arise as follows; How do potential SMEs users perceive the benefits of local currency? How do potential SMEs users perceive obstacles of local currency that influence their usage of this currency?

Since this paper only focuses on potential business users of a local currency and looks at the benefits and constraints of local currencies from firms' perspectives, this paper differs from other studies. Moreover, the firms that this paper analyses have never experienced and adopted local currencies for their operations. For these reasons, this study can make practitioners, policymakers, entrepreneurs, and academicians interested in the results of this research. This is because, regarding the results of this paper, all players in the market can be aware of the fact that whether it is beneficial to implement a local currency for SMEs in a less developed region or not.

The rest of the paper is structured as follows. In section 2, the paper interprets the main points of this paper in detail by doing an extensive literature review and providing important information from other related studies. The data and the methods that this paper applies are clarified in the Data and Methodology section. Section 4 highlights the results of this paper. In section 5, the paper discusses the main results and provides potential reasons for the findings by enabling solutions for the problems that SMEs face in the usage of local currencies. Finally, the paper concludes the main results by summarizing other important facts about this research.

Material and Methods

Material

Implementing a local currency in a specific region, reduces income inequalities, poverty, being excluded from societies for individuals, and changes their buying behaviors, thus increasing productivity. All these facts also enable local currencies to play a trust-building role among communities and support local economic, social, environmental developments and sustainability in specified areas (Nishibe, 2018; Alia & Spiegelman, 2020; Dini & Kioupkiolis, 2019). Local currencies increase users' collective behaviors and increase their participation in common social activities by creating mutual trust among them (Diniz et al., 2019; Littera et al., 2017; Ruddick et al. 2015; Sanz, 2016; Alia & Spiegelman, 2020). This is because they enable its users to have face to face interactions and payments, especially in a paper-based form (Ferreira et al., 2015; Diniz et al., 2019). Since local currencies provide their users to buy or sell products and services, players in trade such as sellers (firms) and buyers (consumers) have closer interactions even in digital form of these currencies (Miszczuk, 2018).

Although these studies highlight the trust-building role of local currencies, as already stated, the trustworthiness of these currencies has been one of the major concerns of merchant users. This is because the trustworthiness of these currencies is highly related to the protection and safety of private data (Mendoza-Tello et al., 2018). Since local currencies circulate independently and without the sovereignty of governments to buy or sell goods and services, private information and previous transactions of its users must not be disseminated.

Otherwise, users might not have a willingness to use these currencies because of their security concerns (Hirotsugu et al. 2011; Hirotsugu et al. 2012), and they might experience the privacy and monetary losses (Roussou et al., 2019). When users' mutual relationships are based on trust, they become more satisfied to be participants or members of these currencies by perceiving local currencies as less risky (Alia & Spiegelman, 2020).

People desire another party's existence to mediate between them and practitioners or merchant users of digital currencies to trust these currencies (Bashir et al., 2016). However, the nonexistence of third parties in digital currency transactions makes potential users reluctant to trust them. Therefore, the success of digital currencies and their adoption by users does not only depend on their practitioners' effective operations but also supports and collaborations of governments, local authorities and businesses carry high importance in implementations of these currencies (Kim et al., 2016).

Another concern of users of local currencies is about the exchange of these currencies with national currencies. Potential users perceive the exchange of these currencies as difficult procedures (Cato & Suarez, 2012; Hirotsugu et al., 2011; Hirotsugu et al., 2012; Dini & Kioupkiolis, 2019). Although some of the local currencies enable its users to convert them to national currencies without any expenses or fees (Mavromatidi et al., 2009; Gomez & Helmsing, 2008; Kim et al., 2016) local currencies charge their merchant users by fees or apply some exchange rate that increases operational costs for potential merchant users (Kim et al., 2016). According to Ryan-Collins (2011), merchants can make redemption for their Stroud pounds and face a 5% fee for this transaction. Aside from this fee, traders also face another cost: annual membership (Ryan-Collins, 2011). Similarly, Eusko is another example of a local currency that charges its users 5% exchange rates as a fee. This fee is required by practitioners to defray the expenses of the local currency (Alia & Spiegelman, 2020).

Another risk that potential users might perceive occurs when they use new technological tools or platforms for the first time (Lee, 2009; Walton & Johnston, 2018). Some studies confirm that the propensity of informed potential users regarding these currencies is higher than that of other people who lack knowledge and ability to use digital currencies (Shahzad et al., 2018; Walton & Johnston, 2018). Besides these problems, some other constraints exist in their widely adopted and usage by businesses (De Carrillo et al., 2018). Although incomes from local currencies are counted as taxable, taxes have to be paid in local currencies that create another obstacle for its users (Eisenstein, 2011; Seyfang, 2005). For this reason, some supplier firms do not accept trading in local currencies (Kim et al., 2016).

Concerning to benefits, incentives, subsidies and supports that practitioners or other players of local currencies provide, a discount is the first tool that comes to the mind. In some of the local currencies, practitioners support their firm users to make discounts for their customers when these consumer users buy products or services (Ryan-Collins, 2011). On the other hand, some of the local currencies also enable their business users to receive discounts from these currencies and redeem their customers with a charging rate. For instance, Eco-Pesa in Kenya has provided a 20% discount for businesses. When redeeming this currency, its firm users charge their customers by the rate of 20% (Ruddick et al., 2015). To encourage the usage of local currencies by businesses to do businesses to provide promotions and increase their awareness of local currencies, practitioners also apply discounts (North, 2010). Another example of community currency that provides subsidies or bonuses is Bangla-Pesa, and each registered business receives 400 Bangla Pesa, and half of this volume is provided by the community representatives (Ruddick et al., 2015).

Moreover, giving some bonuses when making more transactions with these currencies can serve for environmental purposes such as using it for public transportation, and the entrance of cinemas and swimming pools (Miszczuk, 2018). According to Brenes (2011), vouchers might be another example of provided incentives by local currencies. Since vouchers' usage does not make businesses face financial costs, these vouchers can be used for loan repayments with lower interest rates. Registered businesses might also use these currencies to buy raw materials or inputs for their production, to gain local services, to provide bonuses or to pay some part of wage of their workers (Brenes, 2011) and to set new relations with their suppliers that also use these currencies (Hammamia et al., 2014; Brenes, 2011).

Corresponding users' security concerns, practitioners also apply blockchain technologies that might provide more secure transactions for its users by creating trust between them without the help or intermediary role of financial organizations. França et al., 2020; Shaw, 2018). It also overcomes the problem of double-spending (Shaw, 2018). This is because the existence of cryptos in this technology secures the transaction by providing transparency and trustworthiness for its users. Moreover, this technology makes its users face reduced transaction costs that might stimulate and draw potential users' attention. Due to providing reduced costs and secured transactions, users can gain advantages in case of adopting its usage (Mendoza-Tello et al., 2018).

Methods

This research purposes to shed light on the impacts of a local currency implementation in the regional development and perceptions of potential merchant users of a local currency regarding benefits, supports, risks, and obstacles of this novel payment method. Besides the benefits and supports provided by practitioners of local currencies, this paper also interprets the encouragements that trader users might provide for their employees and customers, thus local development. In line with these selected purposes, the researchers have created an online questionnaire survey to collect data. The survey includes 37 questions, and 12 are created to find the characteristics of the business and the respondents, such as work experience, age of respondents, legal form, and size of SMEs. The data collection process was performed from the end of 2019 until the beginning of 2020. The respondents of these surveys are the executives of 24 SMEs, such as owners (15 respondents), shareholders (3 survey participants) and CEOs, managers, and directors (6 respondents) of analyzed businesses. The sample of the current research analyses are SMEs that are located in the Beskyd mountains, which is a mining region of Silesia. None of these businesses have participated and used a local currency.

The top three open questions in Tab. 1 were directed to the respondents to fulfill the aims of this paper regarding benefits, risks, and obstacles of local currency. For this reason, this paper is a kind of descriptive research that provides opportunities for researchers to determine and explain respondents' attitudes and ideas under different circumstances (Saunders et al., 2009). Regarding the support and security of a local currency, dichotomous (yes, no), questions were applied to scale the questionnaires' responses.

Two hypotheses are set by following the study of Cepel et al. (2019). To test the H1 hypothesis, the responses from Q4 and Q5 are considered. On the other hand, the researchers pay attention to the responses of Q6 to evaluate the H2 hypothesis.

H1: More than 50% of the respondents think that the biggest employers in the region and the introduction of a local currency should be more supportive of regional producers and service providers.

H2: More than 50% of the respondents assume that a secured local currency is an appropriate way to provide supports for firms.

Null hypotheses are set as less than 50% of the total respondents agree with the statements specified in H1 and H2 hypotheses.

Tab. 1. Measurements in the Questionnaire

Constructs	Measurements
Benefits	Q1- What do you see as the most significant benefits of the introduction of the local currency?
Risk	Q2- What risks do you see in accepting your local currency?
Other Obstacles	Q3- What are the other main obstacles you see in accepting your local currency?
Support	Q4- Do you agree that major regional employers should give greater support to regional producers and service providers? Q5- Do you agree with the opinion that the introduction of the local currency can significantly support regional producers and service providers in the region of Těšín Silesia?
Security	Q6- Is the coverage of the local currency system by the Czech crown a sufficient guarantee of the security and credibility of the entire system for you?

Concerning the structure of the sample, Table 2 is illustrated below:

Tab. 2. Sample profile

		n	Share
Firm size	Micro	18	75%
	Small& medium	6	25%
Gender	Male	14	58.3%
	Female	10	41.7%
Work exp	Up to 10 years	15	62.5%
	More than 10 years	9	37.5%
Age	Up to 40 years old	11	45.84%
	More than 40	13	54.16%
Education	Less than bachelors'	9	37.5%
	Bachelors and more	15	62.5%
	Total	24	100%

Most of these businesses are located in Třinec, Český Těšín, and Jablunkov in Těšín Silesia region, and 18 of them are local businesses while 6 firms also operate in other regions. One firm works under the legal structure of a Joint Stock company, 14 firms are sole proprietorships, 6 firms are limited liability companies, 3 of them are government-sponsored organizations.

Results

The findings from the survey bear out that although none of these businesses have participated and used a local currency, all businesses are interested in joining a local currency system to support their businesses. This is because they believe that they have goods and services that customers can buy with local currency. On the other hand, 8 of these businesses provide vouchers to their employees for a meal and other leisure activities, and 3 businesses pay around 8.99% commission to the providers when exchanging these vouchers to the national currency. Other SMEs pay 2.99% (1 enterprise), 4.99% (2 enterprises), and 6.99% (2 enterprises) commission to exchange vouchers to Czech koruna.

To find the benefits of local currencies from the perspective of SMEs, the researchers ask an open question: What do you see as the biggest benefit of introducing the local currency? Most of the firms' executives state that local currencies provide supports for regions, entrepreneurs, and local businesses. Moreover, some of the respondents state that local currencies increase awareness of local products, services, businesses, and other regional possibilities. Some company executives also declare that money will be kept and only circulated in the region. One owner of an SME expresses that "Local currency provides support of regional subjects by their promotion, support of cohesion and patriotism in the region and support of the sustainable economy."

Concerning other benefits of local currencies, three respondents claim that "A local currency might be a useful tool for businesses' marketing activities." Increases in the quality of products and services, economic supports and development, close interactions between local producers, service providers and individuals, increasing nationalistic behaviors of individuals and their motives to make purchases in their regions, providing partial independence, sustainability, and ecological advantages are other benefits of a local currency that are perceived by SMEs.

Corresponding to the risks that are perceived by SMEs, high fees, and exchange rates of a local currency are the main concerns of the majority of SMEs' executives. Nine of investigated SMEs remark that when the exchange rate of the local currency to the Czech crowns is 6.99%, they will accept the usage of these currencies. Moreover, the other 3 businesses accept 4.99%, 4 firms accept 3.99%, 4 SMEs accept 2.99%, 2 enterprises accept 1.99%, and a firm accepts 0.99%, and another enterprise accepts 11.99% exchange rate when exchanging the local currency to the national currency of the Czech Republic. Another major risk that SMEs perceive in the analyzed region is the fear of firms' lack of local currency usage by their consumers. The executives also state counterfeiting of paper money, liquidity risks, lack of choices to use, and spend this currency as a risk of local currency. For instance, one of the owner’s remarks that his firm cannot achieve higher sales when adopting the local currency. Some other firm executives also profess that it can be difficult to set the prices and make bookkeeping entries (accounting) when accepting the usage of these currencies for their operations and sales of goods and services.

When it comes to other obstacles that SMEs perceive in accepting local currency usage, some owners and managers state that legislation might be one of the main barriers when adopting a local currency. Two other company executives mention that their technical equipment can create some obstacles to accept the usage of local currency. Another executive highlights the fact that when firms do not have wide networks, it will be another constraint to be a member of this currency implementation.

Regarding the support of these currencies, all of the respondents agree that major regional employers should give greater support to regional producers and service providers. Similarly, all respondents also confirm the fact that the introduction of the local currency can significantly support regional producers and service providers in the region of Silesia. For these reasons, this paper supports the H1 hypothesis that assumed more than 50% of the respondents accept the statements mentioned above related to the support provided by local businesses and practitioners. This is because 100% of the analyzed SMEs agree with this fact.

With reference to SMEs' security concerns, 19 (79.16% of the total respondents) respondents state that the coverage of the local currency system by the Czech crown is a sufficient guarantee of the security and credibility of the entire system for them. However, for the other 5 respondents, this is not sufficient. The credibility and trustworthiness of the practitioners of a local currency carry high importance for these businesses to feel secure when using local currency. Since more than 50% of the respondents (79.16%) assume that a secured local currency is an appropriate way to provide support for firms, this research supports the H2 hypothesis.

Discussion

This study's results regarding the perceived benefits of a local currency confirm that most SMEs have positive thinking about the local currency since this currency encourages regions, entrepreneurs, and local businesses. For this reason, this paper finds similar results with Diniz et al. (2019), Dini and Kioupkiolis (2019) since these studies also profess the positive contributions of local currencies on local businesses, regions, and entrepreneurs. Another benefit of a local currency perceived by SMEs is increasing awareness of local products, services, and businesses. This result of this research is also compatible with the remarks of Shaw (2018) and Miszczuk (2018). As stated in the Results section, some SMEs also perceive the following fact as a benefit; The local currency circulates in the specified region where it is adopted. This statement of SMEs also makes this research to be consistent with the arguments of Dini and Kioupkiolis (2019), Diniz et al., (2019), and Kwon et al. (2019) because these studies also posit the similar opinions of users of local currencies. Since local currency only circulates in the specified region, local SMEs can achieve higher performances by increasing their sales and trade volume. Thus, their revenues, investments, and productivities increase, and all these facts make them face with reduced financial obstacles to operate their firms.

Other benefits of a local currency that are positively perceived by analyzed SMEs are the usage of local currencies as a marketing tool, increasing social interaction between users, quality of goods and services, sustainability, partial independence, and volume of sales in the restricted regions. These benefits are also affirmed by Nishibe (2018), Alia and Spiegelman (2020), Hirotsugu et al. (2011), Hirotsugu et al., (2012), and North (2010). Therefore, this paper also has similar results to these studies. On the other hand, some of the results of this research object to the comments of Krohn and Snyder (2008) and Marshall et al. (2018). This is because of Krohn and Snyder (2008) and Marshall et al. (2018) state that a local currency does not make significant contributions to the local economic activities.

With reference to the risks of local currencies perceived by analyzed SMEs, high participation fees and exchange rates are some of the main risk factors for company executives. These results of this research are also compatible with the findings of Blanc and Fare (2013), Diniz et al. (2016), Pianese et al. (2018), Mavromatidi et al. (2009) because these researchers also mention high exchange rates and fees as a risk factor for potential users to adopt the usage of community currencies.

The findings of this paper regarding other risks factors such as lack of usage of local currencies by consumers, issues related with counterfeiting and fraud, and liquidity risk are also consistent with the studies De Carrillo et al. (2018), Gomez and Helmsing (2008) and Kim et al. (2016).

When it comes to other obstacles, risks and security issues, accounting, legislation, technical issues, and lack of coverage of local currencies by national currency are perceived as constraints in the wide usage of these currencies by merchant users. Hence, these results also confirm the fact that this paper has similar findings with Eisenstein (2011), Seyfang (2005), Cato and Suarez (2012), and Mendoza-Tello et al. (2018) regarding coverage, security, legislation and accounting issues of local currencies. Moreover, this paper also substantiates that practitioners' reliability and trustworthiness influence potential merchant users' perceptions regarding the security of local currencies. In this regard, practitioners' reputations can be a vital factor for potential users to feel secure when making adopting local currencies.

This is because having a good reputation increases the trustworthiness of community currencies (Krabbe, 2015; Alia & Spiegelman, 2020). Similarly, when individuals are aware of a brand name or image of a business, they can positively perceive the discounts provided by practitioners depending on this brand and image (Gavurova et al., 2018). Thus, if individuals are familiar with a brand, its image, and reputation, their propensity to trust increases even the percentage of discount that the owner of this brand provides is high (Bacik et al. 2017; Lee et al., 2015). When looking from merchant users' perspective, if practitioners have a good reputation and image, their trustworthiness might be increased. Thus, SMEs can feel secure to adopt the usage of these currencies. Even practitioners of local currencies make discounts with a higher percentage to increase the usage of these currencies, potential users might become more suspicious, and practitioners might harm the brand image of these currencies. For instance, some currencies such as Totnes and Lewes stopped making discounts since participating firms had not satisfied with discounting practices.

Concerning supports, investigated SMEs contend that the existence of local currency in a region and endorsements of major regional firms motivate and stimulate regional producers and service providers, thus SMEs. Local currencies can also be used as microcredit, and cash (Majuri, 2019; Miszczuk, 2018; Shaw, 2018) notes, secure loans, unsecured loans, exchangeable vouchers, customer's loyalty currency (Miszczuk, 2018). By having such opportunities, merchant SMEs might become more interested in using these currencies to overcome financial impediments that they face and manage their liquidity risk (Bácsi & Herczeg, 2014; Diniz et al., 2019). In the case of providing microcredits with lower interest rates, practitioners can also expand the usage of these currencies to large extents (Majuri, 2019). For instance, in its mutual credit system, Sardex also provides loans for SMEs with free of interest and without asking for collateral (Dini & Kioupkiolis, 2019). Since these currencies are used as alternative payment methods in the financial system, practitioners of local currencies can collaborate with banks and can provide mutual credit or crowdfunding opportunities for their users by making financial empowerment (Diniz et al., 2019).

Besides the support of financial institutions and practitioners to increase awareness and usage of these currencies, governments' subsidies, incentives, and endorsements also play a fundamental role in solving the financial issues of SMEs and reducing their security and reliability concerns regarding local currencies. For example, when governments or local authorities create new rules regarding the usage of these currencies in local trade and add these rules to the regulations and taxes, merchant users might feel secure, and their trustworthiness might be increased (Roussou et al., 2019). On the other hand, if governments have a willingness to receive payments for fees and taxes in local currencies, the demand for local currencies might be increased, and this fact also causes some rises in local trade, production, and consumption (Mauldin, 2015). For these reasons, all major players' support is effective solutions for financial, security, risks, and trustworthiness concerns of SMEs regarding local currencies.

However, except for financial support, governments, local authorities, financing institutions, and practitioners should also provide some educational and administrative support for SMEs' executives to increase the awareness and usage of these currencies. By providing some courses, policymakers can also make businesses informed about the financial, social, and environmental benefits of local currencies. All these facts and supports can also make SMEs quickly adapted to use these currencies for their operations and make positive contributions to the regional development of restricted areas. As local currencies can be created in digital form, in this age, while people try to survive against the Covid-19 pandemic, SMEs can use this digital payment method as a promotion tool to make their consumers make more purchases from their products and services.

Conclusions

Due to having lack of internal financial sources and having problems with their credibility to receive financing opportunities from external institutions such as banks, most of SMEs encounter various financing difficulties. Since local currencies provide alternative solutions to make SMEs cope with these obstacles, their perceptions regarding the benefits of local currencies are of vital importance for their survival, thus, regional developments. Regional developments in cross-border regions also have vital importance since they are less developed and face more economic and social problems. In this regard, local currencies might provide innovative solutions to make local SMEs more powerful in reducing regional differences. However, SMEs might also be disinterested in the usage of these currencies. Thus, this paper aims to find the perceived benefits of local currencies for local SMEs; thus, regional developments and determines to explore the barriers that reduce the adoption of these currencies by SMEs. Since SMEs are vital players of regional development, focusing these facts make policymakers and local authorities to find alternative solutions to develop their regions.

To hit the aims of this paper and collect the data, the researchers created a questionnaire survey and directed them to firms' executives working for SMEs in the Beskyd mountains, a mining region of Silesia. Open questions were employed by researchers to be informed about the perspectives of 24 SMEs regarding benefits, risks, and other main obstacles of local currencies. On the other hand, dichotomous (yes, no), questions were asked to the respondents to see how SMEs perceive supports and security issues of these currencies. None of the analyzed firms has used or adopted these currencies, but all of them are willing to use it. All firms also positively perceive the supports that potential users and practitioners can provide for other potential users. Some firms also state that local currencies can provide effective ways to be used in their marketing activities, improve their goods and services, and their relationship with other businesses and consumers.

When it comes to obstacles that SMEs perceive, costs of exchange and membership, lack of convertibility to national currencies, a high number of disinterested consumers, security issues such as counterfeiting and fraud, issues such as taxing, liquidity, accounting, legislation and technical problems and reliability of practitioners have been main concerns of potential merchant users to accept the usage of local currencies for their operations. These concerns might be reduced with the good reputation and image of local currencies, collaborations of practitioners with financing institutions and governments, usage of these currencies as microcredit, unsecured loans or vouchers with reduced interest rates, less volume of required collaterals and reduced costs, the existence of governments' rules related with their accountability and taxability and the existence of educations and administrative supports. Moreover, using local currencies in digital form can make business users and individuals be more interested in these currencies due to facing with the Covid-19 pandemic. Since digital money can provide contactless transactions, potential users might prefer using this digital currency instead of using national currencies in paper-based form. These results provide opportunities for policymakers to apply the required precautions to support SMEs, thus, regional development.

By focusing on the SMEs' points of view regarding benefits, supports, incentives, risks, security issues, and other main obstacles of local currencies, this paper creates significant value addition to the related academic literature. However, this study has some limitations, especially regarding sample size. The sample that this paper analyses only consists of 24 SMEs. Moreover, this study only analyses SMEs that have been operating in a restricted region. This study also does not consider any characteristics of firms or executives to make comparisons between them. In this regard, further studies can include more firms in their samples by also considering some larger enterprises' perceptions. Researchers can also analyze businesses from different countries with different characteristics. New papers can also compare respondents' characteristics to find differences between respondents' perceptions regarding the benefits and impediments of local currencies.

References

Abraham, J., Sutiksno, D. U., Kurniasih, N., & Warokka, A. (2019). Acceptance and Penetration of Bitcoin: The Role of Psychological *Distance and National Culture. SAGE Open*. https://doi.org/10.1177/2158244019865813

Alia, H. & Spiegelman, E. (2020). Convertible local currency and trust: 'It's Not You, It's Me' – A field experiment in the French Basque Country Local Economy, 1–16. DOI: 10.1177/0269094220905505

Bácsi, J., & Herczeg, I. (2014). Local currency as a tool of risk management in the small and medium enterprises sector. *Roczniki Naukowe Stowarzyszenia Ekonomistów Rolnictwa i Agrobiznesu*, 16(3), 18–23.

Bacik, R., Nastisin, L., & Gavurova, B. (2017). The role of social media in the light of building a strong online brand awareness. In: Proceedings of the 5th International Conference Innovation Management, Entrepreneurship and Sustainability. 5th International Conference Innovation Management, Entrepreneurship and Sustainability (IMES). *Edited by: Dvoulety, O; Lukes, M; Misar, J. Prague, May 25-26, 2017, pp. 38-47.*

Bashir, M., Strickland, B., & Bohr, J. (2016). What motivates people to use Bitcoin? In Y-Y. Ahn, & E. Spiro (Eds.), *Social Informatics - 8th International Conference, SocInfo 2016, Proceedings* (pp. 347-367). Springer-Verlag. https://doi.org/10.1007/978-3-319-47874-6_25

Beer, C., & Weber, B. (2015). Bitcoin – The promise and limits of private innovation in monetary and payment systems. *Monetary Policy and the Economy*, Q4/2014, 53-66. Available at https://ssrn.com/abstract=2556800

Benkler, Y. (2017). Peer Production, the Commons, and the Future of the Firm. Strategic Organization 15 (2): 264–274. doi:10.1177/1476127016652606.

Blanc, J., & Fare, M. (2013). Understanding the role of governments and administrations in the implementation of community and complementary currencies. *Annals of Public and Cooperative Economics*, 84(1), 63–81.

Brenes, E. (2011). Complementary currencies for sustainable local economies in Central America. *International Journal of Community currency research*, 15. doi: 10.15133/j.ijccr.2011.018.

Cannas, R. (2017). Embedding social values in tourism management: community currencies as laboratories of social entrepreneurship? In D. Dredge & S. Gyimóthy (Eds). *Collaborative Economy and Tourism. Tourism on the Verge. Springer, Cham.* doi: 10.1007/978-3-319-51799-5_13.

Carroll, J. M., & V. Bellotti (2015). Creating Value Together: The Emerging Design Space of Peer-To-Peer Currency and Exchange. In Proceedings of the 18th ACM Conference on Computer Supported Cooperative Work & Social Computing, 1500–1510. New York, NY: ACM. doi:10.1039/c4sm02053g.

Cato, M., & Suarez, A. M. (2012). Stroud pound: A local currency to map, meas-ure and strengthen the local economy. *International Journal of Community Currency Research*, 16. doi: 10.15133/j.ijccr.2012.017.

Cepel, M., Kljucnikov, A., Kozubikova, L., & Krajcik, V. (2019). Local Currency as a Mean of Regional Competitiveness Development. *Journal of Competitiveness*, 11(4), 22–39. https://doi.org/10.7441/joc.2019.04.02

Chipere, M. (2018). Virtual currency as an inclusive monetary innovation for the unbanked poor Electronic Commerce Research and Applications 28 ,37–43.

Churski, P. & Dominiak, J. (2014). The impact of innovations on growth and stagnation regions in Poland. European Planning Studies, 22(6): 1143–1164.

Civelek, M., Ključnikov, A., Krajčík, V., Žufan, J. (2019). The Importance of Discount Rate and Trustfulness of A Local Currency for the Development of Local Tourism. Journal of Tourism and Services, 10(19): 77-92. https://doi.org/10.29036/jots.v10i19.117

De', R., Pandey, N., & Pal, A. (2020). Impact of Digital Surge during Covid-19 Pandemic: A Viewpoint on Research and Practice. *International Journal of Information Management*, 102171. Advance online publication. https://doi.org/10.1016/j.ijinfomgt.2020.102171

De Carrillo, C. I. P., Esteva, J. L. R., Pena, P. N. C., & Pharow, P. (2018). Identification of barriers and solutions for adoption of social, complementary and/or virtual currencies. *International Journal of Community currency Research,* 22. doi:10.15133/j.ijccr.2018.020.

De Filippi, P. (2015). Translating Commons-Based Peer Production Values into Metrics: Toward Commons-Based Cryptocurrencies. In Handbook of Digital Currency: Bitcoin, Innovation, Financial Instruments, and Big Data, edited by D. Lee and K. Chuen, 463–483. Singapore: Elsevier Science & Technology.

Dini, P. & Kioupkiolis, A. (2019). The alter-politics of complementary currencies: The case of Sardex Politics & International Relations, *Cogent Social Sciences (2019),* 5: 1646625 https://doi.org/10.1080/23311886.2019.1646625

Diniz, E. H., Cernev, A. K., & Nascimento, E. (2016). Mobile social money: An exploratory study of the views of managers of community banks. *Revista de Administração,* 51(3), 299–309.

Diniz, E. H., Siqueira, E. S. & Van Heck, E. (2019). Taxonomy of digital community currency platforms, *Information Technology for Development*, 25:1, 69-91, DOI: 10.1080/02681102.2018.1485005

Dittmer, K. (2013). Local currencies for purposive degrowth? A quality check of some proposals for changing money as usual. *Journal of Cleaner Production*, 54(1), 3-13. DOI: 10.1016/j.jclepro.2013.03.044

Dołzbłasz, S. & Raczyk, A. (2015). Different Bordera – Different Cooperation? Transborder Cooperation in Poland. Geographical Review, 105(3): 360–376.

Dupont, J., & Squicciarini, A. C. (2015). Toward de-anonymizing Bitcoin by mapping users location. *Paper presented at the Proceedings of the 5th ACM Conference on Data and Application Security and Privacy*. https://doi.org/10.1145/2699026.2699128

Eisenstein, C. (2011). Sacred Economics: Money, Gift, and Society in the Age of Transition Paperback. Evolver Editions.

Ferreira, J., Perry, M., & Subramanian, S. (2015, February). Spending time with money: From shared values to social connectivity. *In Proceedings of the 18th ACM conference on computer supported cooperative work & social computing* (pp. 1222–1234). Vancouver, BC: ACM.

Fesenfeld, L., Stuckatz, J., Summerson, I., Kiesgen, T., Ruß, D. & Klimaschewski, M. (2015). It's the motivation, stupid! The influence of motivation of secondary currency initiators on the currencies' success. International Journal of Community Currency Research, 19, 165-172.

França, A.S.L., Amato Neto, J., Gonçalves, R.F. & Almeida, C.M.V.B. (2020). Proposing the use of blockchain to improve the solid waste management in small municipalities, *Journal of Cleaner Production*, 244, https://doi.org/10.1016/j.jclepro.2019.118529.

Gajdová, K. & Tuleja, P. (2015). Analysis of the Economically Active Population in the Czech-Polish Border Regions. International Journal of Information and Education Technology, 5(3): 237-241.

Gao, X., Clark, G. D., & Lindqvist, J. (2016). Of two minds, multiple addresses, and one ledger: Characterizing opinions, knowledge, and perceptions of Bitcoin across users and non-users. *Paper presented at the Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems.* https://doi.org/10.1145/2858036.2858049

Gavurova, B., Bacik, R., & Fedorko, R. (2018). Analytical View of Online Marketing Tools in the Dimension of Marketing Campaigns' Personalization in Slovakia. Marketing and Management of Innovations*, 2, pp. 186-200. doi: 10.21272/mmi.2018.2-15*

Gardner, B. (2020). Dirty banknotes may be spreading the coronavirus, WHO suggests. March 2, Retrieved June, 20, 2020, from The Telegraphhttps://www.telegraph.co.uk/news/2020/03/02/exclusive-dirty-banknotes-may-spreading-coronavirus-world-health/.

Gentilal, M., Martins, P., & Sousa, L. (2017). TrustZone-backed bitcoin wallet. *Paper presented at the Proceedings of the Fourth Workshop on Cryptography and Security in Computing Systems.* https://doi.org/10.1145/3031836.3031841

Glaser, F., Zimmermann, K., Haferkorn, M., Weber, M. C., & Siering, M. (2014). Bitcoin - Asset or currency? Re-vealing users' hidden intentions. Retrieved from https://ssrn.com/abstract=2425247

Gomez, G., & Helmsing, A. (2008). Selective spatial closure and local economic development: what do we learn from the Argentine local currency systems? *World Development*, 36(11), 2489-2511. https://doi.org/10.1016/j.worlddev.2007.11.015

Hammami, R., Temponi, C., & Frein, Y. (2014). A scenario-based stochastic model for supplier selection in global context with multiple buyers, currency fluctuation uncertainties, and price discounts. *European Journal of Operational Research*, 233, 159–170. http://dx.doi.org/10.1016/j.ejor.2013.08.020

Hartono,E., Holsapple, C. W., Kim, K., Na, K. & Simpson, J. T. (2014). Measuring perceived security in B2C electronic commerce website usage: A respecification and validation, *Decision Support Systems*, 62, 11-21, https://doi.org/10.1016/j.dss.2014.02.006.

Hirotsugu, K., Yoshiaki, T., Naoya, K., Tetsuya, M. & Kazuhiro, S. (2011). A local currency system reflecting variety of values. *2011 IEEE/IPSJ International Symposium on Applications and the Internet*. DOI 10.1109/SAINT.2011.104

Hirotsugu, K., Yoshiaki, T., Tetsuya, M., Masato, N., Hideyuki, K. & Sumiko, M. (2012). A local currency system reflecting variety of values with a swarm intelligence. *2012 IEEE/IPSJ 12th International Symposium on Applications and the Internet*.

Hur, Y., Jeon, S., & Yoo, B. (2015). Is Bitcoin a viable e-business? Empirical analysis of the digital currency's speculative nature. *Paper presented at the Thirty Sixth International Conference on Information Systems*.

Huttunen,J. & Joutsenvirta, M. (2019) Monies, economies and democracy: cultivating ambivalence in the co-design of digital currencies, CoDesign, 15:3, 228-242, DOI: 10.1080/15710882.2019.1631352

Kakushadze, Z. & Liew, J. K. (2020). Coronavirus: Case for Digital Money? *World Economics* 21(1) (2020) 177-190. arXiv:2005.10154 [q-fin.GN]

Ključnikov, A., Civelek, M., Čech, P. & Kloudová, J. (2019). Entrepreneurial orientation of SMEs' executives in the comparative perspective for Czechia and Turkey. *Oeconomia Copernicana*, 10(4), 773–795. doi: 10.24136/oc.2019.035

Kim, S. M., Lough, B., & Wu, C.-F. (2016). The conditions and strategies for success of local currency movements. *Local Economy*, 31(3). doi: 10.1177/0269094216637332.

Krabbe, R. (2015). Building trust: Exploring the role of community exchange and reputation. *International Journal of Community Currency Research* 19(D): 62–71.

Krohn, G. & Snyder, A. (2008). An economic analysis of contemporary local currencies in the United States. *International Journal of Community Currency Research*. Vo, (22), pp. 53-68.

Kwon, M., Lee, C., Xiao, Y., & McIntosh, W. A. (2019). Community currency activities, community attachment, and quality of life: A case study of the Crooked River Alliance of TimeBanks. *Time & Society,* 28(3), 1181–1220. https://doi.org/10.1177/0961463X17716737

Lee, M.-C. (2009). Factors influencing the adoption of internet banking: An integration of TAM and TPB with perceived risk and perceived benefit. *Electronic Commerce Research and Applications,* 8(3), 130-141. https://doi.org/10.1016/j.elerap.2008.11.006

Lee, S. H., Bai, B., & Murphy, K. (2012). The role demographics have on customer involvement in obtaining a hotel discount and implications for hotel revenue. Management Strategy. *Journal of Hospitality Marketing & Management,* 21(5). doi: 10.1080/19368623.2012.682622.

Lee, K., Lee, B. & Oh, W. (2015). Thumbs up, sales up? The contingent effect of Facebook likes on sales performance in social commerce. *Journal of Management Information Systems*, 32(4). doi: 10.1080/07421222.2015.1138372.

Li, L., Rhee, C., & Moon, J. (2018). Identifying the effect of product types in the relationships between product discounts and consumer distrust levels in China's online social commerce market at the era of big data. KSII *Transactions on Internet And Information Systems*, 12(5). doi: 10.3837/tiis.2018.05.016.

Littera G, Sartori L, & Dini P. (2017). From an idea to a scalable working model: Merging economic benefits with social values in Sardex. *International Journal of Community Currency Research* 21: 6–21.

Ly, M. K.-M. (2013). Coining Bitcoin's legal-bits: Examining the regulatory framework for Bitcoin and virtual currencies. *Harvard Journal of Law & Technology*, 27(2), 587-608.

Majuri, Y. (2019), "Overcoming economic stagnation in low-income communities with programmable money", *Journal of Risk Finance*, Vol. 20 No. 5, pp. 594-610. https://doi.org/10.1108/JRF-08-2019-0145

Maličká, L. (2019). Fiscal Decentralization And Regional Disparities In Czechia And Slovakia: Regression Analysis At The Nuts 2 And Nuts 3 Level. Scientific Papers of the University of Pardubice, Series D: Faculty of Economics and Administration, SciPap 2019, 27(3), 1007, 91-101.

Marshall, A. P., & O'Neill, D. W. (2018). The Bristol pound: a tool for localization*? Ecological Economics*, 146. doi: 10.1016/j.ecoleon.2017.11.002.

Mauldin, R. L. (2015). Local currency for community development: Policy barriers and support. *Journal of Community Practice*, 23(3-4). doi: 10.1080/10705422.2015.1091420.

Mavromatidi,V. M., Gravas, E. M., Metsiou, A. X., Kostas, P., Zissopoulos, D. A., & Mavromatidis, I. G. (2009). A Digital community local currency to restore overturned banks of money and ethic, our answer to worldwide credit crisis*. Proceedıngs Of The 3rd Internatıonal Conference On Communıcatıons And Informatıon Technology,* 203-206.

Mendoza-Tello, J. C., Mora, H., Pujol-López F. A& Lytras, M. D. (2018). "Social Commerce as a Driver to Enhance Trust and Intention to Use Cryptocurrencies for Electronic Payments," *in IEEE Access*, vol. 6, pp. 50737-50751, 2018.

Miszczuk, M. (2018). Local currencies as an instrument for implementing the concept of sustainable development. *Problems Of Sustainable Development*, 13(2), 83-90.

Mohammadali, Z. M., Abdulkhaliq S. S. (2019). Prospects and Challenges of Entrepreneurship Development in the Kurdistan Region of Iraq: An Overview. International Journal of Entrepreneurial Knowledge, 7(2), 4-16. doi:10.12345-0006

Netrdová, P. & Nosek, V. (2020). Spatial Dimension of Unemployment: Space-Time Analysis Using Real-Time Accessibility in Czechia. International Journal of Geo-Information, ISPRS Int. J. Geo-Inf. 2020, 9, 401; doi:10.3390/ijgi9060401.

Nishibe, M. (2018). Understanding the diversity of CCS world-wide in globalization and deindustrialization as an evolutionary tree diagram. *International Journal of Community Currency Research* 22: 16–36.

North, P. (2010). Local Money – How to make it happen in your community, Tran-sition Books. Totnes, Devon: UIT Cambridge Ltd.

Olszewski, M. (2016). The Benefits and Challenges for Cross-border Cooperation in the Cieszyn Silesia Euroregion. The Journal of Cross Border Studies in Ireland 2016, retrieved from http://crossborder.ie/site2015/wp-content/uploads/2015/11/CCBS-JOURNAL-2016.pdf#page=43

Pianese, F., Signorini, M. & Sarkar, S. (2018). "Small Transactions with Sustainable Incentives," 2018 *9th IFIP International Conference on New Technologies, Mobility and Security (NTMS),* Paris, 2018, pp. 1-5.

Roussou, I., Stiakakis, E., & Sifaleras, A. (2019). An empirical study on the commercial adoption of digital currencies. *Information Systems and e-Business Management* (2019) 17:223–259. https://doi.org/10.1007/s10257-019-00426-7

Ruddick, W. O., Richards, M., & Bendell, J. (2015). Complementary currencies for sustainable development in Kenya: the case of the Bangla-Pesa. *International Journal of Community Currency Research*, 19. doi: 10.15133/j.ijccr.2015.003.

Ryan-Collins, J. (2011). Building local resilience: the emergence of the UK transition currencies. *International Journal of Community Currency Research*, 15. doi: 10.15133/j.ijccr.2011.023.

Samantha, M. K. (2020). Dirty money: The case against using cash during the coronavirus outbreak. March 7, Retrieved June, 21, 2020, fromCNNhttps://www.cnn.com/2020/03/07/tech/mobile-payments-coronavirus/index.html.

Sanz, E. O. (2016). Community currency (CCs) in Spain: an empirical study of their social effects. *Ecological Economics,* 121. doi: 10.1016/j.ecolecon. 2015.11.008.

Saunders, M., Lewis, P., and Thornhill, A. Research methods for business students. India, Pearson Education, 5th edition, 2009.

Seyfang, G. (2005). Community currencies and social inclusion: A critical evaluation. CSERGE Working Paper EDM, No. 05-09, University of East Anglia, The Centre for Social and Economic Research on the Global Environment (CSERGE), Norwich.

Seyfang, G., & N. Longhurst (2012). Money, Money, Money? A Scoping Study of Grassroots Complementary Currencies for Sustainability. 3S Working Paper 2012–02. Norwich: Science Society and Sustainability Research Group. doi:10.1094/PDIS-11-11-0999-PDN.

Seyfang, G. & Longhurst, N. (2013). Desperately seeking niches: Grassroots innovations and niche development in the community currency field. Global Environmental Change 23 (2013) 881–891.

Shahzad, F., Xiu, G., Wang, J., & Shahbaz, M. (2018). An empirical investigation on the adoption of cryptocurrencies among the people of mainland China. *Technology in Society*, 55. doi: 10.1016/j.techsoc.2018.05.006.

Sirohi, J., Kukalová, G. & Moravec, L. (2018). Analysis of Regional Disparities in Agriculture Focusing on Economically Weak Regions of the Czech Republic. Scientia agriculturae bohemica, 50, 2019 (2): 141–153.

Shaw N. (2018) Helping the Local Community with Crypto-Currency: A Case Study. In: Nah FH., Xiao B. (eds) HCI in Business, Government, and Organizations. HCIBGO 2018. Lecture Notes in Computer Science, vol 10923. Springer, Cham

Svatošová, L. (2012). The development of regional disparities in Czech Republic over the 2005–2010 years. Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis 60(7), pp. 337–344. DOI: 10.11118/actaun201260070337

Svobodová, J., Dömeová, L., & Jindrová, A. (2018). Economic Differences Of Border Regions In The Czech Republic. Acta Universitatis Agriculturae Et Silviculturae Mendelianae Brunensis, 66(2), https://doi.org/10.11118/actaun201866020571

Szemerédi, E. (2018). An attempt to categorize Hungarian community currencies. Deturope, 10(1), 144-159.

Wróblewski, L. (2016). Creating an image of a region – Euroregion Beskydy and Euroregion Cieszyn Silesia examples. Economics and Management, 8(1), 91-100.

Vu, H.M, Ngo, V.M.. (2019). Strategy Development from Triangulated Viewpoints for a Fast Growing Destination Toward Sustainable Tourism Development – A Case Of Phu Quoc Islands in Vietnam, Journal of Tourism and Services 10(18): 117-140. https://doi.org/10.29036/jots.v10i18.86

Walton, A., & Johnston, K. (2018). Exploring perceptions of bitcoin adoption: The South African virtual community perspective. *Interdisciplinary Journal of Information, Knowledge, and Management, 13*, 165-182. https://doi.org/10.28945/4080

Acta Montanistica Slovaca
ISSN 1335-1788
actamont.tuke.sk

Analysis and risk assessment of the supply of copper ore in the belt conveyor system in an underground mine

Anna BURDUK[1]**, *Dorota WIĘCEK*[2]*, *Ivan ZAJAČKO*[3]*, *Leszek JURDZIAK*[1]*
and *Ryszard BŁAŻEJ*[1]

Authors' affiliations and addresses:
[1] Wrocław University of Science and Technology, ul. Wybrzeże Wyspiańskiego 27, 50-370 Wrocław, Poland
e-mail: anna.burduk@pwr.edu.pl
e-mail: leszek.jurdziak@pwr.edu.pl
e-mail: ryszard.blazej@pwr.edu.pl

[2] University of Bielsko-Biala, ul. Willowa 2, 43-309 Bielsko-Biała, Poland
e-mail: dwiecek@ath.bielsko.pl

[3] University of Žilina, Univerzitná 1, 010 26 Žilina, Slovak Republic
e-mail: ivan.zajacko@fstroj.uniza.sk

***Correspondence:**
Anna Burduk, Wrocław University of Science and Technology, ul. Wybrzeże Wyspiańskiego 27, 50-370 Wrocław, Poland
tel.:+48 71 320 37 10
e-mail:anna.burduk@pwr.edu.pl

How to cite this article:
Burduk, A., Więcek, D., Zajačko, I., Jurdziak, L. and Błażej, R. (2020). Analysis and risk assessment of the supply of copper ore in the belt conveyor system in an underground mine. *Acta Montanistica Slovaca,* Volume 25 (2), 236-249

DOI:
https://doi.org/10.46544/AMS.v25i2.10

Abstract
Risk management, through the systematic implementation of policies related to analysis, assessment, and action leading to a reduction in the amount of risk-related losses, is increasingly used in manufacturing companies. We are looking for opportunities in order to improve efficiency and an opportunity of gaining a competitive advantage in reducing the risk level of having a negative impact on the economic results of enterprises. The article presents the concept of reliable analysis and risk assessment for the horizontal transport system of copper ore. The risk has been defined as the probability of not achieving the objective set for the transport system, i.e., not delivering the planned amount of copper ore in a given time to the mining shaft. Unplanned downtime and belt conveyor failures have been assumed as risk factors. The proposed method consists of three stages. The FMEA (Failure Mode and Effects Analysis) method was used in the first stage, which allowed for the designation of structural elements of the belt conveyor, which are most often damaged. The FMEA method uses operational data collected over a period of three years as well as the expert knowledge of maintenance staff. In the second stage, the transport system was divided into components (transport lines) for which the risk of failure was determined, allowing the identification of transport lines most exposed to the risk of failure. The third and final stage of the method consisted of determining the reliability structure of the entire transport system by belt conveyors, taking into account the functions of individual elements (transport lines) in the system. The total risk calculated for the reliability structure determined in this way is the probability of not achieving the objective set for the transport system.

Keywords
risk, risk analysis and assessment, FMEA analysis, reliability structures.

Introduction

Recently, there has been a clear increase in the interest of manufacturing enterprises in risk management due to the successive increase in the economic risk and the introduction of risk management to many management standards. An example here may be the ISO standards used in most manufacturing companies, such as ISO 9001, ISO 14001, ISO 45001, ISO /IEC 27001, ISO 23301, IATF 16949, ISO 22000, ISO 17025 and others, which includes aspects of risk management. The most recent ISO 9001:2015 standard contains an obligatory approach to risk management, which was not in the previous version of the 9001:2008 standard. The issue of risk management also appears in the context of risk assessment and reliability of machine systems and transport systems in mining (Andrejiova et al., 2015; 2020; Blazej& Jurdziak, 2017;Blokus-Roszkowska & Kolowrocki, 2015; Czaplicki, 2008; Czaplicki, 2009; Dhillon, 2017; Tworek et al. 2018). In copper ore mines having no market sales problems, any downtime in the transport system can lead to production losses that cannot be overcome at a later date. The lack of downtime also serves to minimize the unit costs of extraction, which are higher in underground mines than open-pit ones. Reducing production increases costs by making competition conditions even worse (Więcek et al., 2020). Downtime costs also increase the optimal cut-off grade (Kržanović et al., 2015), which reduces the resources that are profitable for extraction.

In general, the risk associated with an organizational or production system is the probability that the system will not perform the functions for which it was designed. The magnitude of the risk is, in turn, the difference between the defined and achieved goals of the production system resulting from the impact of the interfering factors (Aven, 2015; Simon et al., 2018; Więcek et al., 2019). Risk management is a systematic policy related to the implementation of procedures and practical action, aimed at bringing damage to a reasonable level. In other words, risk management boils down to reducing the degree of impact of risk factors on the functioning of an enterprise (Waters, 2002; Tworek et al., 2018). For this, however, it is necessary to quantify the size of the risk and use methods to assess it (Aabo et al., 2005). Mines collect data from automation systems on the states of the transport system; however, they are not used everywhere(Kuric et al., 2018).

Individual elements of the belt conveyor system may be subject to operational failures resulting in downtime at work and thus may significantly affect the achievement of the production objective. In many mines, there are catastrophic conveyor failures caused by factory defects, random overloads, or damage caused by impacts of large lumps of excavated material (Andriejova et al., 2020; Bajda et al., 2016). Damaged elements can be repaired or replaced with other elements (new or regenerated). Downtime may be shorter (several minutes as in the case of most electrical repairs) or longer (lasting several hours or changes as in the case of repair or replacement of elements such as gear or belt, depending on the type of failure). Therefore, the reliability of individual conveyor elements has a major impact on the reliability of the entire transport system and is reflected in the number of production losses (Czaplicki, 2014).

Some elements and components of belt conveyors are subject to a faster aging process, and for them, the intensity of failure increases quicker with age. These include gears, belt conveyors, and connections (Błażej et al., 2018). Due to a large number of elements in the entire transport system and the fact that after many years of operation, the system has elements of very different ages, there is no sense in averaging their properties. Therefore, in the case of different age of elements, it is allowed to describe the frequency of their damage by exponential distribution (Czaplicki, 2014). The exponential distribution can describe both the frequency of failure of individual components (Szymański, 2007) as well as complex machines such as excavators on wheels (Lazarević et al., 2018).

Monitoring, visual inspections, and NDT diagnostics are often introduced for the most expensive components and subassemblies. Systematic monitoring of the condition of gearboxes of belt conveyors working in very difficult conditions at hazardous production facilities enables not only detecting defects at an early stage but also to predict the development of defects. The introduction of the technique in the diagnosis system results in technical maintenance cost reductions (Antosz & Ratnayake, 2019; Kuzin et al., 2019). Visual inspections and NDT diagnostics of expensive belts are also carried out (Błażej et al., 2018). The age and condition diagnosed affect individual decisions related to the continued use or preventive replacement (Kirjanów-Błażej et al., 2019). In the paper (Wodecki et al., 2017), authors presented the application of unsupervised learning method used for data classification in order to detect anomalies in diagnostic temperature signal from heavy-duty gearbox used in underground mining industry. The methodology is based on the Expectation-Maximization algorithm for Gaussian mixture model estimation, and parameterization with simple statistics. The technique applied to real data gives much better and more reliable results than direct one-dimensional time series analysis. The results obtained enabled detecting the unusual behavior of the gearbox.

The purpose of the article is to present and verify the concept of the method of reliable risk assessment based on the practical example. The developed method is based on the theory of reliability and reliability structure of complex objects, which in this case, is the belt conveyor transport system in one of the copper ore mines. The risk assessment takes into account the technical aspects of the analyzed object, according to which risk can be treated only in the category of loss, and not as in the case of economic systems in the category of profit or loss. The verification of the method was based on operational data collected over a period of 3 years on the failure of the belt conveyor system. From the point of view of this study, the belt conveyor transport system's risk management comes down to:

- Designation of elements of the belt conveyor system, the failure of which affects the transport system most, and thus the possibilities of delivering ore to mining shafts. This is especially important from the point of view of quickly aging or worn expensive components and subassemblies, which are not kept in the stock of spare parts or whose purchase time is lengthy.
- Determining the level of risk that is the probability of damage for individual belt conveyor transport lines.
- Determining the risk of failure of the entire system, taking into account its reliability structure, which has a significant impact on the reliability of the entire horizontal transport system.

The risk assessment of the analyzed belt conveyor system was carried out in three stages. In the first stage, the FMEA (Failure Mode and Effects Analysis) table was constructed, which enabled determining the risk for individual elements of the belt conveyor system. In the second stage, the risk of failure of individual transport lines included in the belt conveyor system was calculated. In the third stage, the reliability structure for the analyzed transport system was determined, and the total risk of the system was calculated. The advantage of the proposed method of reliable risk assessment is that in addition to the number of losses and the likelihood of their occurrence, it also takes into account the reliability structure of complex technical systems and objects, and not just like other methods proposed in the literature, the magnitude of the losses and the probability of their occurrence.The combination of the proposed methods allows us to quantify and assess the failure risk, taking into account its reliability structure for the entire transport system.

Material and Methods

Review of the literature on the reliability of machine systems and transport systems in mining

The main causes of damage, basic methods of reliability testing of propulsion systems, and a review of the propulsion systems of mining conveyors operating in 20 hard coal mines are presented in the paper (Szymański, 2007). Reliability indicators, calculated for a representative group of objects, were used to increase the times of trouble-free operations. Belt conveyors are driven by a system of one, two, or four drive motors, single or double speed. Mining conveyors are repairable objects according to the theory of reliability, while conveyor components belong to both classes of repairable and non-repairable facilities. According to the theory of reliability, an electric motor is an irreparable object, working with random gaps, and the operation of the system can be continued after replacing the engine. The research was carried out for data for the period 1995-1999. Data analysis showed that:

- *In turbine clutch conveyors*: 70% of the damage was caused by clutch failure, 20% - gear transmission failure, 8% - damaged drive motor, and *in conveyor drives with a flexible clutch*: 65% of the damage was caused by gear transmission failure, 20% - drive motor failure, 12% - clutch failure.
- The main causes of *drive motor failure* were: short circuit of stator winding - 80%, bearing damage - 16%. The main causes of turbine *clutch failure* were: loss of tightness - 70%, damage to bearings - 25%, while the most common damage to *the gear transmission* was: high-speed shaft - 70%, bearings - 15%, gears - 10% and loss of tightness - 4%.
- In the *motors* tested, the following were most often damaged: rotor winding 52%, stator winding - 18%, bearing nodes - 15%, and other - 15%.

The introduction of a proactive monitoring system for mining machinery in open-pit mines enables the analysis of work processes and the state of units and components by reviewing the collected condition assessment parameters. This creates the opportunity to make rational decisions related to extending the service life. The obtained parameters form the basis for making decisions regarding the regeneration, reconstruction, or replacement of the unit and components, and also allows for developing guidelines for the design of these machines. One of the significant benefits of a proactive approach is the ability to update existing forecasting methods implemented in predictive programs. The compiled procedures enable the prediction of the behavior of the structure and potential failures, assessing the reliability of the structure under operating load(Lazarević et al., 2018; Tlach et al., 2017; Zajačko et al., 2018).

Used for aging objects (with increasing failure intensity over time), the exponential distribution can be used to describe catastrophic events that occur suddenly. The study (Bugarić et al., 2014) modeled the reliability of rubber belt conveyors used in the overburden stripping system at the Tamnava-East Field open cast mine using this type of distribution. The methodology used the fact that the working time of the belt until the damage can be represented by the composition of the exponential distribution (sudden damage) and normal distribution (damage developing gradually) and the existence of a linear relationship between the length of the belt and the average time of its operation until gradual damage. The proposed approach methodology and developed reliability function can be used to analyze the operation of other open-pit mines, with some adjustments, to ensure better downtime planning, backup conveyor belt planning, and to reduce the operational costs of the open-pit mine, for example, implementation of an optimal service strategy. This approach can also be used to calculate the cost of failure (Bugaric et al., 2012).

Preventive belt replacements are widely used in Poland due to their aging. Most often on the basis of age (recorded in the databases of PGE GiEK SA Turów and Bełchatów Branch) and cyclical visual inspections of the condition of belts on conveyors. Exchanges based on statistical data and distributions are not used. Currently, visual inspection is increasingly being replaced by diagnostic systems. This applies especially to steel ropes (type St), whose core state can be assessed by magnetic systems (for example, Błażej et al., 2018). A different approach was presented in the studies (Kolowrocki 2004; Blokus-Roszkowska & Kolowrocki,2014; 2015; Blokus, 2020).

In the book (Kolowrocki, 2004), the author, taking into account the importance of security and efficiency of complex systems' operational processes, extended the two-state approach to the multi-state approach in analyzing their reliability. The assumption that systems consist of multi-state components whose reliability states degrade over time without repair allows for a more accurate analysis of their reliability, safety, and efficiency of operational processes. This assumption allowed him to distinguish the critical state for the reliability of the system, exceeding it is dangerous for the environment or not providing the necessary efficiency of the operational process. It has been found that an important feature of system reliability is the time until the critical state of the entire system's reliability is exceeded and its distribution, which is called the system's risk function. This distribution is closely related to the multi-state system reliability function, which is the basic feature of the multi-state system. For large systems, determining the exact reliability functions of complex systems and risk functions leads to very complex patterns that are often inconvenient for reliability practitioners. One important technique in this situation is the asymptotic approach to assessing system reliability. In this approach, instead of the preliminary complex formula for the system reliability function, after assuming that the number of system elements tends to infinity and finding the limit system reliability, its simplified form is obtained.

Mathematical methods used in the asymptotic approach to analyzing the reliability of complex systems are based on limiting assumptions on the distribution of ordinal statistics considered widely in the literature. These assumptions were used to develop the limit function of the reliability of systems composed of two- and multi-state components.

More emphasis than ever before is placed on the belt conveyor's reliability that transports the extracted raw materials. In operation with a longwall system, up to 90% of extraction comes from one wall, which in turn must be efficiently operated by one receiving conveyor. That is why modern mines are looking for conveyors with reliability close to 100%, and the machine industry is under increasing pressure to achieve this objective. This intention can be achieved by the machine-building industry by following the five design guidelines in Figure 1. (Hall et al., 2000; Kuric, 2011).

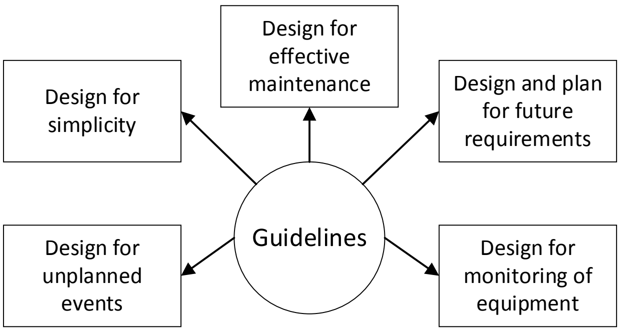

Fig. 1. Useful design-related guidelines for improving conveyor reliability (Dhillon, 2008)

In the studies (Ratnayake & Antosz, 2017; Dhillon, 2008; Leugner, 1996; Chlebus et al., 2015) it was proposed to use the Total Productive Maintenance (TPM method) to eliminate losses that are considered to be the reasons for limiting the efficiency of devices (Figure 2).

The losses associated with machine system downtime described in the book (Dhillon, 2008) were caused by equipment failures and shutdowns of machines and control systems to replace machine tools/stamps from the production process. Damage losses related to the following two items:

- Reduced performance due to time and production loss problems from starting equipment to achieving a stable level of production.
- Defective production due to poor production quality, which causes discards and waste in the production process.

And also the losses related to the production speed regarding:

- Performance reduction due to differences between design and actual speeds.
- Idle work and slight downtime due to incorrect sensor operation, causing machine shutdown or blocking of conveyors, dumps, etc.

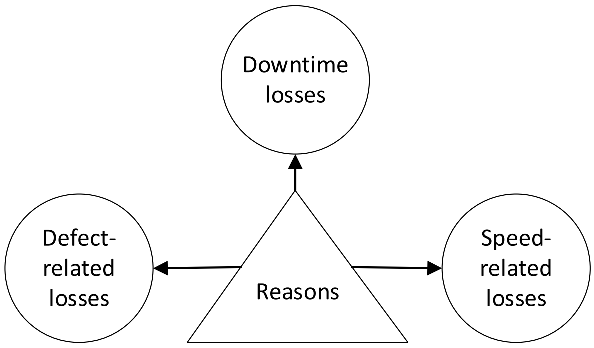

Fig. 2. Principal reasons for the performance of Total Productive Maintenance (TPM) (Dhillon, 2008).

In the 8th chapter (Reliability by Design. Reliability-Centered Maintenance) of the book (Campbell et al., 2016) James Picknell rightly stated that "since most failures are random, Reliability Centred Management (RCM) logic first asks if it is possible to detect the problem in time to keep the system running. If the answer is "yes", condition monitoring is needed. One must monitor often enough to detect deterioration, with enough time to act before the function is lost".

Of course, the knowledge of the age of the elements can and should be taken into account when choosing the frequency of inspections and indicating more endangered elements or choosing the moment of preventive replacement. Computer-aided systems for tape management are used for this, ERP system or other databases, or even Excel spreadsheets with information. Continuous and cyclical diagnostic systems that can build a knowledge base on the state of components (for example, belts) can also be helpful. However, it is sufficient to use the frequency of failure of individual elements and subassemblies in order to analyze and assess the risk of a conveyor belt transport system in a mine.

The concept of a reliable risk assessment methods in production systems

Reliability in the operational sense is most often defined as the probability that the system or its component will perform its tasks for which it was designed for a scheduled time under specific operating conditions (Aabo, 2005). However, risk can be defined as the probability of system losses due to risk factors. In the case of the analyzed mine, the risk will be understood as a failure to achieve the objective set out for the production system, i.e., not mining the appropriate size of copper ore assumed in the production plansW_{plan}. The formulated concept of the risk assessment method is based on the assumption that risk*R* as a probability of these losses being synonymous with unreliability *Z*, that is (Billinton &Allan, 1992; Burduk, 2010; Burduk & Chlebus, 2009):

$$R(t) = Z(t). \quad (1)$$

With this risk interpretation, the following formula for system reliability *N* can be used (Bazovsky, 2004):

$$N(t) + Z(t) = 1. \quad (2)$$

Then the following equations should be accurate:

$$N(t) + R(t) = 1. \quad (3)$$

and

$$R(t) = 1 - N(t). \quad (4)$$

The diversified level of reliability of individual elements of the production system means that the system's reliability as a whole will largely depend on the way its elements are connected, i.e., on the reliability structure. This means that different system reliability structures, built of the same number of identical, independent elements, result in different levels of system reliability. The system reliability structure's analysis should be preceded by the division of the system into individual components of the so-called system decomposition, reflecting logical connections in the system so that its individual parts are statistically independent and as large as possible. Depending on the type of element connections in the system, the most common are basic (series and parallel) and mixed (series-parallel and parallel-series) structures (Billinton &Allan, 1992). In practice, systems with mixed structure will be most common: series-parallel and parallel-series.

The system has a serial reliability structure if any element's failure causes the failure of the entire system. This definition means that the object is functional if and only if all its elements are functional and that as the number of system elements increases, its reliability decreases. The reliabilityN_S of the system with a serial structure is determined by the formula (Billinton &Allan, 1992):

$$N_S = N_1 \cdot N_2 \cdot \ldots \cdot N_n = \prod_{i=1}^{n} N_i, \quad (5)$$

where $N_1, N_2, \ldots, N_n$ are the reliabilities of individual system components.

Using the formula (4), the total risk $R_C$of the system with serial structure can be determined by:

$$R_C = 1 - [(1 - R_1) \cdot (1 - R_2) \cdot \ldots \cdot (1 - R_n)], \quad (6)$$

where $R_1, R_2, \ldots, R_n$ are the risks of individual elements of the system.

A system with a parallel reliability structure is exploitable if at least one of its components is fit. The parallel structure is characteristic of systems in which the elements perform the same task. The reliability of such a system will increase as the number of system components increases and is determined by the formula (Billinton &Allan, 1992):

$$N_S = 1 - [(1 - N_1) \cdot (1 - N_2) \cdot \ldots \cdot (1 - N_n)] = 1 - \prod_{i=1}^{n}(1 - N_i), \quad (7)$$

where $N_1, N_2, \ldots, N_n$are the reliabilities of individual system components.

The total risk R_c of systems with a parallel structure can be determined based on the formula:

$$R_c = R_1 \cdot R_2 \cdot \ldots \cdot R_n = \prod_{i=1}^{n} R_i, \quad (8)$$

where $R_1, R_2, \ldots, R_n$are the risks of individual areas/elements of the system.

In practice, production systems with a parallel reliability structure defined in this way do not occur or are very rare, as the excess of elements (for example, machines, employees, means of transport, etc.) means unused resources, which increases production costs (Aabo, 2005; Burduk & Krenczyk, 2017; Burduk & Chlebus, 2009; Więcek & Więcek, 2017). Risk determination for parallel production structures is much more appropriate in this case. An example of such a structure is shown in Figure 3.

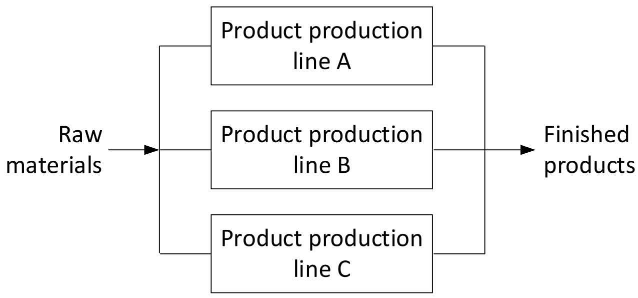

Fig. 3. An example of a parallel production structure

Treating the system structure from Figure 3 as a parallel production structure, and taking into account the nature and specificity of production systems, the risk formula considers the system weights should be according to formula 9.
Weights are assigned depending on the line's capacity and show how each line has an impact on total risk. These lines work independently of each other and supply the output in varying degrees:

$$R_{SC} = \alpha_1 R_1 + \alpha_2 R_2 + \cdots + \alpha_n R_n, \text{ where } \alpha_1 + \alpha_2 + \cdots + \alpha_n = 1, \ \alpha_1, \ldots, \alpha_n \geq 0. \quad (9)$$

The concept of risk interpretation proposed in the method presented above as a synonym of unreliability allows for identification of elements of the production system most exposed to the impact of risk factors or elements in which the impact of risk factors will most transform into the functioning of the entire production system. Of course, real production systems most often have serial-parallel and parallel-serial structures. Thus, the above-mentioned basic structures should be modified to suit the needs of the risk assessment of the analyzed system.

Application of the FMEA method to risk assessment

The analysis of the causes and effects of FMEA (Failure Mode and Effects Analysis) defects was used to assess the risk of failure of individual elements of belt conveyors. The method belongs to the group of quality management methods and is included in the standard ISO 9001 and ISO 31000. The use of the method allows, among others, to identify the area in the process where the risk is greatest (Burduk & Krenczyk, 2017; Ferencz et al. 2015). The size of the failure risk for a given element expressed by RPN (Risk Priority Number) is determined based on indicators whose values are estimated on the basis of knowledge and experience of persons participating in the assessment.

A special form was developed in which the following information was entered to conduct FMEA analysis of the failure of belt conveyors in the analyzed mine:

- potential defects for individual elements included in the construction of the belt conveyor,
- the probability of their occurrence (P),
- the degree of hazard (Z), determining the magnitude of the effects that arise as a result of the appearance of a defect during the production process and the use of the product,
- traceability (T), determining the possibility of detecting that a potential defect or its cause will become apparent later.

In the next step, numerical values were given to individual parameters (Wolfgang & Klaus, 2007). Values, according to the scale shown in Figure 4, were given by employees who are responsible for the efficiency of belt conveyors on a daily basis (Table 4).

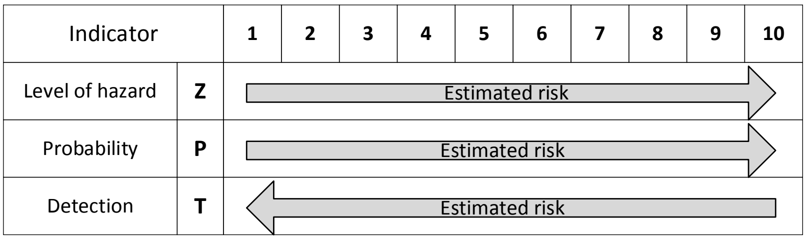

Fig. 4. The scale and magnitude of risk parameters (Burduk & Krenczyk, 2017)

Next, the risk value was determined for individual elements of belt conveyor system construction according to the formula:

$$RPN = (Z) \cdot (P) \cdot (T). \tag{10}$$

Calculating the RPN allows the assessment of the risk of damage to individual elements included in the construction of the belt conveyor, and thus indicates the element most vulnerable.

Characteristics of the transport system

The analyzed mining plant, which verified the proposed risk assessment method, is one of the three plants of the largest copper and silver producers in the world. The mining area and area of the plant is 176 km^2 and is located in the southwestern part of Poland. The mine exploits copper-bearing sandstones, tar-shale (copper-bearing), and carbonate copper ore (calcite-dolomitic layers), from which copper and silver are obtained. In addition, rock salt is mined in one of the mines as an accompanying mineral from higher deposits. In a part of the "Sieroszowice" mining area, above the copper ore deposit, at a distance of 80-100 meters, a rock salt deposit has been documented, having the character of a seam with a thickness ranging from 40 to 150 meters, from which over 300 thousand tons of rock salt is extracted annually intended for the domestic market (Bartlett et al., 2013).

The ore is transported to glass wells located in the vicinity of the mining shafts by means of a belt conveyor system (departmental and collective). There are three mining shafts operating in the mine: SI (two skips with a capacity of 18 Mg), SII (four skips with a capacity of 30 Mg), and SIII (two skips with a capacity of 18 Mg). Figure 5 shows a diagram of belt conveyors in the mine, mining areas, storage reservoirs, and mining shafts in one of the underground copper ore mines.

The length of the conveyor transport system at the mine is over 30 km and is divided into two subsystems:

1. departmental transport, which is the initial phase of hauling spoil from discharge points (grates) located in the areas of mining divisions for main haulage conveyors,

2. main transport, the purpose of which is to collect spoil from departmental conveyors and transport it towards the mining shafts.

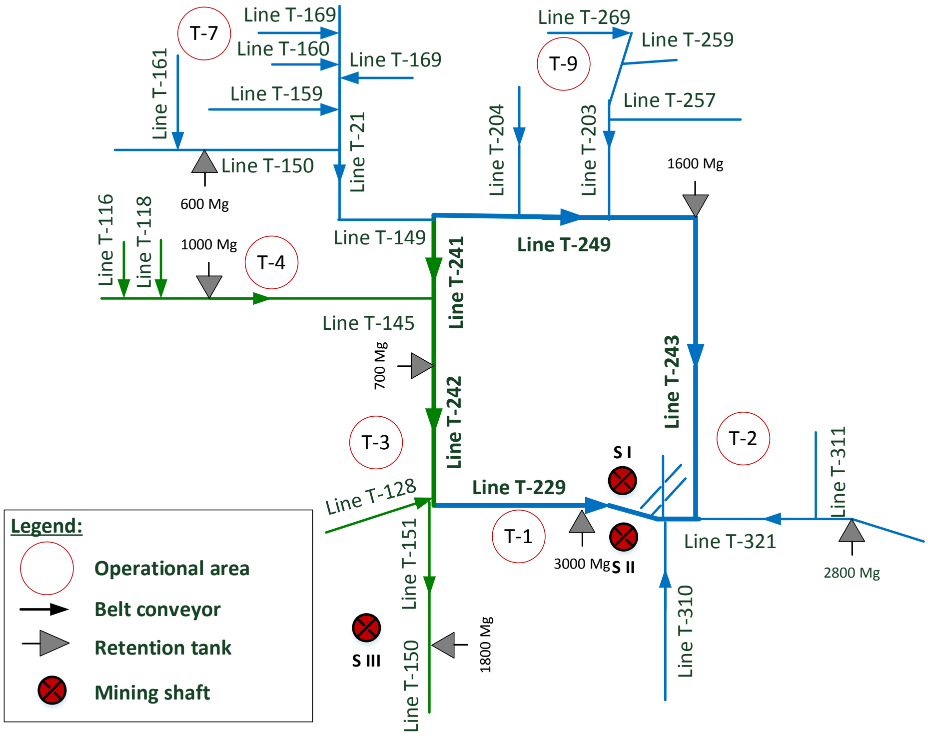

Fig. 5. Map of belt conveyors, storage reservoirs, mining fields, and mine shafts (Koman and Laska, 2014).

From the point of view of reliability, the conveyor system in the mine creates a multi-branch serial structure, in which each branch consists of departmental conveyors having several loading points (grates) (at the beginning and on the route) that can feed spoil to the next conveyor in series or ore on the collecting conveyor from another branch. Collective conveyors can be fed with ore through grilles or loading from other conveyors. The system becomes a parallel-series system due to the arrangement of main conveyors in the so-called "Square" (Figure 5), because the ore from the faces to the shafts travels in a series of departmental and collective conveyors, and after reaching the "square" it has the opportunity to reach the shaft tanks by three main conveyor routes, which ensures parallel arrangement of conveyors and the possibility of their reversion. However, a single conveyor will be treated as a serial system, because it consists of many elements cooperating in such a way that the failure of any of them stops the conveyor and all preceding it.
The basic elements that make up the construction of the conveyor belt and associated devices are:

- head station (drive) of the drum/drums or,
- the drive system (engines, clutches, and gears),
- power supply and automation system,
- a closed-loop of belts consisting of sections and connections (vulcanized, glued or mechanical),
- tensioning system;

and repeatable segments of the route structure with:

- upper and lower idler sets,
- turning station with drum,
- loading and unloading devices, which include a grille, hoppers and dispenser nozzles,
- retention tanks with loading and unloading system.

Despite the huge financial outlays incurred in this area, all components of the conveyor are highly exposed to failures. After many years of operation, the system contains elements of very different ages, and there are thousands of them. For example, there are almost 60 km of tape in the analyzed mine (which consists of several thousand sections and the same number of connections), there are hundreds of thousands of pulleys, several dozen gears, etc. The whole system and individual elements have their own specificity and averaged properties. In fact, individual damages are rare, and the destruction of even such elements as gears may soon intensify wear or cause damage to other parts of the conveyor. Even the shortest unplanned downtime, in this case, is associated with losses, not to mention the cost of buying new components (Bartlett et al., 2013).

Results and Discussion

Data analysis on belt conveyor system failure

The exploitation process in the analyzed mine takes place in a 4-shift system (24 hours a day) from Monday to Friday. During each day of work, there are 2 breaks related to blasting works at 6.00 and 18.00 (plus waiting time after blasting works). The spoil transport process takes place at the same time as the exploitation process, with the difference that it is shorter by the time of transporting people operating conveyor belts to the workplace. Depending on the conveyor location, this time is approximate, from 240 to 270 minutes of operation of the glazing and main haulage conveyors and from 180 minutes to 240 minutes for departmental conveyors.

Data from a 36-month (3-year) period were used for the risk analysis, derived from the dispatcher's database of the horizontal transport department. The data set contained almost 3,000 records about the stoppages of the conveyor system in the mine. Each record contained information such as the name of the conveyor, date of failure, shift number, stop time, the reason for failure divided into categories (for example, mechanical, electrical, other), description of the failure, the department responsible for repairing the failure and impact on mining. Only failures that affected the volume of production (2,511 records) were taken for further analysis. The first analysis that was made was a breakdown of failure durations in individual years (Table 1).

Tab.1. Summary of the number and duration of conveyor failure

Year	Number of stoppages	The average duration of stoppage[min]	Standard deviation	Minimal duration [min]	Maximum duration [min]
I	643	46	58	8	801
II	786	52	62	8	860
III	1082 (2511)	45	53	5	595

The analysis of the collected data shows that the average failure time is generally about 47 minutes and ranges from 5 minutes to 860 minutes. Attention should be drawn to the increase in the number of failures in subsequent years. A more detailed analysis of the data showed that most failures occur in the range of 5 to 240 minutes (these are faults removed during 1 work shift), while the fewer failures were lasting from 240 minutes to 860 minutes (these failures last longer than 1 work shift).

Another analysis of this data concerned the division of causes of failures into 3 main groups: electrical (E), mechanical (M), other (I). Table 2 presents the results of failures by a group of causes.

Tab.2. Number and duration of breakdowns by a group of causes

Type of failure	Number of stoppages	The average duration of stoppage [min]	Minimal duration [min]	Maximum duration [min]
E	1749	42	5	680
M	443	62	8	860
I	319	53	8	595

As it results from the analysis of the data from Table 2, most failure is caused by an electric cause, and the average conveyor downtime is the shortest. A more detailed breakdown of the type of failure, taking into account the type of the conveyor belt element, to which the failure relates, is presented in Table 3. In addition, the analysis included failures related to the power supply of the belt conveyor.

Tab.3. Division of failures into types and components of the belt conveyor

Damaged object	Type of failure	Number of stoppages	The average duration of stoppage [min]	Minimal duration [min]	Maximum duration [min]
Supply system	E	926	65.5	12	680
	M	11	26.9	15	45
	I	18	35.3	30	88
Belt	E	0	0	0	0
	M	106	85.1	21.5	450
	I	6	28.5	20	70
Roller sets	E	0	0	0	0
	M	89	55.8	12	412
	I	2	73.5	20	127
The head station (Transmission)	E	544	65.1	5	417.5
	M	39	64.2	18.8	135
	I	15	51.7	22	112
Turning station	E	41	27.9	26	30
	M	14	130.3	25	186
	I	1	26.0	26	26
Equipment Loading / Unloading	E	171	46.2	15	360
	M	295	58.5	15	860
	I	233	89.6	30	595

Risk assessment of the failure of individual elements of belt conveyors

The FMEA table was constructed, which enabled determining the RPN for individual elements of the belt conveyor system.The RPN value is between 1 and 1000. The high RPN value is the equivalent of high risk in the process. In the case of increased RPN value, the team of employees should make efforts to reduce risk, using corrective action. An expert team of maintenance staff decided that RPN values below 100 would be considered an acceptable risk. In the case of an RPN value above 100, corrective action leading to the reduction of the risk level to an acceptable value will be further developed. Table 4 presents the results of the expert team's work in the form of a developed FMEA table based on data on the frequency of non-compliance in the considered process and their effects and causes.

Tab.4. FMEA form with the calculated RPN for the belt conveyor transport system

The element of the belt conveyor	Potential fault / defect	Probability of occurrence (P) [pts.]	Degree of danger (Z) [pts.]	Traceability (T) [pts.]	RPN [pts.]
Supply system	no voltage	9	10	2	**180**
	low voltage	8	8	3	**192**
	overload	9	10	5	**450**
	optical fiber failure	6	9	4	**216**
Belt	belt speed sensor failure	4	6	3	72
	failure of the belt tensioning system	4	6	4	96
	failure of the rim	6	5	4	**120**
	belt rip	5	5	4	100
	belt tear	4	10	2	80
	belt converging	5	10	6	**300**
Roller sets	damage to the roller	9	4	7	**252**
	roller wear	8	4	9	**288**
	no roller	7	5	6	**210**
The head station (Transmission)	drives not ready	10	8	4	**320**
	system failure	7	10	2	**140**
	failure of the drive drum	8	10	4	**320**
	activation of safety sensors	7	9	1	63
	overload	7	9	3	**189**
Turning station	control system failure	6	9	3	**162**
	backfilling the excavated material (spoil)	7	8	2	**112**
	the outflow of spoil from tanks/dispensers	8	8	2	**128**
Loading/unloading device	dispenser failure	6	10	5	**300**
	blockade of the dispenser nozzle	8	6	2	96
	no dispenser control	7	8	6	**336**
	blocked stone	8	9	4	**288**
	failure of the hydraulic hammer	8	6	1	48
	no control of the hydraulic hammer	2	6	2	24
	mud-covered conveyor route under the grille	3	10	2	60
	tank overflow	8	9	2	**144**
TOTAL RPN					**5286**

The maximum *RPN* value of the analyzed system is 29,000 (29 faults of 1,000 points each). Thus, the value of losses due to the risk of belt conveyor failure for this transport system is:

$$RS = \frac{5286}{29000} = 0.182$$

The use of FMEA does not allow to identify the risk size of the entire transport system. Value $RS = 0.182$ is the average value of the risk of loss of structural components of one belt conveyor that is affected by:

- the probability of failure of individual conveyor elements,
- the magnitude of the threat to the transport process caused by the failure of these elements,
- the traceability.

According to the FMEA analysis, the risk and overloading of the supply system and the risk of drive drum failure are the most significant risks and the most impacting on the transport system. However, in accordance with the principles of the FMEA method, corrective actions should be taken for all elements for which the *RPN* value is higher than 100. Only 9 out of 29 cases in the table reach the limit values in the method, i.e., less than 100 of the coefficients of *RPN* of the FMEA table. The FMEA method allows us to identify the system elements most exposed to the impact of risk factors or whose trouble-free operation affects most strongly the functioning of the entire system. An important element of the transport system's overall risk is the cost risk that incurs specific costs of the enterprise (so-called risk costs)—incurring additional prevention costs for the most critical elements by introducing changes to transport processes that improve system reliability. If the cause of the failure cannot be eliminated, costs should be incurred to increase the detection of this failure or reduce the negative effects of their occurrence regarding the transport process or the production process. This method also impacts the cost of non-compliance that may occur, paying attention to the most emergency elements and their impact on the effects during the production process and the possibility of their detection. The next item will review the concept of a reliable risk assessment method.

Verification of the reliable risk assessment method for a horizontal copper ore transport system

There are 3 mining shafts in the analyzed mine: SI, SII, and SIII. The production volume of the entire mine depends on their production capacity. The production capacity of the mine W_{plan} is 16,000,000 tonnes of copper ore per year and 55,900 tonnes per day. The production capacity for individual mining shafts /subsystems is summarized in Table 5.

Tab.5. Summary of shafts and lines extraction capacity

Shaft mining capacity [tons of copper ore/day]	Line mining capacity (subsystems) [tonsof copper ore/day]
$\boldsymbol{W_{planSI}}$= 8,300	$S^1_{I,II}$=19,600
$\boldsymbol{W_{planSII}}$ = 39,000	$S^2_{I,II}$=27,700
$\boldsymbol{W_{planSIII}}$ = 8,600	S_{III}=8,600

Mining extraction shafts SI and SII are located very close to each other and supplied by the same systems of belt conveyors transporting copper ore from mining fields: T-1, T-2, T-7, T-9, and through the belt conveyor lines of the main haulage square T-229, T-243, T-249, and T-321. Mining shaft SIII is supplied by departmental conveyors from T-3 and T-4 mining fields and by T-241, T-242, and T-151 lines of the haulage square. In view of the adopted assumptions, the conveyor transport system in the analyzed mine will have a parallel-series structure shown in Figure 6, in which 3 lines stand out (subsystems) $S^1_{I,II}$, $S^2_{I,II}$, S_{III}.

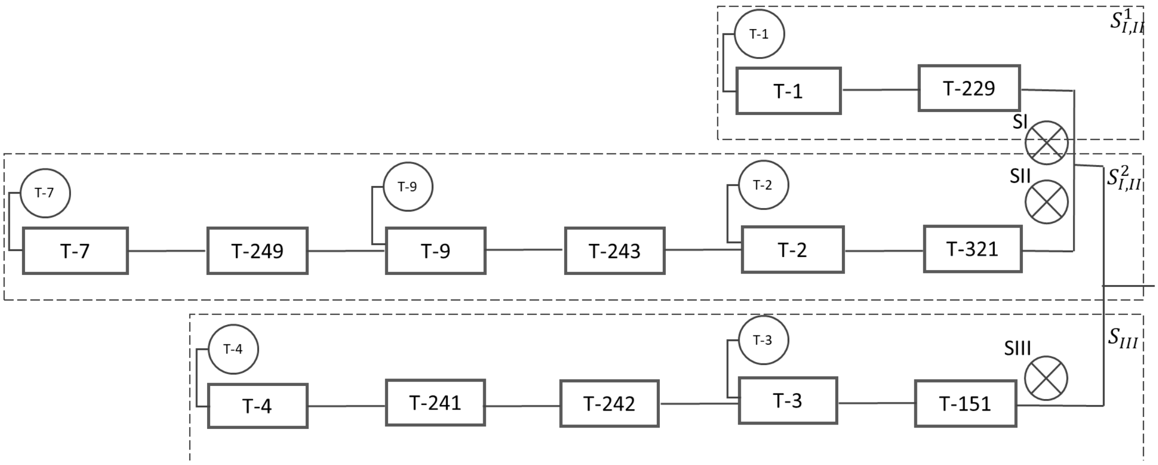

Fig. 6. Series-parallel structure of the belt conveyor transport system

Weights should be assigned to individual elements for the presented parallel-serial structure of the analyzed transport system $\alpha_{s^1_{I,II}}$, $\alpha_{s^2_{I,II}}$, $\alpha_{s_{III}}$corresponding to the daily production capacity of the line. It is assumed that the system components work independently of each other, i.e., a failure of one line does not cause a break in the functioning of the other lines.

Considering first the parallel structure of the analyzed transport system and denoting by $Rs^1_{I,II}$risk of line $S^1_{I,II}$(Fig. 6), by $Rs^2_{I,II}$risk of line $S^2_{I,II}$, and by Rs_{III}risk of line S_{III}, a formula for the total risk of the system R_{SC}has the form:

$$R_{SC} = \alpha_{s^1_{I,II}} Rs^1_{I,II} + \alpha_{s^2_{I,II}} Rs^2_{I,II} + \alpha_{s_{III}} Rs_{III}, \quad (11)$$

where

$$\alpha_{s^1_{I,II}} + \alpha_{s^2_{I,II}} + \alpha_{s_{III}} = 1.$$

Weights were determined based on daily extraction (Table 5): $\alpha_{s^1_{I,II}} = 0.3506$; $\alpha_{s^2_{I,II}} = 0.4955$; $\alpha_{s_{III}} = 0.1538$. Substituting these values to formula (11) we obtain:

$$\mathbf{R_{SC} = 0.3506 \cdot Rs^1_{I,II} + 0.4955 \cdot Rs^2_{I,II} + 0.1538 \cdot Rs_{III}.}$$

The risk of the parallel system's individual components is calculated from the formula for the risk of a serial system. Based on Fig. 6, the risks of individual lines take the form:

$$Rs_{I,II}^{1} = 1 - (1 - R_{T-1})(1 - R_{T-229}) = 1 - (1 - 0.182)(1 - 0.182) = 0.331,$$

$$\begin{aligned} \mathrm{Rs}_{\mathrm{I,II}}^{2} &= 1 - (1 - \mathrm{R}_{\mathrm{T}-7})(1 - \mathrm{R}_{\mathrm{T}-249})(1 - \mathrm{R}_{\mathrm{T}-9})(1 - \mathrm{R}_{\mathrm{T}-243})(1 - \mathrm{R}_{\mathrm{T}-2})(1 - \mathrm{R}_{\mathrm{T}-321}) \\ &= 1 - (1 - 0.182)(1 - 0.182)(1 - 0.182)(1 - 0.182)(1 - 0.182)(1 - 0.182) = 0.7, \end{aligned}$$

$$\begin{aligned} Rs_{III} &= 1 - (1 - R_{T-4})(1 - R_{T-241})(1 - R_{T-242})(1 - R_{T-3})(1 - R_{T-151}) \\ &= 1 - (1 - 0.182)(1 - 0.182)(1 - 0.182)(1 - 0.182)(1 - 0.182) = 0.634. \end{aligned}$$

As can be seen, the risks of all transport lines are very high. The probability of an unfulfilled target is greatest for the line $\mathrm{Rs}_{\mathrm{I,II}}^{2}$ and amounts to 70%, while for lines $\mathrm{Rs}_{\mathrm{III}}$63%, and for lines $\mathrm{Rs}_{\mathrm{I,II}}^{1}$33%. These risk levels are unacceptable because the likelihood of failure to meet the production target set for the transport system is too high. The presented risk amounts confirm the need to introduce measures to reduce it. In the next step, the risk was determined for the entire transport system.

Substituting the risks of individual lines to the total risk formula we obtain:

$$\begin{aligned} R_{SC} = 0.3506\big(1 - (1 - R_{T-1})(1 - R_{T-229})\big) + \\ 0.4955\big(1 - (1 - R_{T-7})(1 - R_{T-249})(1 - R_{T-9})(1 - R_{T-243})(1 - R_{T-2})(1 - R_{T-321})\big) + \\ 0.1538\big(1 - (1 - \mathrm{R}_{\mathrm{T}-4})(1 - \mathrm{R}_{\mathrm{T}-241})(1 - \mathrm{R}_{\mathrm{T}-242})(1 - \mathrm{R}_{\mathrm{T}-3})(1 - \mathrm{R}_{\mathrm{T}-151})\big). \end{aligned}$$

Having determined the risk of failure of elements of a single conveyor belt $\mathrm{R}_{\mathrm{T_i}} = 0.182$ and assuming it is the same for all conveyors, the total risk $\mathrm{R}_{\mathrm{SC}}$for the entire system can be calculated as follows:

$$\begin{aligned} R_{SC} = 0.3506\big(1 - (1 - 0.182)(1 - 0.182)\big) + \\ 0.4955\big(1 - (1 - 0.182)(1 - 0.182)(1 - 0.182)(1 - 0.182)(1 - 0.182)(1 - 0.182)\big) + \\ 0.1538\big(1 - (1 - 0.182)(1 - 0.182)(1 - 0.182)(1 - 0.182)(1 - 0.182)\big) \\ = 0.1160 + 0.3471 + 0.0975 = 0.5606. \end{aligned}$$

The total risk of the transport system calculated in this way means that with a probability of 56.06%, the objective set for the production system (extraction of 16,000,000 tonnes of copper ore per year or 55,900 tonnes per day) will not be carried out.

The obtained results confirm the actual data on the failure and conversations with employees of the mine maintenance department. One of the practical conclusions of the method used is to indicate the belt conveyor's structural elements most vulnerable to failures and the transport lines with the greatest risk of failure. The proposed method allows determining the risk for the entire transport system, taking into account its reliability structure.

Conclusions and Further research

Nowadays, companies wanting to gain a competitive advantage are looking to improve the efficiency of their processes in various areas. One of them is the analysis, assessment, and then elimination of the risk constantly present in production systems. The introduction of risk management is increasingly seen by manufacturing companies as one of the ways to improve production efficiency. This article proposes and verifies a practical method for the reliability of risk assessment. The method allows the risk assessment of complex technical systems, which is the belt conveyor transport system.

The method was verified using data on the construction of belt conveyors, functions of individual transport lines, and detailed operational data on the failure and standstill of the conveyor for three years. Risk factors were identified, and their occurrence characteristics determined based on these data. For this purpose, the failures were divided into types for which repair times were analyzed.

The risk assessment of the belt conveyor system was carried out in three stages. In the first stage, the structural elements with the greatest impact on its failure rate were determined using the FMEA method. In the second stage, transport lines with the highest risk of failure were identified. At the third stage, the risk of the entire transport system by transport conveyors was determined, taking into account its reliability structure.As a result, it is also possible to quickly determine the number and type of corrective actions leading to a reduction in the level of acceptable risk for the entire system.

The calculations presented above show that the risk of belt conveyors' failure is very high. However, the analysis did not take into account shaft tanks' occurrence that compensates for the losses associated with the risk of conveyor failure.

References

Aabo, T., Fraser, J.R.S., & Simkins, B.J. (2005). The rise and transformation of the chief risk officer: A success story on enterprise risk management. *Journal of Applied Corporate Finance*, 17(3), 8-18.

Andrejiova, M., Grincova, A., & Marasova, D. (2020). Monitoring dynamic loading of conveyer belts by measuring local peak impact forces. *Measurement*, 158, 107690, https://doi.org/10.1016/j.measurement.2020.107690

Andrejiova, M., Grincova, A., Marasova, D., & Grendel, P. (2015). Multicriterial assessment of the raw material transport. *Acta Montanistica Slovaca*, 20(1), 26-32.

Antosz, K., & Ratnayake, R. C. (2019). Spare parts' criticality assessment and prioritization for enhancing manufacturing systems' availability and reliability. *Journal of Manufacturing Systems*, 50, 212-225, https://doi.org/10.1016/j.jmsy.2019.01.003

Aven, T. (2015). *Risk analysis*. Chichester, West Sussex: Wiley Blackwell.

Bazovsky, I. (2004). *Reliability theory and practice*. Courier Corporation.

Bajda, M., Błażej, R., & Jurdziak, L. (2016). A new tool in belts resistance to puncture research. *Mining Science*, 23, 173-182, DOI: 10.5277/msc162314

Bartlett, S. C., Burgess, H., Damjanović, B., Gowans, R. M., & Lattanzi, C. R. (2013). Technical report on the copper-silver production operations of KGHM Polska Miedź SA in the Legnica-Głogów copper belt area of southwestern Poland. *MICON report*.

Billinton, R., & Allan, R. N. (1992).*Reliability evaluation of engineering systems*. New York: Plenum press.

Blazej, R., & Jurdziak, L. (2017). Condition-based conveyor belt replacement strategy in lignite mines with random belt deterioration. In *IOP Conference Series: Earth and Environmental Science* (Vol. 95, No. 4, p. 042051). IOP Publishing, https://doi.org/10.1088/1755-1315/95/4/042051

Błażej, R., Jurdziak, L., Kozłowski, T., & Kirjanów, A. (2018). The use of magnetic sensors in monitoring the condition of the core in steel cord conveyor belts–tests of the measuring probe and the design of the DiagBelt system. *Measurement*, 123, 48-53, https://doi.org/10.1016/j.measurement.2018.03.051

Blokus, A. (2020). *Multistate System Reliability with Dependencies*. Academic Press.

Blokus-Roszkowska, A., & Kolowrocki, K. (2014). Failure dependency analysis of series system with example of conveyor belt. *The 10th International Conference on Digital Technologies 2014*(pp. 290-297). IEEE, doi: 10.1109/DT.2014.6868730

Blokus-Roszkowska, A., & Kołowrocki, K. (2015). Reliability analysis of conveyor belt with dependent components. *Safety and Reliability of Complex Engineered Systems*, 1127-1136.

Bugaric, U., Tanasijevic, M., Polo Vina, D., Ignjatovic, D., & Jovancic, P. (2012). Lost production costs of the overburden excavation system caused by rubber belt failure. *Eksploatacja i Niezawodność*, 14, 333-341.

Bugarić, U., Tanasijević, M., Polovina, D., Ignjatović, D., & Jovančić, P. (2014). Reliability of rubber conveyor belts as a part of the overburden removal system-case study: Tamnava -east field open cast mine. *Technical Gazette*, 21(5), 925-932.

Burduk, A., & Krenczyk, D. (2017). Risk Assessment in a Parallel Production System with the Use of FMEA Method and Linguistic Variables. *Computer Information Systems and Industrial Management Lecture Notes in Computer Science*, 379-390, https://doi.org/10.1007/978-3-319-59105-6_32

Burduk, A. (2010). An attempt to adapt serial reliability structures for the needs of analyses and assessments of the risk in production systems. *Eksploatacja i Niezawodność-Maintenance and Reliability*, (3), 85-96.

Burduk, A., & Chlebus, E. (2009). Evaluation of the risk in production systems with a parallel reliability structure. *Eksploatacja i Niezawodnosc-Maintenance and Reliability*, (2), 84-95.

Campbell, J. D., Jardine, A. K., & McGlynn, J. (Eds.). (2016). *Asset management excellence: optimizing equipment life-cycle decisions*. CRC Press.

Chlebus, E., Helman, J., Olejarczyk, M., & Rosienkiewicz, M. (2015). A new approach on implementing TPM in a mine - A case study. *Archives of Civil and Mechanical Engineering*, 15(4), 873-884, https://doi.org/10.1016/j.acme.2015.07.002

Czaplicki, J. M. (2008). *Shovel-Truck Systems: Modelling, Analysis and Calculations*. CRC Press.

Czaplicki, J. M. (2009). *Mining equipment and systems: theory and practice of exploitation and reliability*. CRC Press.

Czaplicki, J. M. (2014). *Statistics for mining engineering*. CRC Press.

Dhillon, B.S. (2008). *Mining Equipment Reliability, Maintainability, and Safety*. Springer Science & Business Media.

Dhillon, B.S. (2017). *Engineering systems reliability, safety, and maintenance: an integrated approach*. CRC Press.
Ferencz, V., Dugas, J., Prividi, D., Andrejkovič, M., Cehlár, & M., Jurkasova Z. (2015). The implementation of knowledge-intensive services in drawing out and bottling of natural mineral water. *Acta Montanistica Slovaca*, 20(2), 125-140.
Hall, R. A., Daneshmend, L. K., Lipsett, M. G., & Wong, J. (2000). Reliability analysis as a tool for surface mining equipment evaluation and selection. *CIM bulletin*, 78-82.
Kirjanów-Błażej, A., Jurdziak, L., Burduk, R., & Błażej, R. (2019). Forecast of the remaining lifetime of steel cord conveyor belts based on regression methods in damage analysis identified by subsequent DiagBelt scans. *Engineering Failure Analysis*, 100, 119-126, https://doi.org/10.1016/j.engfailanal.2019.02.039
Kolowrocki, K. (2004). *Reliability of large systems*. Amsterdam: Elsevier.
Koman, M., & Laska, Z. (2014). Rozwiązania konstrukcyjne elementów systemu transportu taśmowego O/ZG Rudna, pozwalające na zmianę kierunku przesyłu urobku. *Cuprum: czasopismo naukowo-techniczne górnictwa rud*, 3(72), 69-82.
Kržanović, D., Kolonja, B., & Stevanović, D. (2015). Maximizing the net present value by applying an optimal cut-off grade for long-term planning of the copper open pits. *Acta Montanistica Slovaca*, 20(1), 49-61.
Kuzin, E., Gerike, B., Mamaeva, M., & Singh, K. (2019). Diagnostics of Gearboxes of Mining Belt Conveyors Using Floating Spectral Masks. *In E3S Web of Conferences* (Vol. 105, p. 03011). EDP Sciences, https://doi.org/10.1051/e3sconf/201910503011
Kuric, I. (2011). New methods and trends in product development and planning. *Academic Journal of Manufacturing Engineering,* 9(1), 453-456.
Kuric, I., Císar, M., Tlach, V., Zajačko, I., Gál, T., & Więcek, D. (2018). Technical diagnostics at the department of automation and production systems. In *International Conference on Intelligent Systems in Production Engineering and Maintenance* (474-484). Springer, Cham, https://doi.org/10.1007/978-3-319-97490-3_46
Lazarević, Ž., Aranđelović, I., & Kirin, S. (2018). The reliability of bucket wheel excavator-review of random mechanical failures. *Tehnički vjesnik*, 25(4), 1259-1264, https://doi.org/10.17559/TV-20160727170019
Leugner, T. (1996). Developing a total productive maintenance(TPM) programme. *Quarry Management*, 23(8), 21-25.
Ratnayake, R. C., & Antosz, K. (2017). Risk-Based Maintenance Assessment in the Manufacturing Industry: Minimisation of Suboptimal Prioritisation. *Management and Production Engineering Review*, 8(1), 38-45, DOI: 10.1515/mper-2017-0005
Simon, P., Zeiträg, Y., Glasschroeder, J., Gutowski, T., & Reinhart, G. (2018). Approach for a Risk Analysis of Energy Flexible Production Systems. *Procedia CIRP*, 72, 677-682, http://dx.doi.org/10.1016/j.procir.2018.03.073
Szymański, Z. (2007). Badania niezawodnościowe silników napędowych maszyn górniczych. *Maszyny Elektryczne: zeszyty problemowe*, (78), 115-120.
Tlach, V., Císar, M., Kuric, I., & Zajačko, I. (2017). Determination of the industrial robot positioning performance. In *MATEC Web of Conferences* (Vol.137, p.01004). EDP Sciences, https://doi.org/10.1051/matecconf/201713701004
Tworek, P., Tchórzewski, S., & Valouch, P. (2018). Risk Management in Coal-Mines-Methodical Proposal for Polish and Czech Hard Coal Mining Industry. *Acta Montanistica Slovaca*, 23(1), 72-80.
Waters, D. (2002). *Operations management producing goods and services*. Harlow: Prentice Hall.
Więcek, D., Burduk, A., & Kuric I. (2019). The use of ANN in improving efficiency and ensuring the stability of the copper ore mining process. *Acta Montanistica Slovaca*, 24(1), 1-14.
Więcek, D., & Więcek, D. (2017). The influence of the methods of determining cost drivers values on the accuracy of costs estimation of the designed machine elements. In *International Conference on Information Systems Architecture and Technology* (pp. 78-88). Springer, Cham, https://doi.org/10.1007/978-3-319-67223-6_8
Więcek, D., Więcek, D., & Dulina, L. (2020). Materials requirement planning with the use of activity based costing. *Management Systems in Production Engineering*, 28(1), 3-8, https://doi.org/10.2478/mspe-2020-0001
Wodecki, J., Stefaniak, P., Polak, M., & Zimroz, R. (2017). Unsupervised Anomaly Detection for Conveyor Temperature SCADA Data. *Applied Condition Monitoring Advances in Condition Monitoring of Machinery in Non-Stationary Operations*, 361-369, https://doi.org/10.1007/978-3-319-61927-9_34
Wolfgang, B., & Klaus, M. (2007). Remarks to the risk assessment for abandoned mine sites.*Acta Montanistica Slovaca*, Ročník 12(3), 340-348.
Zajačko, I., Gál, T., Ságová, Z., Mateichyk, V., & Wiecek, D. (2018). Application of artificial intelligence principles in mechanical engineering. In *MATEC Web of Conferences* (Vol. 244, p. 01027). EDP Sciences, https://doi.org/10.1051/matecconf/201824401027

Acta Montanistica Slovaca
ISSN 1335-1788
actamont.tuke.sk

Prediction of the Future Development of Gold Price

***Tomas BRABENEC*[1], *Petr SULER*[2], *Jakub HORAK*[3]* and *Milos PETRAS*[4]**

Authors' affiliations and addresses:
[1] Faculty of Finance and Accounting, University of Economics, nám. W. Churchilla 1938/4, 13067 Prague, Czech Republic
e-mail: tomas.brabenec@vse.cz

[2] School of Expertness and Valuation, Institute of Technology and Business, Okruzni 517/10, 37001 Ceske Budejovice, Czech Republic
e-mail: petr.suler@cez.cz

[3] School of Expertness and Valuation, Institute of Technology and Business, Okruzni 517/10, 37001 Ceske Budejovice, Czech Republic
e-mail: horak@mail.vstecb.cz

[4] Institute of Earth Resources, Faculty of Mining, Ecology, Process Control and Geotechnologies, Technical University of Kosice, Park Komenskeho 19, 04200 Kosice, Slovakia
e-mail: milos.petras@tuke.sk

***Correspondence:**
School of Expertness and Valuation, Institute of Technology and Business, Okruzni 517/10, 37001 Ceske Budejovice, Czech Republic
tel.: +420 775 867 033
e-mail: horak@mail.vstecb.cz

How to cite this article:
Brabenec, T., Suler, P., Horak, J. and Petras, M. (2020). Prediction of the Future Development of Gold Price. *Acta Montanistica Slovaca*, Volume Volume 25 (2), 250-262

DOI:
https://doi.org/10.46544/AMS.v25i2.11

Abstract
Gold belongs, thanks to its extraordinary qualities, to the most interesting and well-known precious metals as far as investment is concerned. The paper aims to estimate the future development of the gold price and determine whether the gold price actually increases in times of economic recession. For the purpose of the analysis, data about the daily gold price from 2006 to July 2020 is used. To elaborate this paper, five methods of time series balancing were employed, namely Neural Networks, Decision Tree, Gradient Boosted Tree, Linear Regression, and Nearest Neighbours. The methods are applied to a training data set, and the final model is tested on the testing data set. The respective models' residues are presented in a graphic form as well as the Probability Density Histogram, Training Data Set Residues Histogram, and a graph of testing data set residues. The future development of the gold price for the next calendar year is predicted. Market participants buy gold in the first moments of the economic recession in order to keep the value of their property. Consequently, however, they lack cash and are forced to sell the gold again. A similar development can be expected now too. A global economic recession can be expected. Debtors will have to get rid of their investments, which will cause the gold price to fall dramatically. The gold price reaches its maximum value at the end of the observed period; then, it should decrease progressively to the end of 2020. At the beginning of 2021, the price should slump. Then, in the following six months, it should follow a growth path again.

Keywords
Gold price, prediction, global economic recession, state precautions, liquidity

Introduction

The fast and dynamic development of the global economy provides the investors with a number of new opportunities for depositing their available financial means, according to Vrbka and Rowland (2017). As it is stated by Marecek and Machova (2017), one of these opportunities can be represented, for example, by investing in precious metals. Rehman et al. (2018) observe that the awareness of precious metals as a tool of investment increased mainly after the financial crisis in 2008-2009 as a result of the so-called "flight to security" tendency on the commodity market. Out of these commodity markets, mainly gold but also other precious metals such as silver, copper, platinum, or palladium were historically used as safe assets and value preservers (Vigne et al., 2017). In order for metals to carry the attribute "precious", they have to fulfill some criteria such as fineness, relative rarity, homogeneity, high durability, and easy divisibility, according to Endou et al. (2000). As for other qualities of precious metals, according to Hammoudeh and Yuan (2020), the metals have to dispose of high weight, conductivity, or a high mechanic resistance. However, the main quality distinguishing precious metals from other commodities is their limited amount. Moreover, it is exactly a limited amount, and the steadily increasing demand results in their increasing importance (Dutta, 2018). Currently, precious metals are used in a wide scale of use not only for electronics and communication devices, engines of spaceships, and jet planes but also for cell phones and catalytic converters. The most common metals are gold from jewelry and electronics, silver from electronics, radiography, film, and photographic emulsions, jewelry, and industrial application; metals such as platinum from catalytic converters for refining oil, etc. (Canda, Heput and Ardelean, 2016).

Mirmirani and Li (2004) do not doubt that one of the most interesting and well-known metals as far as investments are concerned is gold. Thanks to its extraordinary qualities such as divisibility, rarity, ability to treasure, etc., gold plays a very important role in monetary systems and is considered to be a symbol of wealth for a couple of thousand years (Tri and Nga, 2019). Vravec (2012) adds that gold resists acids, salts, and rusting very well; it is chemically stable, soft, ductile, malleable, and functions as a great conductor of warmth and electricity. Investors consider it to be some sort of a "safe haven" at times of economic crises, which is also reflected by its price development on commodity markets (Ismail, 2009). Gutiérrez, Franco and Campuzano (2013) observe that the history of actual gold trading dates back to the 14th century. Furthermore, the author adds that gold played the role of a financial guarantee for issued banknotes, and later, it served as a tool of exchange trade in the 19th and 20th centuries. Later on, other types of investments, such as stocks or commodities, joined gold on the market. For the purpose of trading gold on the stock market or its storage for bank purposes, gold is calibrated into a weight unit. The gold price is given in USD for Troy ounce corresponding with approx. 31.1034768 grams. Gold is distinguished according to its fineness, in which case the gold with the highest level of fineness 99.99 is considered to be suitable for investment purposes (Tully and Lucey, 2007).

Part of the paper is literary research, including a literature review on the topic of predicting the future development of the gold price. Furthermore, the used data are described, including basic statistical characteristics, and the used methods – Neural Networks, Decision Tree, Gradient Boosted Tree, Linear Regression, and Nearest Neighbors are described. In the result part, the time series is first balanced by all the above methods. Furthermore, the balanced time series are compared with the actual course of the gold price. The Probability Density Histogram is used to identify the most accurate method, and a histogram of the residues of the training data set and the graph of the testing data set residues. The final gold price prediction is given. The next section discusses the development of the gold price and the future development of the gold price. In the end, the results, limitations, and directions of future research are briefly summarized.

The aim of the paper is to estimate the future development of gold prices.

With regard to the conducted literary research, we set the following research questions:

1. Does the gold price increase in the period of recession?
2. What kind of development of the gold price can be expected in the time period to 8th July 2021?

Literary Research

Arouri et al. (2012) claim that empirical studies focusing on precious metals can be divided into two main research lines. The first one is oriented on macroeconomic determinants of precious metals, and the second one concentrates on modeling and prediction of precious metals volatility. According to Paramita, Vivekananda and Debasmita (2017), it can be observed that the research in the field of demand for gold as the essential economic variable has been attracting the researchers' attention for ages. During this time, a number of studies and research have been conducted to identify the microeconomic and macroeconomic factors influencing the demand for gold (Balagopal and Sanket, 2018). Baur and McDermott (2010) add that the recent collapse of financial and economic conditions in the USA and European countries contributed to the motivation to study gold as a safe haven from a shortage of financial markets.

Some of the authors dealing with the issue of demand for gold are, for example, Starr and Tran (2008), who were the first ones to provide complex research of the factors influencing the physical demand for gold using panel data covering 21 countries in the years 1992-2003. They discovered that the persisting heterogeneity in physical demand for gold across nations is in accordance with the influence of socio-cultural aspects. Furthermore, the determinants of physical demand for gold differ from determinants of the same demand for portfolios, and they also differ in cases of developed and under-developed economies.

O'Connor et al. (2015) state that, according to a number of studies, gold is considered to be an investment asset in which case its significance in the portfolio diversification and its role as a safe haven in times of turbulences and crises on financial markets is emphasized. Also, Baur and Lucey (2010) identify with this statement, who observes that, during extreme conditions on financial markets, gold seems to be the right tool for securing the supplies. Beckmann, Berger and Czudaj (2015) add that this effect differs in individual countries. Cohen and Quadan (2010) analyzed the mutual dependence of the gold price and volatility index (VIX). They found that, during highly volatile time periods, the former leads the latter, which means that gold plays the role of some sort of a safe haven during the periods of stress on oil market or during extreme fluctuation of the exchange rate of the USD (Reboredo, 2013a; Reboredo 2013b). Tran and Starr (2007) examined the role of gold in exchange and monetary policy in Vietnam where, in the turbulent time period after the start of economic reform, gold served not only to preserve the value but also as an accounting unit and, for some types of transactions, as an exchange medium.

Baur (2016) discovers that coordinated purchases and sales of gold by central banks have an asymmetric effect on the gold price, which results from their ability to keep the price limit but not the price ceiling.

Balagopal and Sanket (2018) use their research to examine further the influence of global risk on the possession of gold by central banks. The research was conducted on the basis of yearly data for the time period 1990-2015 on a sample of 100 different countries. For the purpose of the study, the authors use the dynamic panel generalized method of movements model observing a number of factors. In accordance with the portfolio diversification and perception of gold as a safe asset, it was discovered that the possession of gold by central banks increases in reaction to higher global risk (Sinicakova and Gavurova, 2017). This effect differs depending on the openness of capital accounts, adequacy of reserves, state of income, and monetary regimes (Sinicakova et al., 2017). These findings indicate that central banks adjust their possession of gold in reaction to changes in global risk conditions, in which case the extent of the reaction depends on the vulnerability of the respective country. Karunagaran (2013) concentrates on the general trend of central banks' demand for gold as a consequence of a recent global financial crisis and observes that the demand for gold increases in the period of crisis. In the study, the issue of the optimal amount of gold in foreign exchange reserves and the reasons for banks buying gold with regard to the global crisis are discussed as well.

Materials and Methods

For the analysis of the time series and, subsequently, for the prediction of the future development of the gold prices, the London Fix Price AM data are used as standard. The key value for setting the reference gold price is the so-called London Fix Price, also known as London Golden Fix or London Fix. The gold price is determined twice a day on business days of the London Commodity Stock Exchange (i.e., apart from bank holidays). Since 1919, it has been set in cooperation with the five biggest traders on the stock market (Scotia-Mocatta, Barclays Capital, Deutsche Bank, HSBC, and Société Générale). London Fix is set twice a day – the morning publication at 10:30 a.m. GMT called AM and the afternoon publication at 15:00 p.m. GMT called PM.

The process of establishing the London Fix is as follows: the lead participant proposes an opening price near the current spot price. Subsequently, the participants contact their sales department and negotiate the number of gold ingots sold and bought for this particular price. The price can be slightly adjusted in order for the supply and demand of these five business subjects was in equilibrium without any significant excess of supply and demand. Consequently, the London Fix is set. The whole process usually takes about 10 to 20 minutes. The London Fix Price is set in USD, GBP, and EUR for one Troy ounce (i.e., 31,1034807 grams). The biggest business subjects trade approximately 20 tons of gold for the set price; the information about the official amount is not available (Machova, Krulicky and Horak, 2020).

The data for this contribution was collected from the website kurzy.cz (Gold – the current price of gold, investment gold, 2020). Kurzy.cz calculates the gold exchange rate from several (moreover continuously changing) sources. In addition, they compare them with the Bloomberg and Reuters exchange rates. Therefore, the exchange rate, in this case, does not correspond to any specific stock exchange or broker; it is primarily an expression of the general tendency of the exchange rate. Dates in the time period from 3rd January 2006 to 8th July 2020, i.e., 3,663 entries about the gold price, will be examined. The gold price will be expressed due to the nature of the input data in CZK.

The following graph illustrates the development of the gold price in the observed time period in Figure 1.

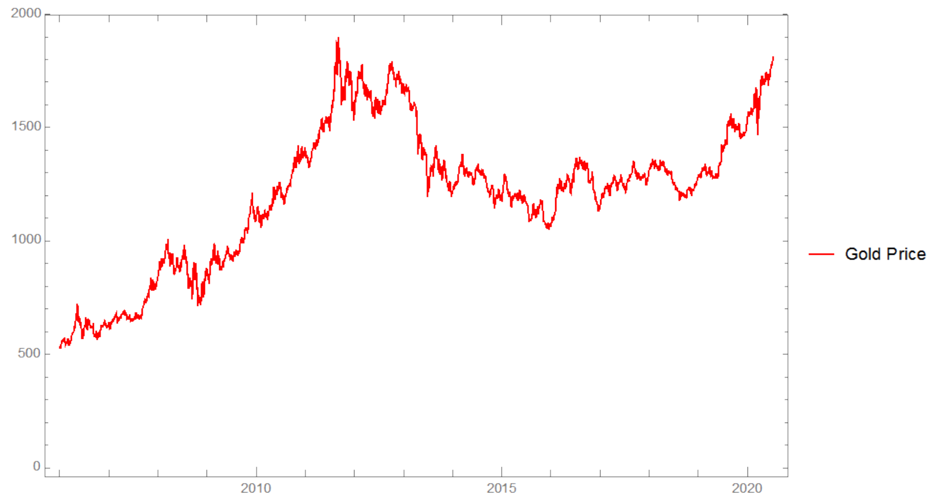

Fig. 1. The development of gold price in the time period from 3rd January 2006 to 8th July 2020
Source: Gold – the current price of gold, investment gold (2020)

The gold price is given in CZK. In 2006, the price started at a value higher than 500 CZK. Subsequently, it grows. In 2011, the gold price for one ounce reached almost 1,900 CZK. Later, it progressively decreases up to the year 2016 when it grows to 1,800 CZK for ounce again. The development in 2008 is interesting as well. Compared to the previous year, the gold price increased significantly and held its value for the whole year 2008. This could indicate the situation, as mentioned above. Gold keeps the value and serves as a tool of treasuring. Therefore, it is more than logical that, at the time of economic recession, the demand for gold grows, resulting in an increase in the gold price. The descriptive characteristics of the observed time series are stated in Table 1.

Tab. 1. Characteristics of the data collection

Descriptive Characteristics	Value in CZK
Minimum	524.75
Maximum	1,895
Average	1,205.03
Middle Value	1,248
Variance	98,337.9
Standard Deviation	313.589

Source: Authors.

To elaborate this paper, the software Mathematica from the company Wolfram in its version 13, will be employed. Specifically, five methods for balancing the time series and, therefore, obtaining the development model of the observed time series will be used. The following methods will be applied:

1. Neural Networks: A neural network consists of stacked layers, each performing a simple computation. Information is processed layer by layer from the input layer to the output layer. The neural network is trained to minimize a loss function on the training set using gradient descent. This method uses a multilayer perceptron network, and the training determines the number of neurons in the hidden layer for one thing and the weight of individual neurons for another. The weight of the respective neurons intensifies or weakens the signal that is transmitted in the neuron structure. The number of neurons in the input layer is one in this case. It represents the number of input quantities. Given the fact that there is only one continuous variable at the input, the number of neurons in the input layer equals one. The output variable is continuous as well, and it is the only one. Therefore, there is one neuron in the output layer as well. The following functions will be employed to activate the hidden and output layer of neurons: linear, identical, sine, hyperbolic tangent, and logistic function.
2. Decision Tree: A decision tree is a flow chart-like structure in which each internal node represents a "test" on a feature, each branch represents the outcome of the test, and each leaf represents a class distribution, value distribution or probability density.
3. Gradient Boosted Tree: Gradient boosting is a machine learning technique for regression and classification problems that produces a prediction model in the form of an ensemble of trees. Trees are trained sequentially to compensate for the weaknesses of previous trees. The current implementation uses the LightGBM framework in the back end.
4. Linear Regression: the linear regression predicts the numerical output y using a linear combination of numerical features:

$$x=(x_1, x_2, \ldots, x_n) . \quad (1)$$

The conditional probability $P(y|x)$ is modeled according to:

$$P(y|x) \propto exp\left(-(y-f(\theta,x))^2/(2\sigma^2)\right) \text{, with } f(\theta,x)=x.\theta . \quad (2)$$

The estimation of the parameter vector is done by minimizing the loss function:

$$\frac{1}{2} \sum_{i=1}^{m} (y_i - f(\theta,x_i))^2 + \lambda_1 \sum_{i=1}^{n} |\theta_i| + \frac{\lambda_2}{2} \sum_{i=1}^{n} \theta_i^2 , \quad (3)$$

where m is the number of examples, and n is the number of numerical features.

5. Nearest Neighbours: Nearest neighbors is a type of instance-based learning. Its simplest form picks the commonest class or averages the values among the k nearest neighbors.

The methods will be applied to the training data set every time. This set will include two-thirds of the data collected from the observed time period, i.e., 2,442 entries about the gold price altogether. The testing data set will be working with 1,221 entries about the gold price. The obtained models will be presented in a graphic form. The illustrations will include a graph of the analyzed time series development and the predictions calculated by means of the acquired model. Furthermore, the residues of the individual models will be presented in a graphic form. In order to choose the most suitable prediction model, the results of the testing data set will be analyzed as well. Specifically, it is the case for:

1. Probability Density Histogram: a histogram of the differenced of the original time series probability density and the predictions. The final value always lies in the interval of the values [y_j, y_m]. The Probability Density Histogram is derived from the following formula:

$$P(y \in [y_j, y_m]) = \int_{y_j}^{y_m} f_y(y)dy \quad (4)$$

provided that the relation

$$fy\text{-}(y)>0fy\_(y)>0, \forall y \text{ and } \int_{-\infty}^{+\infty} f_y(y)dy = 1 . \quad (5)$$

2. Residue of the testing data set histogram
3. Residue of the testing data set graph

Finally, the future development of the gold price converted to CZK will be predicted for the next calendar year (258 business days in particular). This predicted development will be presented in the form of a graph as well.

Results

Based on the calculations, the time series was balanced by means of the five methods – the gold price given in CZK (see Figure 2). The graphs in Figure 2 provide a comparison between the balanced time series and the real course of the gold price. Pictures a to c reflect the actual development of the gold price. Every picture then includes all or chosen a balanced time series. The picture provides a comparison of the actual course of the gold price and the balanced time series of all methods employed. The Nearest Neighbours method seems to be the most interesting of all. This particular method is left out in the next picture. Consequently, we get the basic idea about the development of other balanced time series. Out of all, mainly the ones balanced using the Neural Network and Gradient Boosted Trees seem to be the most promising. This presupposition is confirmed by picture c as well, which does not include the time series balanced according to Linear Regression. The most successful method cannot, however, be chosen based only on one's perception. Figure 3 provides, therefore, a comparison of the respective balanced time series with the actual development of the gold price in CZK. The illustration provides insight into the predicted development for the 12-month period and the development of residues.

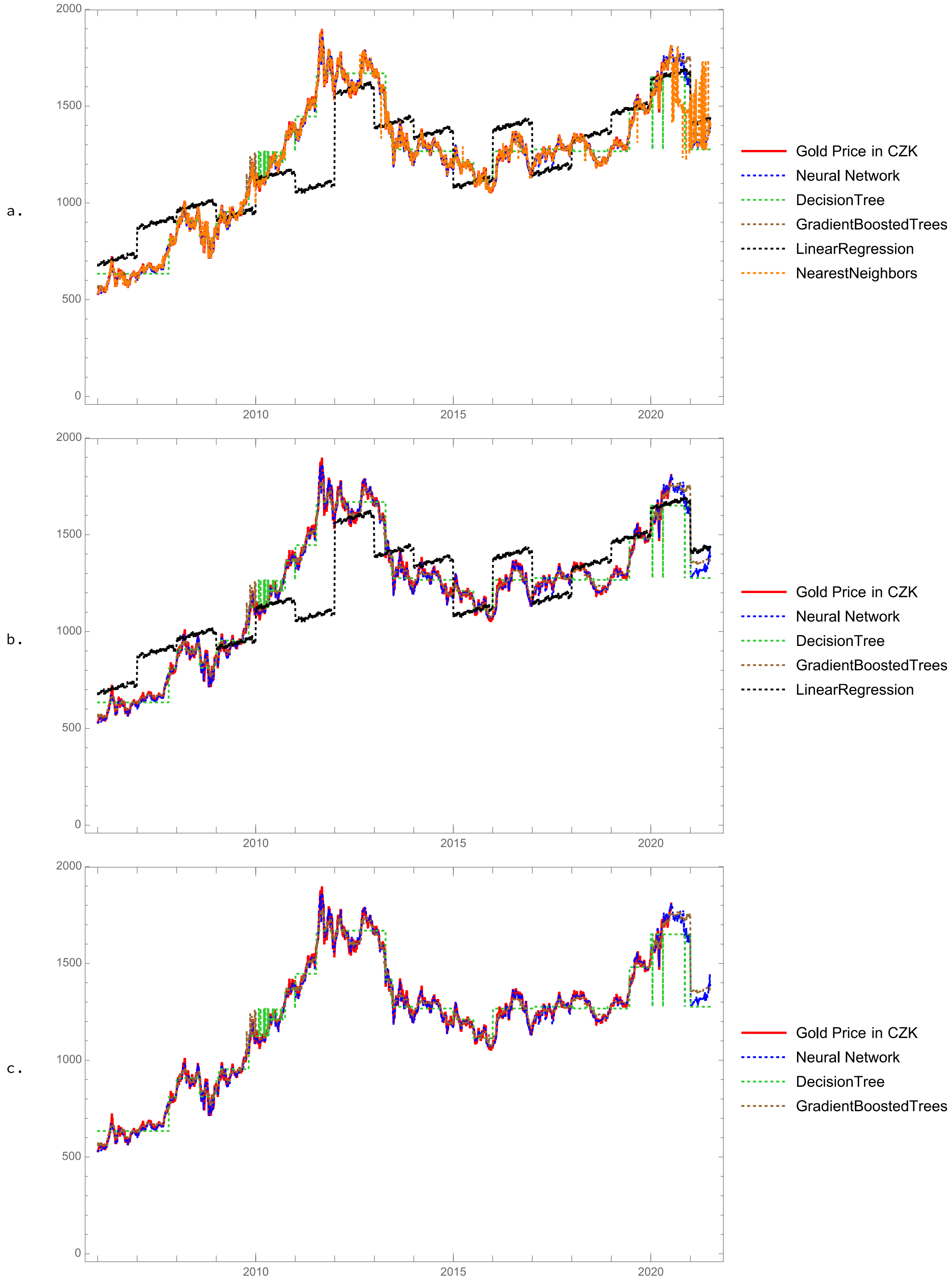

Fig. 2. The gold price given in CZK and the balanced time series
Source: Authors.

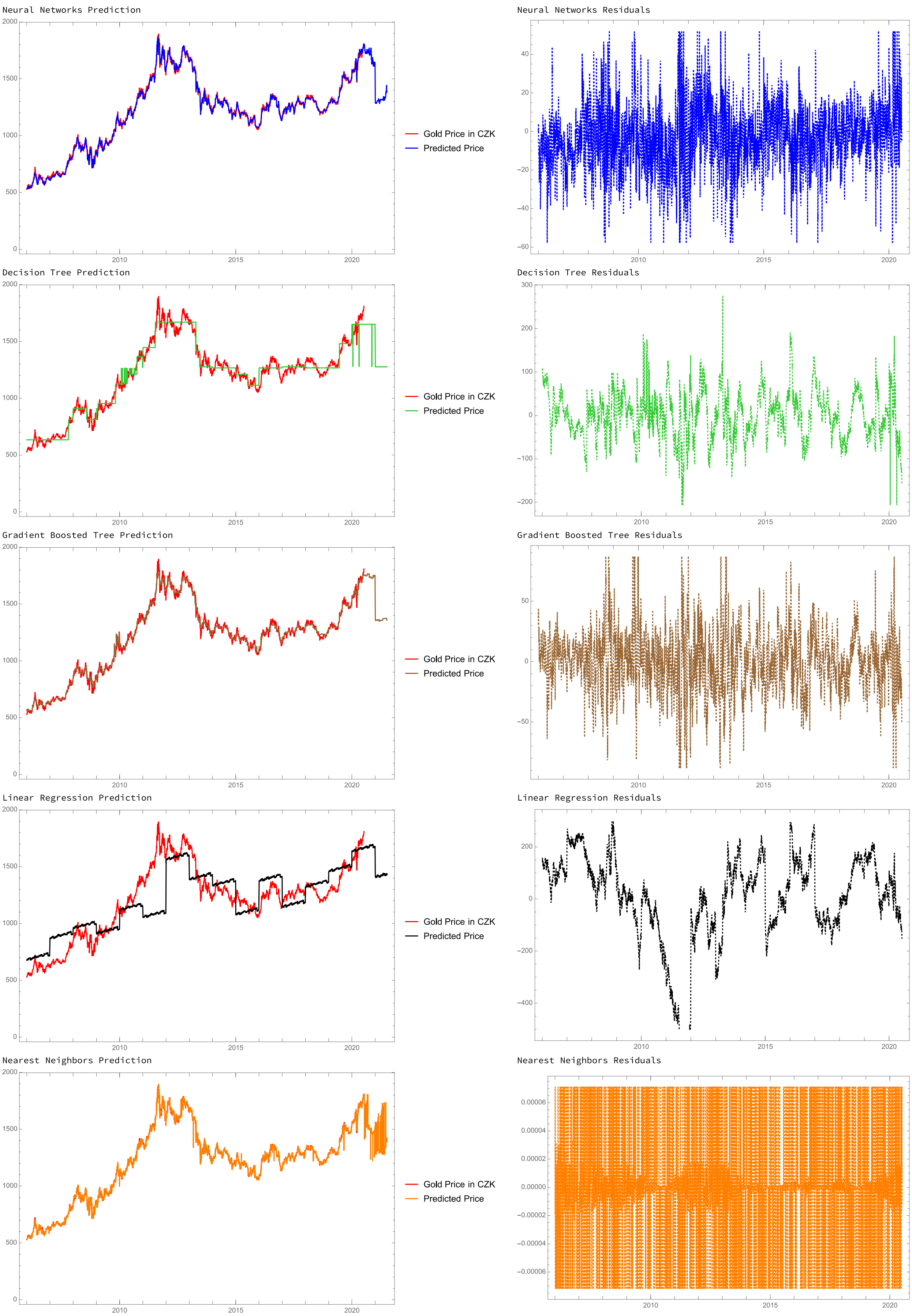

Fig. 3. Comparison of balanced time series with the gold price development, residues
Source: Authors.

The illustration shows that three methods are suitable for the analysis: Neural Network, Gradient Boosted Trees, and Nearest Neighbours. Although we will focus primarily on these three methods with more promising results, other methods will not be left out either. Taking into account the graphs in the right part of the illustration, a conclusion can be drawn that the method that was able to provide the best balance of the time series was the Nearest Neighbours method. Residues of this time series oscillate in the interval from -0.00006 to +0.00006 CZK for ounce. Residues of the Neural Network method range in the interval from -60 to +40 CZK for ounce. Residues of the Gradient Boosted Trees fluctuate even in the interval from -100 to +100 CZK for ounce. To identify the most accurate method, we use the Probability Density Histogram, a histogram of residues of the training data set, and the graph of testing data set residues (Figure 4).

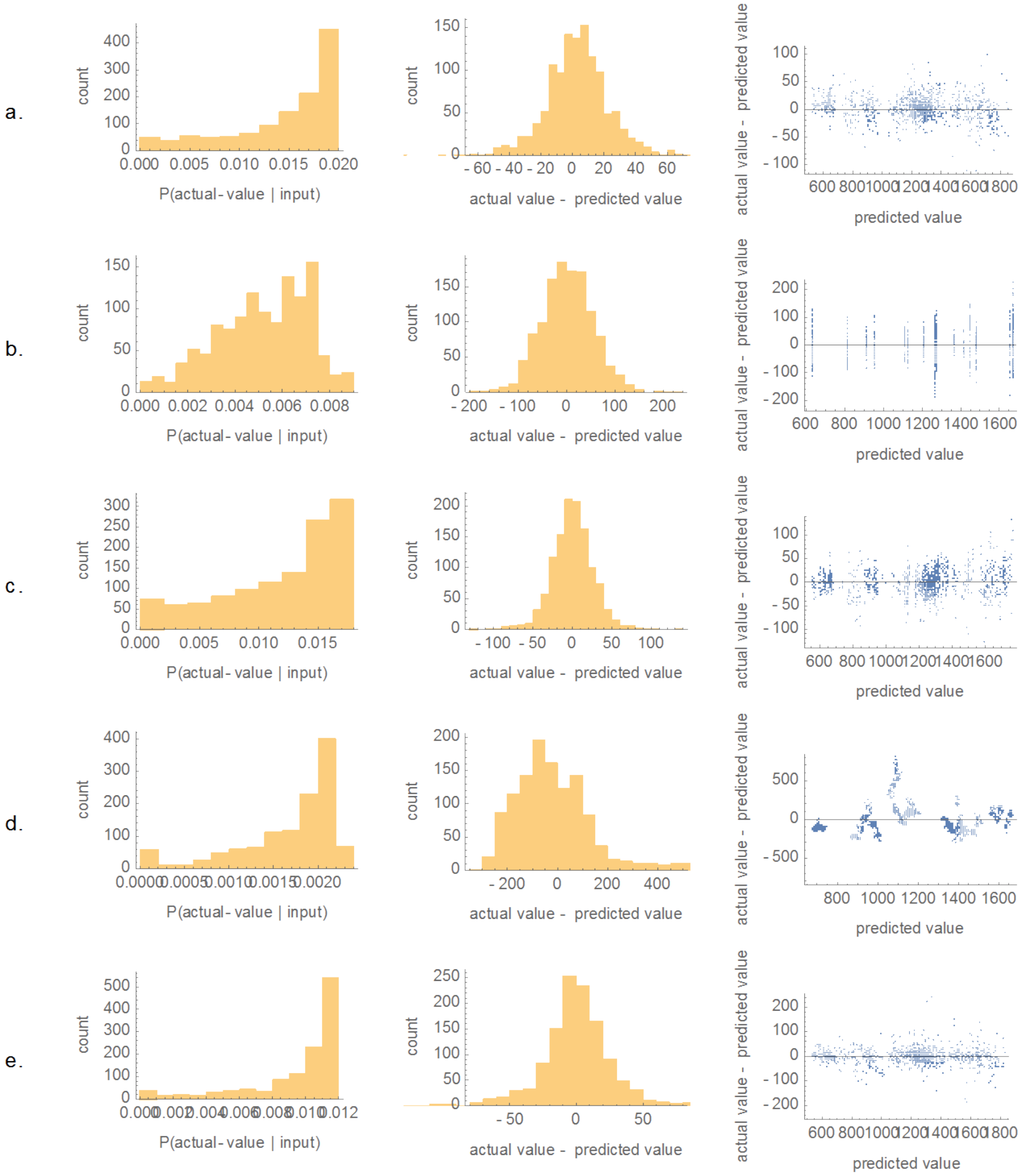

Fig. 4. Probability Density Histogram, a histogram of residues of the training data set and the graph of testing data set residues
Note: a. = Neural Network, b. = Decision Tree, c. = Gradient Boosted Trees, d. = Linear Regression, e. = Nearest Neighbours.
Source: Authors.

The Probability Density Histogram defines the way of the probability density distribution in the set intervals. From the outputs of the Probability Density Histogram, it is evident that the most successful method is Nearest Neighbours, followed by Neural Network and Gradient Boosted Trees. The middle illustration in each line shows the training data set residue histogram. It is ideal when the histogram takes on the form of the Gaussian curve. This goal is reached in all cases apart from Linear Regression. So far, however, all models were assessed only based on the characteristics of the training data set, i.e., on the data set serving for the creation of the models. However, the actual state is presented by the graph of testing data set residues. It provides the space for validation of the results of the models. The best results were reached by the Neural Network residues. These range approximately in the interval [-100, 100]. On the imaginary second rank, there is the model created using the Gradient Boosted Trees. The values of the testing data residues oscillate in the interval [-150, 150]. Even slightly worse results were reached by the residues of the Nearest Neighbours residues. The basic statistics of the balanced time series and the predictions for individual models are stated in Table 2.

Tab. 2. Basic statistics of the balanced time series and the predictions according to individual models

Method	Minimum	Maximum	Mean	Standard Deviation	Variance
Neural Network	528.762	1,863.17	1,222.25	318.805	101,637
Decision Tree	634.318	1,669.27	1,221.46	307.28	94,421
Gradient Boosted Tree	558.587	1,776.47	1,227.42	313.74	98,432.5
Linear Regression	673.503	1,698.86	1,228.72	262.965	69,150.8
Nearest Neighbours	529.5	1,895	1,221.17	311.539	97,056.6

Source: Authors.

Therefore, the best method must be chosen by an expert assessment of the prediction of the future gold price development. The final predictions of the gold price for the following 12 months are shown in Figure 5.

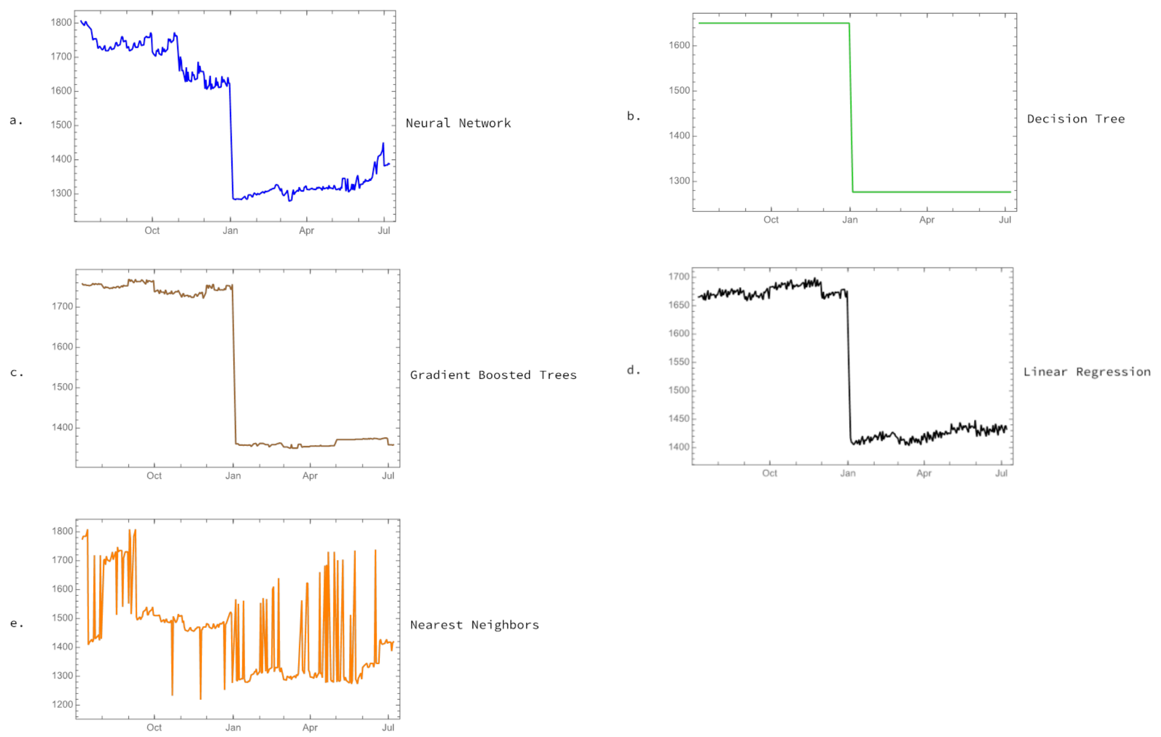

Fig. 5. Prediction of the gold price to 7th July 2021, given in CZK
Source: Authors.

The model created using the method Nearest Neighbours seemed to be the most promising one. However, its values are strongly fluctuating, and the differences between individual business days reach even more than 400 CZK for ounce. In the case of other models, such a fluctuation can be observed as well. There is, however, only one predicted fall at the beginning of the year 2021. For the rest of the time period, rather regular development is predicted. Considering the input values of the prediction (i.e., the last known values of the gold price), the volatility of the time series, and characteristics of the balanced time series, Neural Network seems to prove itself the best method for the gold price prediction in CZK.

Discussion

For the purpose of the analysis, two research questions were determined. The first task was to determine whether the gold price grew even in times of economic recession or crisis. Generally, gold is understood as a preserver of value and a tool of treasuring. Both of these characteristics stem from its physical and chemical qualities and are determined by the preciousness of this metal on Earth (Gutiérrez, Franco and Campuzano, 2013). Therefore, it is logical that economic theories are based on the premise that the demand for gold and, consequently, its price grows at times of economic crises when the value of national currencies decreases (Cohen and Qadan, 2010). Paramita, Vivekananda and Debasmita (2017) state that it is also worth mentioning that, in the past, money existed in many forms. It was present in the form of cattle, specific products (for example, linen scarfs in the 10th century at the Czech territory), later as silver or gold (or coins made of these metals). Given the fact that these metals occur very rarely, they were very valuable (Ismail, Yahya and Shabri, 2009). According to Tully and Lucey (2007), with the world economic boom, however, humankind encountered a lack of money. Therefore, economists looked for new means of payment. Consequently, treasury notes and later banknotes were issued. They were, at first, covered by gold, precious metals, and other possessions. Such coverage came to its final end in the case of American Dollar in the 1960s when the USA withdrew from the so-called Gold standard (E, Ye and Jin, 2019). Nowadays, money is covered mainly by the trust of market participants – state, companies, and households. Moreover, it is exactly this trust or mistrust in the national currency that, in specific cycles of the national economy, increases or decreases the demand for gold that is compact, keeps its value, and makes it possible even to cumulate this value. At the times of an economic crisis, it occasionally happened that states covered their economy's deficits by issuing new banknotes. Given the fact that the economic performance did not increase (rather the other way around), the real value of money decreased. The ones who wanted to save their property and its value had to exchange it from money to a different property. If the investor tries to profit at times of an economic crisis, they buy securities, most preferably stocks. During the crisis, the stock price decreases (Stefko, Jencova and Vasanicova, 2020). In the conditions of the market economy, all business entities, which can be viewed as socio-economic systems, must be competitive (Ginevicius, 2019). The investor can, therefore, buy a relatively large amount of property for a low price. However, there has to be an assumption that the crisis passes in a short period of time, and the stock price increases. However, if the investor cares about preserving the value, they consider rather a purchase of precious metals, mainly gold and gemstones (Mahato and Attar, 2014). Contrary to gemstones, gold preserves its value in its pure form. In the case of gemstones, their value is influenced by their purity or cutting. Gold has, therefore, an exceptional status. Nevertheless, the essential axiom of the economic theory is the rational behavior of the market participants. In practice, however, a number of market participants behave in a different way. The reason is the prevailing uncertainty, lack of information, or different than rational reasons for making a decision (Balagopal and Sanket, 2018).

In the observed time period, we can identify the so-called Great Recession dating back to 2007-2015. It was caused by the financial crisis of the mortgage market in the USA. It hit its full force on a global scale, mainly in 2008-2010 (Fragkogianni, 2016). In 2008, the gold price grew significantly, specifically from 650 CZK to more than 1,000 CZK for ounce. Subsequently, the gold price remained stable on a relatively high level for about a year and then dropped to 700 CZK. In 2009-2012, the gold price increased up to almost 1900 CZK for ounce. Then, it decreased gradually. Its lowest point, approx. 1,000 CZK, was reached in 2016. In 2019 and 2020, the time series grows again. The answer to the research question can, therefore, be summarized in the following way: When the market participants identify the upcoming market crisis, they have the tendency to buy gold. This reflects itself in its growing price. After a relatively short period of time, however, they sell the gold again, and the price stabilizes or even decreases. Such behavior can be caused by two causes:

1. Market participants buy gold at the moment when they have available financial means that can be invested this way. As soon as they realize that the negative expectations predicted in connection with the economic crisis did not come true, they sell the investment gold in order for their investment not to lose its value. In a short period of time of the investment, the market participants can profit from the transaction. Therefore, some subjects might invest in gold at the time of the beginning economic crisis for speculative reasons. Their goal does not necessarily have to be the preservation of the value but its increase.
2. Market participants buy gold even when they do not have enough available financial means for their activities because they fear to lose the value of the national currency. However, due to the fact that they did not have enough financial means at the beginning, they are forced to sell after a relatively short period of time.

The second question draws attention to the future development of the gold price. The prediction of gold price future development is represented in Figure 6.

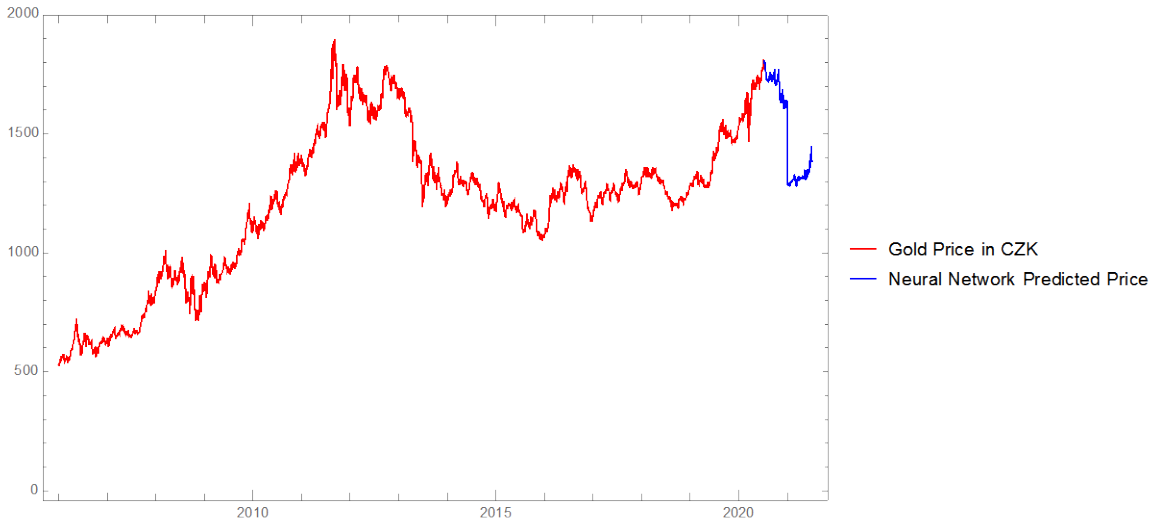

Fig. 6. Future development of the gold price in CZK and prediction of the future development to 7th July 2021
Source: Gold – the current price of gold, investment gold (2020), authors.

The red part of the curve illustrates the past development of the London Fix up to 8th July 2020; the blue part represents the observed variable's prediction to 7th July 2021. The graph shows that the gold price reached its maximum exactly in the observed period. Subsequently, it should decrease progressively to the end of 2020. At the beginning of 2021, the gold price should fall dramatically in order to grow gradually again in the next six months. Is such development probable? The current situation is caused mainly by COVID-19 precautions and introduced sanctions in the sector of international trade. A number of countries adopted measures against the COVID-19 pandemics. These cost an enormous amount of financial means as they did not include only epidemiological precautions. The governments tried to prevent economic bankrupts and slump in the standard of living. Market participants were heavily subsidized by the state, although they did not produce any value. This caused the deficit of the national economy to grow. In the future, countries like the Czech Republic will suffer under the consequences as they have not created financial reserves for such situations. Therefore, it can be expected that the return to some sort of a standard working economy will be gradual. The country will run short of financial means for supporting businesses and inhabitants. An economic recession is, therefore, to be expected. Although the governments do not admit it, the first signs confirming the probability of such a scenario start to emerge (Sukharev, 2020). Market participants now look for the most suitable investment opportunities with the goal of keeping their property on its current value. That is the reason for the increase in the gold price with the introduction of international sanctions. However, according to Corbet, Larkin and Lucey (2020), there are some indications that companies start running out of cash. The gold price will, therefore, rather stagnate first before falling significantly as such a situation is not sustainable in the long run. Companies, trying to secure their operation, will sell gold.

Conclusions

The aim of the paper was to estimate the future development of the gold price. Two research questions were set at the beginning.

Dates in the time period from 3rd January 2006 to 8th July 2020, i.e., 3,663 entries about the gold price, were examined. To elaborate this paper, the software Mathematica from the company Wolfram in its version 13 was employed. Specifically, five methods for balancing the time series and, therefore, obtaining the development model of the observed time series were used – Neural Networks, Decision Tree, Gradient Boosted Tree, Linear Regression, and Nearest Neighbours. Considering the input values of the prediction (i.e., the last known values of the gold price), the volatility of the time series, and characteristics of the balanced time series, Neural Network seems to prove itself the best method for the gold price prediction in CZK. The gold price should decrease progressively to the end of 2020. At the beginning of 2021, the gold price should fall dramatically in order to grow gradually again in the next six months.

It can be concluded that market participants buy gold in the first moments of the economic recession in order to keep the value of their property. Subsequently, however, they lack cash and are forced to sell the gold again. A similar development can be expected now too. Experts expect a global economic recession. For this reason, companies and households purchased gold. Its price increased. Now, however, they encounter problems connected with their liquidity and do not dispose of cash. This state is sustainable to the end of the year. This will put the debtors under pressure, and they will be forced to get rid of their investments. This will cause a dramatic fall in the gold price. In a couple of the following months, the gold price will increase only minimally.

The aim of the paper was fulfilled.

The next development of the gold price is based on the presupposition of a coming economic recession. An interesting topic for further research would be the examination in the field of substitute goods, i.e., investments serving for preserving the value of the property or alternatively of an investment portfolio (in this case, the portfolio does not have to serve only for preserving the value but also for its potential growth).

The limitation of the contribution may be the expression of the gold price in CZK. However, it is the currency of a small economy that has experienced the monetary intervention of the central bank. It would be appropriate to repeat the research also with input data in USD units. Further research should aim at comparing actual and predicted gold price development. This will determine the real success of the methods and predictions.

References

Arouri, M. E. H., Hammoudeh, S., Lahiani, A. and Nguyen, D. K. (2012). Long memory and structural breaks in modeling the return and volatility dynamics of precious metals. *The Quarterly Review of Economics and Finance*, 52(2), 207-218.

Balagopal, G. and Sanket, M. (2018). Global risk and demand for gold by central banks. *Applied Economics Letters*, 25(12), 835-839.

Baur D. G. and Lucey, B. M. (2010). Is gold a hedge or a safe haven? An analysis of stocks, bonds and gold. *Financial Review,* 45, 217-229.

Baur, D. G. and McDermott, T. K. (2010). Is gold a safe haven? International evidence. *Journal of Banking of Finance,* 34, 1886-1889.

Beckmann, J., Berger, T. and Czudaj, R. (2015). Does gold act as a hedge or a safe haven for stocks? A smooth transition approach. *Economic Modelling*, 48, 16-24.

Canda, L., Heput, T. and Ardelean, E. (2016). Methods for recovering precious metals from industrial waste. *International conference on Applied Sciences 2015 (ICAS2015)*, 106. IOP Publishing.

Cohen, G. and Qadan, M. (2010). Is gold still a shelter to fear? *American Journal of Social Management Sciences*, 1(1), 39-43.

Corbet, S., Larkin, C. and Lucey, B. (2020). The contagion effects of the COVID-19 pandemic: Evidence from gold and cryptocurrencies. *Finance Research Letters,* 35.

Dutta, A. (2018). Impacts of oil volatility shocks on metal markets: a research note. *Resources Policy*, 55, 9-19.

E, J. W., Ye, J. M. and Jin, H. H. (2019). A novel hybrid model on the prediction of time series and its application for the gold price analysis and forecasting. *Physica A-Statistical Mechanics and its Applications,* 527.

Endou, A., Ohashi, N., Takami, S., Kubo, M., Miyamoto, A. and Broclawik, E. (2000). The adsorption and activation properties of precious metal clusters toward NO: a density functional study. *Topics in Catalysis*, 11(1-4), 271-278.

Fragkogianni, M. (2016). Island destination marketing in an era of recession. *Journal of Tourism and Services*, 7(13), 8-34.

Ginevicius, R. (2019). Quantitative assessment of the compatibility of the development of socioeconomic systems. *Journal of Competitiveness*, 11(2), 36-50.

Gold – current price of gold, investment gold (2020). *Kurzy.cz* [online]. Available from: https://zlato.kurzy.cz/

Gutiérrez, M., Franco, G. and Campuzano, C. (2013). Gold prices: Analyzing its cyclical behavior. *Lecturas de Economía*, 79(79), 113-142.

Hammoudeh, S. and Yuan, Y. (2008). Metal volatility in presence of oil and interest rate shocks. *Energy Economics*, 30(2), 606-620.

Ismail, Z., Yahya, A. and Shabri, A. (2009). Forecasting gold prices using multiple linear regression method. *American Journal of Applied Sciences*, 6(8), 1509-1514.

Karunagaran, A. (2013). Global crisis and the demand for gold by central banks: a review essay with reference to India. *Journal of International Commerce Economics and Policy*, 4(1).

Machova, V., Krulicky, T. and Horak, J., 2020. Comparison of neural networks and regression time series in estimating the development of the afternoon price of gold on the New York stock Exchange. *Social and Economic Revue*, 2020(1), 61-72.

Mahato, P. K. and Attar, V. (2014). Prediction of Gold and Silver Stock Price using Ensemble Models. *Proceedings Paper International Conference on Advances in Engineering and Technology Research (ICAETR).* IEEE New York.

Marecek, J. and Machova, V. (2017). The influence of public debt on the performance of the economy. *Innovative Economic Symposium 2017: Strategic Partnership in International Trade*. SHS Web of Conferences.

Mirmirani, S. and Li, H. C. (2004). Gold price, neural networks and genetic algorithm. *Computational Economics*, 23(2), 193-200.

Mukherjee, P., Mukherjee, V. and Das, D. (2017). Estimating elasticity of import demand for gold in India. *Resources policy,* 51, 183-193.

O'Connor, F. A., Lucey, B. M., Batten, J. A. and Baur, D. G. (2015). The financial economics of gold a survey. *International Review of Financial Analysis,* 41, 186-205.

Paramita, M., Vivekananda, M. and Debasmita, D. (2017). Estimating elasticity of import demand for gold in India. *Resources Policy,* 51, 183-193.

Reboredo, J. C. (2013a). Is gold a hedge or safe haven against oil price movements? *Resources Policy,* 38(2), 130-137.

Reboredo, J. C. (2013b). Is gold a safe haven or a hedge for the US dollar? Implications for risk management. *Journal of Banking and Finance* 37, 2665-2676.

Rehman, U. M., Shahzad, S. J. H., Uddin, G. S. and Hadström, A. (2018). Precious metal returns and oil shocks: A time varying connectedness approach. *Resources Policy*, 58(SI), 77-89.

Starr, M. and Tran, K. (2008). Determinants of the physical demand for gold: evidence from panel data. *World Economy,* 31, 416-436.

Sinicakova, M., Sulikova, V. and Gavurova, B. (2017). Twin Deficits Threat in the European Union. E&S *Ekonomie a Management*, 20(1), 144-156.

Sinicakova, M. and Gavurova, B. (2017). Single Monetary Policy versus Macroeconomic Fundamentals in Slovakia. *Ekonomicky casopis*, 65(2), 158-172.

Stefko, R., Jencova, S. and Vasanicova, P. (2020). The Slovak spa industry and spa companies: Financial and economic situation. *Journal of Tourism and Services*, 11(20), 28-43.

Sukharev, O. S. (2020). Economic crisis as a consequence COVID-19 virus attack: risk and damage assessment. *Quantitative Finance and Economics,* 4(2), 274-293.

Tran, K. and Starr, M. (2007). *Monetary Policy in Vietnam: An SVAR Analysis of the Role of Gold*. Working Paper (American University).

Tri, H. T. and Nga, V. T. (2019). Factors affecting the disparity of Vietnamese gold prices and worldwide gold prices. *Journal of Competitiveness*, 11(3), 160-172.

Tully, E. and Lucey, B. M. (2007). A power GARCH examination of the gold market. *Research in International Business and Finance*, 21(2), 316-325.

Vigne, S. A., Lucey, B. M., O'Connor, F. A. and Yarovaya, L. (2017). The financial economics of white precious metals: a survey. *International Review of Financial Analysis,* 52, 292-308.

Vravec, J. (2012). Fundamental analysis – gold investment versus silver investment. *Conference on Management 2012 – Research in Management and Business in the Light of Practical* (pp. 75-79). Bookman.

Vrbka, J. and Rowland, Z. (2017). Stock price development forecasting using neural networks. *Innovative Economic Symposium 2017: Strategic Partnership in International Trade*. SHS Web of Conferences.