Monitoring Open Pit Mining in TE-KO Kostolac Issues and Challenges

Nikola Zogović*, Snežana Pantelić*, Dragan Stošić*
* University of Belgrade/Institute Mihajlo Pupin, Belgrade, Serbia
{nikola.zogovic, snezana.pantelic, dragan.stosic}@pupin.rs

***Abstract*—Supporting mining processes by modern information and communications technologies is emerging area. We have previously enabled monitoring of some important parameters in open pit mining and set an integral framework for sustainable mining. In this paper, we extend our activities in monitoring phase according to the proposed framework and analyze various ways of data collecting. We show that combining data from proprietary, open data and public sources, sufficient set of data for sustainable control of open pit mining process can be established.**

I. Introduction

Sustainability and sustainable development recognized as a promising approach for humans to continue living on the Earth [1] is defined from global to local level by United Nations [2]. Moreover, the most important players in transformation process towards sustainability are industries and companies. Mining as the primary economic sector activity is also the subject of the transformation [3, 4].

Since application of modern information and communications technologies (ICT) in open pit mining constantly increases [5-7] a number of frameworks were proposed focusing on assessment of mining sustainability. We proposed the framework [8] for assessment and dynamic control of mining. The framework is supported by modern ICT and it should keep controlled system within sustainability constraints. The framework defines objectives for five sustainability pillars/cornerstones – economy (EC), production efficiency (PE), safety (SAF), environment (ENV) and community (COM). It also considers design space divided into five phases of a mine lifecycle, and four phases of control cycle for the system.

Current mining companies usually rely on the single objective, e.g. fulfilment of annual economic plan that is given by mass of excavated ore, while sustainability and sustainable development parameters report under the force of law or in the sense of compliance with environment protection recommendations. On the other hand, control process in sustainable mining encompasses a number of objectives and consequently, the number of monitored parameters is much larger compared to the control in the single objective mining.

Dealing with the transformation in mining we focus on monitoring phase of the control cycle and the problem of procurement of the sufficient set of data for tracking all the objectives. For the purpose of the problem analysis we set the hypothesis H - modern ICT can enable the collection of data set, sufficient to support the control of sustainable mining process. To test H we build testing system in the use case of open pit coal mine TE-KO Kostolac[1], a subsidiary of Electric Power Industry of Serbia. We also try to detect issues and challenges in the transformation of monitoring phase of the control process, from current mining practice to sustainable mining.

II. Related work

A number of ICT applications regarding monitoring in mining focusing on particular aspects of mining control or local loops, have already been proposed. We list here some of the applications and systemize them according to the target aspects.

Monitoring tools used in mining such as machinery, trucks, shovels, etc. targeting localization service and efficiency is proposed in [9-11].

Rapid increase in monitoring of mining activities impact on environment is evident [12-19]. Since the increase is related with growth of ecological conscience, wider monitoring with a number of ecological parameters including both abiotic and biotic parameters is still missing. Air pollution seems to attract the most monitoring efforts, with pollution characterization in [13, 14, 16], monitoring systems based on satellite imaging [12, 17], monitoring system based on airborne imaging [15], etc. Water monitoring is discussed in [18, 19] while ground monitoring is discussed in [14].

Various open pit mine monitoring systems with the aim of mitigation of risks - dangerous conditions and situations recognition, where alarms or warnings have to be issued, are proposed in [20-25]. Mine slopes stability is monitored in [20-23, 25] while tailings dam stability is monitored in [24]. Radar sensor is used in [21], data fusion from radar and satellite sensors is presented in [23] while the examples of Wireless Sensor Networks (WSN), Internet of Things (IoT) and Cloud Computing (CC) modern ICT usage for monitoring and data processing are presented in [24, 25].

Monitoring of ground deformation, movement and 3D ground mapping for exploitation purposes are given in [26-30]. Various monitoring techniques were used, such as: GPS/Pseudolites technology in [26] for high precision slope deformation, differential SAR interferometry for ground movement in [27], unmanned aerial vehicle based photogrammetry and terrestrial laser scanning fusion for 3D ground mapping in [28], or WSN based on ultra-wide band sensors for ground monitoring in [29].

Long term monitoring of mining activities influence on human health is presented in [31, 32]. It is indicated that depending on ore type various diseases are present more in mine surrounding than usual, while PM10 and PM2.5

[1] see http://www.te-ko.rs (in Serbian)

seriously affects lung and cancer diseases in mine surrounding. How wearables can contribute to health monitoring improvement for employees in mining companies is presented in [33].

Some examples of monitoring mining energy and production efficiency are presented in [34-36]. Monitoring of environment rehabilitation process efficiency after mine exploitation is presented in [37].

III. System Description and Problem Formulation

TE-KO Kostolac is lignite open-pit mine in Kostolac, Serbia, on the right bank of the river Danube, with origins dating from 1870, Fig. 1. The company is equipped with old machinery/tools, which should be modernized, as well as, modern equipment ready for integration, according to the framework [8]. Illustrative figure of the mine is given in Fig. 2.[2]

Figure 1. TE-KO Kostolac place

Main facts regarding the company profile are given in Table 1. It is large size public company operating in the primary economic sector within bigger company Electric Power Industry of Serbia. It is profit oriented with the middle and the first level of management. It is split-up into several places with most of continual excavation activities in Drmno and Cirkovac.

Figure 2. TE-KO Kostoalc open-pit mine

Current control is single objective oriented, where the objective is given by the average excavation speed, mass of excavated ore per year/month/day in annual/monthly/daily company plans. Certainly, the other processes, important for company functioning also exist and they are subject to side objectives, e.g. equipment maintenance, which is the subject of efficiency objective, or heath care and protection of employees, which is the subject of safety objective. Company is obligated by the Law to issue financial, environmental, etc. reports toward governmental bodies. However, limits set by the Law are

TABLE I. TE-KO Kostolac company profile

size	micro	small	medium-sized	large
ownership	private	public	private-public	
economic sector	primary	secondary	tertiary	quaternary
purpose	non-profit	profit	hybrid	
independence	linked	partner	autonomous	
management level	top	middle	first	
distribution	split-up	non-split-up		
type of production	single-part	batch (line)	continual	

rather treated like recommendations than mandatory in the transition period. In such circumstances company system control loop is sufficiently closed by self-monitoring and community is satisfied by mandatory reports, Fig 3.

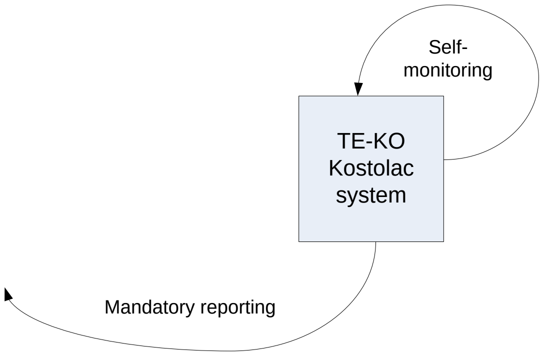

Figure 3. Current TE-KO Kostolac control

To upgrade TE-KO Kostolac system to sustainable operation we use the framework [5] for sustainable mining and five sustainability cornerstones to define high level objectives. Let $\mathbf{x}$ be the vector of TE-KO Kostolac system state, where $\mathbf{x}\epsilon\mathbf{X}$, and $\mathbf{X}$ is the set of all possible states. Let $\mathbf{z}$ be the vector of TE-KO Kostolac system state observables, where $\mathbf{z}\epsilon\mathbf{Z}$, and $\mathbf{Z}$ is the set of all possible observable vector values. Let $\mathbf{o}$ be the vector of TE-KO Kostolac system objectives in context of sustainability mining framework [5], where $\mathbf{o}\epsilon\mathbf{O}'$, and $\mathbf{O}'$ is the set of all possible $\mathbf{o}$ vector values, which satisfy all constraints in the objective space. Let $\mathbf{F}_{\mathbf{O}'\mathbf{X}'}: \mathbf{O}' \to \mathbf{X}'$ be the mapping function form the set of objectives to the set of sustainable TE-KO Kostolac system states $\mathbf{X}'$, where $\mathbf{X}' \subset \mathbf{X}$. Let $\mathbf{F}_{\mathbf{ZX}}: \mathbf{Z} \to \mathbf{X}$ be the mapping function from the set of observables to the set of states and consequently $\mathbf{F}_{\mathbf{ZX}'}: \mathbf{Z} \to \mathbf{X}'$ be the mapping function from the set of observables to the set of sustainable states. We define condition C1 - monitoring subsystem supports the system control in sustainability sense, if it can observe all the elements belonging to the set $\mathbf{X}'$, in other words, if $\mathbf{F}_{\mathbf{ZX}'}$ exist and it is feasible**.** Therefore, to test H we should check if the

[2] Figures 1 and 2 are taken from the mine website

monitoring subsystem enables observation of TE-KO Kostolac's $\mathbf{X}'$ all the elements.

Since TE-KO Kostolac is in the transition towards sustainable operation and $\mathbf{X}$, $\mathbf{Z}$, $\mathbf{O}'$, $\mathbf{X}'$ sets and corresponding mapping functions are not defined, we are not able to test C1. However, we can define high level objective space $\mathbf{O}$, according to the framework [8], where $\mathbf{O}' \subset \mathbf{O}$. We can also define the feasible observables space $\mathbf{Z}'$, where $\mathbf{Z}' \subset \mathbf{Z}$. Now we can relax C1 and define the condition C2 – monitoring subsystem, which collects $\mathbf{z} \epsilon \mathbf{Z}'$, supports the control in sustainability sense, if objectives $\mathbf{o} \epsilon \mathbf{O}$ can be observed. Further, we use C2 to test the hypothesis H.

IV. Analysis

To check whether hypothesis H satisfies relaxed condition C2 we determine high level objective space according to the framework [8] and analyze which observable space is feasible by extending the traditional observable space by means of modern ICT. Than we analyze whether all objectives have corresponding observables.

High level sustainable mining objectives are defined in [8] and we list them in Fig. 15.

To assess observable space of mining in TE-KO Kostolac we consider data availability from proprietary, open data (OD) and public data sources, Fig 4. For available data we focus on average daily values during the year 2015. Three reasons stand behind the decision. First, 3 years period is sufficient for all sources to present data; second, data from the same observing interval are suitable for further processing; and third, one year observing interval seems to be sufficient for many objectives estimation. Generally, we detect five data sources.

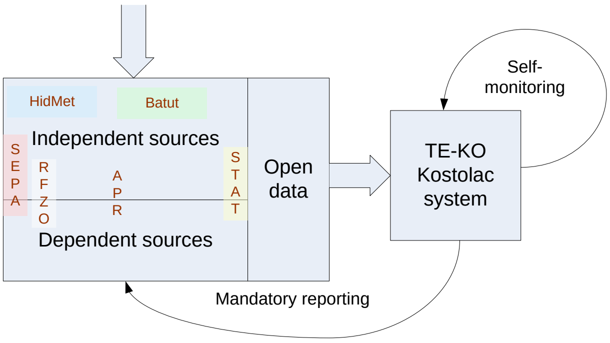

Figure 4. Data sources for monitoring TE-KO Kostolac system

First, we enable existing aged enterprise sources such as old machinery/tools to network with the system through the Internet of Things (IoT) concept. In this manner an IoT device capable to collect machine parameters such as: position (GPS coordinate), ID device, time, working hours, amount of fuel in the tank [38], is developed and 100 machines are monitored for four years. This device collects data relevant for production efficiency objectives. We also have two devices in TE-KO Kostolac testbed for monitoring air pollution parameters such as: CO, NO, CO_2, O_3, NO_2, SO_2 and basic meteorological data - atmospheric pressure, temperature and humidity. Some of the collected observables are shown in Figs. 5-9.

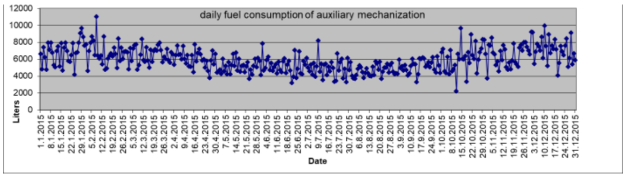

Figure 5. Average daily fuel consumption of auxiliary mechanization

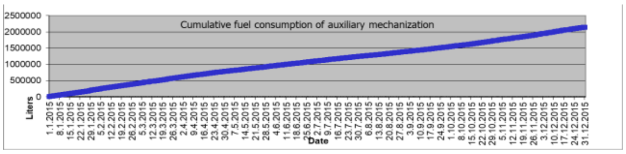

Figure 6. Cumulative fuel consumption of auxiliary mechanization

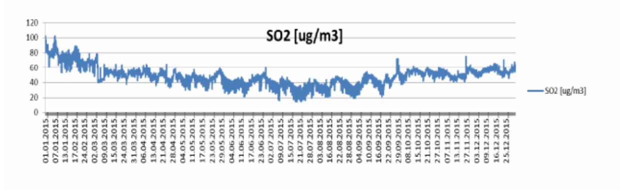

Figure 7. SO2 average daily concentration

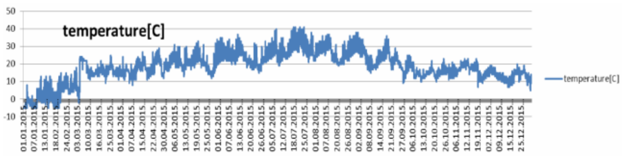

Figure 8. Average daily temperature

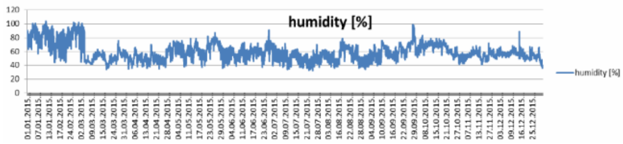

Figure 9. Average daily humidity

Second, we collect open data, which should be provided by Serbian government and public bodies. However, since a number of regulative obstacles are present and OD initiative is still in the beginning phase[3], we succeeded to obtain data from Republic Hydro-meteorological Service of Serbia[4] (HidMet), after payment and we still negotiate how to obtain detailed data from Environmental Protection Agency[5] (SEPA) from appropriate measuring stations. Potentially, relevant data can also be obtained from public bodies such as: Institute of Public Health of Serbia (Batut), National Health Insurance Fund (RFZO), Serbian Business Register Agency (APR), etc. For example, we present in Figs. 10, 11 some of the observables collected from SEPA. Open data can contribute to observation of various sustainability objectives.

[3] https://data.gov.rs/, started in 2017
[4] http://www.hidmet.gov.rs
[5] http://www.sepa.gov.rs/

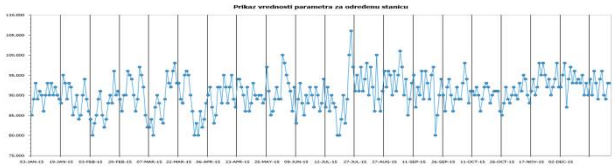

Figure 10. Daily average of underwater relative dissolved oxygen obtained from SEPA, Lubicevski most station

Figure 11. Daily pH average obtained from from SEPA, Lubicevski most station

Third, TE-KO Kostolac in the process of modernization procured modern machines/tools, already designed to interchange data by means of Internet, e.g. machines produced by Hidromek, JCB, Caterpillar, and Merlo companies. Since these machines/tools have Internet access mainly for maintenance purposes, they often lack of protected interfaces problem, where interfaces are even not accessible for customers. However, data provided by the machines/tools are useful for control of production efficiency related objectives.

Fourth, the pool of manually collected and processed data inherited from obsolete process organization is significant for sustainability of open pit mining processes' control. Such the processes TE-KO Kostolac should modernize and upgrade to the acceptable level of automatization. E.g. installing the sensors into the coal digging excavator can provide satisfactory data sets for calculating the daily produced amount of coal. For example, we present in Figs. 12, 13 some parameters obtained from manually generated plans and report [39].

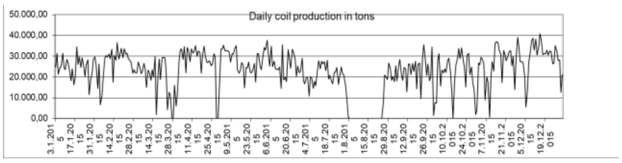

Figure 12. Daily average coil production in tons

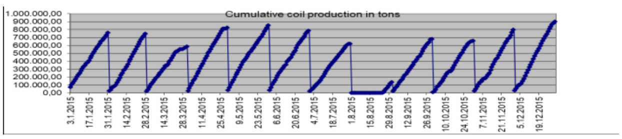

Figure 13. Cumulative coil production in tons

Fifth source of useful data for sustainability of open pit mining processes' control is Statistical Office of the Republic of Serbia[6] (STAT). It differs from the sources in the second group by the willing of the Office to open data but the process of opening is still running. On the other hand, we have great expectation from these sources to provide significant data regarding economy, safety and community related objectives. For example, we present average monthly salaries from local to country level in Fig. 14.

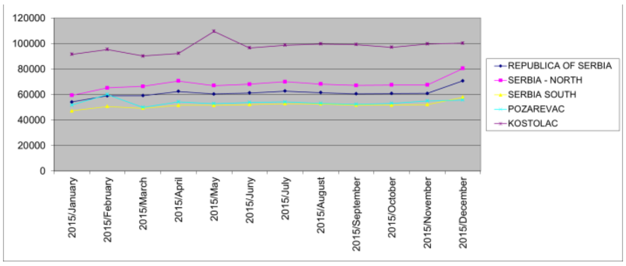

Figure 14. Monthly average salaries from Kostolac municipal to country level in Dinar currency

A. Issues in system observation

Several issues of monitoring subsystem transformation from current to sustainable mining rise. Issues are related to the cost of data sets needed for control process, automatization of data collection, data collection process cost reduction and suppression of conflict of interest in the control loop.

We detect two examples of non-free data. First example concerns data collected by modern machines/tools for which the machine/tool producers require payment. This problem belongs to the set of intentional interoperability problems. Second problem is concerning to legal regulation rules regarding open data, which in some cases allow public bodies to request payment for data that are of public importance.

Various procedures of mining company, especially in data collection and procession, can be automatized by application of modern ICT. However, automatization cost vs. quality of automated processes trade-off should be kept within acceptable constraints.

It can be seen from the diagram given in Fig. 4 that open data generated by dependent data from mandatory reports issued by the subject of sustainable control may lead to conflict of interest. Therefore, monitoring branches in dependent flow should be treated with respect to conflict of interest suppression.

The example of integration of modern machines monitoring systems with maintenance purpose into the sustainable mining monitoring subsystem showed that interoperability issues are significant. Since sustainable mining monitoring subsystem is complex and consists of many various technical parts interoperability certainly is considerable issue [40-42].

B. Challenges in system oservation

Monitoring subsystem is challenged by regulatory and technical challenges on the way from current to sustainable mining.

Although technological progress enables data to be open according to the Open Data Initiative (ODI) [43], national regulation rules do not support the initiative fully, but it is the process in national regulation bodies worldwide. E.g., Law on Free Access to Information from Public Meaning[7] in Republic of Serbia obligates all governmental bodies to provide data on a request in

[6] http://www.stat.gov.rs

[7] Official Gazette of the Republic of Serbia, No. 120/2004, 54/2007, 104/2009 and 36/2010

required form without specification of a purpose. However, one must know exactly what kind of data exist and to request them. On the other hand, the Law does not prevent governmental bodies to open their data and make them available for everybody. Such the way there exist the web portal[8] for open data where many governmental bodies from local to national level issue the data.

Even data regarding phenomenon relevant for subject system control is open or can be obtained from some proprietary source, they often do not provide sufficient spatial-temporal resolution, e.g., HidMet observes meteorological parameters over 88361 square kilometers of Serbia with 31 meteorological stations. Observing frequency for some parameters is given in Fig. 15.

Another challenge in monitoring relates to collected data credibility and confidence. Credibility concerns procedures, which stand back the monitoring process, and responsibility for quality of collected and reported data. E.g., SEPA and HydMet can provide raw or processed data while they guarantee just for quality just of processed data. On the other hand, there is a question of measurement errors introduced by sensors.

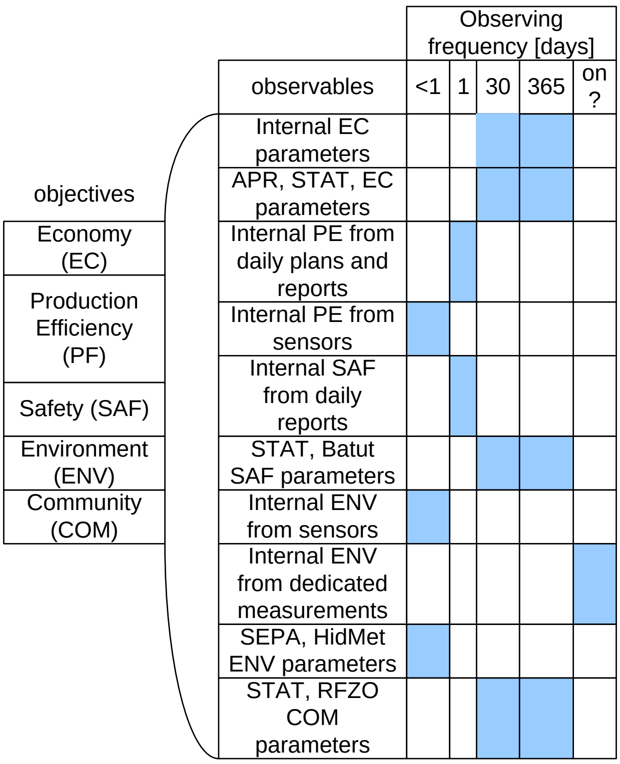

Figure 15. Objectives observing

Although there are a number of issues and challenges that monitoring subsystem confronts in the transformation from the current to the state of sustainability, we show that modern ICT has potential to enable building appropriate monitoring subsystem for sustainable mining according to sustainability framework [8]. Actually, we detect proper observables and their source and show that all high level sustainable mining objectives can be observed. Therefore, we can state that hypothesis H holds true.

[8] data.gov.rs

V. CONCLUSION

In this paper, we continue working on the topic of sustainable mining and further analyze the framework set in [8] by focusing on feasibility of monitoring phase of the control loop. We analyze availability of necessary data for observation of high level objectives defined in the framework. Analysis are performed with the goal of testing the hypothesis H, which state that modern ICT can enable the collection of data set, sufficient to support the control of sustainable mining process. The hypothesis is tested by relaxed test, which checks whether high level objectives observation is feasible.

Various open data, proprietary and public data sources are assessed and issues and challenges that monitoring subsystem confronts in the transformation from the current to the state of sustainability are detected. We show that the hypothesis holds true

ACKNOWLEDGMENT

The Ministry of Education, Science and Technological Development of Republic of Serbia supported the work by grants TR-32051 and TR-35030.

REFERENCES

[1] J.D. Sachs, “The age of sustainable development”, Columbia University Press, 2015

[2] "Indicators and a monitoring framework for the sustainable development goals – Launching a data revolution for the SDGs", A report to the SG of the UN by the LC of the SDSN, May 15, 2015

[3] H.S. Dashwood, "Sustainable development and industry self-regulation: developments in the global mining sector", SAGE - Business & Society 53.4 (2014): 551-582

[4] J. Fraser, "Mining companies and communities: Collaborative approaches to reduce social risk and advance sustainable development", Elsevier - Resources Policy (2018), https://doi.org/10.1016/j.resourpol.2018.02.003

[5] R.C. Goodfellow, R. Dimitrakopoulos, "Global optimization of open pit mining complexes with uncertainty", Elsevier - Applied Soft Computing 40 (2016): 292-304

[6] S.Q. Liu, E. Kozan, "New graph-based algorithms to efficiently solve large scale open pit mining optimisation problems", Elsevier - Expert Systems with Applications 43 (2016): 59-65

[7] L.G.U. Garcia, et al. "Mission-critical mobile broadband communications in open-pit mines", IEEE Communications Magazine 54.4 (2016): 62-69

[8] N. Zogović, S. Dimitrijevic, S. Pantelić, D. Stošić, “A Framework for ICT Support to Sustainable Mining - An Integral Approach”, In: Zdravković, M., Trajanović, M., Konjović, Z. (Eds.) ICIST 2015 Proceedings Vol.1, pp.73-78, 2015

[9] Q. Gu, et al. "Monitoring dispatch information system of trucks and shovels in an open pit based on GIS/GPS/GPRS", Journal of China University of Mining and Technology 18.2 (2008): 288-292

[10] J. Baek, et al. "Performance comparison of bluetooth beacon and reverse RFID systems as potential tools for measuring truck travel time in open-pit mines: a simulation experiment", Taylor & Francis - Geosystem Engineering 21.1 (2018): 43-52

[11] C. Rizos, et al. "Open cut mine machinery automation: Going beyond GNSS with Locata", Proc. 2nd Int. Future Mining Conf., Sydney, Australia, 2011

[12] H. Schmidt, C. Glaesser, "Multitemporal analysis of satellite data and their use in the monitoring of the environmental impacts of open cast lignite mining areas in Eastern Germany", Taylor & Francis – Int. Journal of Remote Sensing 19.12 (1998): 2245-2260

[13] J.I. Huertas, M.E. Huertas, D.A. Solís, "Characterization of airborne particles in an open pit mining region", Elsevier - Science of the Total Environment 423 (2012): 39-46

[14] J.I. Huertas, et al. "Air quality impact assessment of multiple open pit coal mines in northern Colombia", Elsevier - Journal of Environmental Management 93.1 (2012): 121-129

[15] M. Alvarado, et al. "Towards the development of a low cost airborne sensing system to monitor dust particles after blasting at open-pit mine sites", MDPI - Sensors 15.8 (2015): 19667-19687

[16] C. Richardson, R. Shannon, I. Agranovski, "Characterisation of particulate emissions from Australian open cut coal mines: towards improved emission estimates", Taylor & Francis - Journal of the Air & Waste Management Association, accepted (2018).

[17] W. Sun, et al. "Monitoring the ecological environment of open-pit coalfields in cold zones of northeast China using landsat time series images of 2000-2015", Tehnicki vjesnik/Technical Gazette 24.1, 2017

[18] K.E. Eang, et al. "Groundwater monitoring of an open-pit limestone quarry: groundwater characteristics, evolution and their connections to rock slopes", Springer - Environmental monitoring and assessment 190.4 (2018): 193.

[19] P.T. Mativenga, A. Marnewick, "Water quality in a mining and water-stressed region", Elsevier - Journal of Cleaner Production 171 (2018): 446-456.

[20] A. Vaziri, L. Moore, H. Ali, "Monitoring systems for warning impending failures in slopes and open pit mines", Springer - Natural hazards 55.2 (2010): 501-512

[21] G.J. Dick, et al. "Development of an early-warning time-of-failure analysis methodology for open-pit mine slopes utilizing ground-based slope stability radar monitoring data", Canadian Geotechnical Journal 52.4 (2014): 515-529

[22] T. Carlà, et al. "On the monitoring and early-warning of brittle slope failures in hard rock masses: Examples from an open-pit mine", Elsevier - Engineering Geology 228 (2017): 71-81

[23] T. Carlà, et al. "Integration of ground-based radar and satellite InSAR data for the analysis of an unexpected slope failure in an open-pit mine", Elsevier - *Engineering Geology* 235 (2018): 39-52

[24] E. Sun, X. Zhang, Z. Li, "The internet of things (IOT) and cloud computing (CC) based tailings dam monitoring and pre-alarm system in mines", Elsevier - Safety science 50.4 (2012): 811-815

[25] S. Bhattacharjee, et al. "Wireless sensor network-based fire detection, alarming, monitoring and prevention system for Bord-and-Pillar coal mines", Elsevier - Journal of Systems and Software 85.3 (2012): 571-581

[26] W. Jianpeng, et al. "High precision slope deformation monitoring model based on the GPS/Pseudolites technology in open-pit mine", Elsevier - Mining Science and Technology (China) 20.1 (2010): 126-132

[27] G. Herrera, et al. "Mapping ground movements in open pit mining areas using differential SAR interferometry", Elsevier - International Journal of Rock Mechanics and Mining Sciences 47.7 (2010): 1114-1125

[28] Tong, Xiaohua, et al. "Integration of UAV-based photogrammetry and terrestrial laser scanning for the three-dimensional mapping and monitoring of open-pit mine areas", MDPI - *Remote Sensing* 7.6 (2015): 6635-6662

[29] E. Intrieri, et al. "Application of an ultra-wide band sensor-free wireless network for ground monitoring", Elsevier - Engineering Geology 238 (2018): 1-14

[30] M. Rezaei, A. Majdi, M. Monjezi. "An intelligent approach to predict unconfined compressive strength of rock surrounding access tunnels in longwall coal mining", Springer - Neural Computing and Applications 24.1 (2014): 233-241

[31] L. Espitia-Pérez, et al. "Cytogenetic instability in populations with residential proximity to open-pit coal mine in Northern Colombia in relation to PM 10 and PM 2.5 levels", Elsevier - Ecotoxicology and environmental safety 148 (2018): 453-466

[32] A.M Knoblauch, et al. "Monitoring of selected health indicators in children living in a copper mine development area in northwestern Zambia", MDPI - International Journal of Environmental Research and Public Health 14.3 (2017): 315

[33] M. Mardonova, Y. Choi, "Review of wearable device technology and its applications to the mining industry." MDPI - Energies 11.3 (2018): 547

[34] N. Wang, et al. "Constructing an energy efficiency benchmarking system for coal production", Elsevier - Applied Energy 169 (2016): 301-30

[35] K. Awuah-Offei, "Energy efficiency in mining: a review with emphasis on the role of operators in loading and hauling operations", Elsevier - Journal of Cleaner Production 117 (2016): 89-97

[36] A. Soofastaei, et al. "A comprehensive investigation of loading variance influence on fuel consumption and gas emissions in mine haulage operation", Elsevier – Int. J. of Mining Science and Technology 26.6 (2016): 995-1001

[37] J. Herrick, G.E. Schuman, A. Rango, "Monitoring ecological processes for restoration projects", Elsevier - Journal for Nature Conservation 14.3-4 (2006): 161-171

[38] S. Pantelić, et al. "Improvement of auxiliary mechanization operations management at an open-pit coal mine based on a process approach with ICT support", Advanced Materials Research, Vol. 633. Trans Tech Publications, 2013

[39] "Report on the environment state in - JP Elektroprivreda Srbije", JP Elektroprivreda Srbije – Environment Protection, Beograd – in 2015, Belgrade, Apr 2016

[40] J. Dahmann, K.J. Baldwin, G. Rebovich, "Systems of systems and net-centric enterprise systems", 7th Annual Conference on Systems Engineering Research. 2009

[41] M. Zdravković, et al. "On the formal definition of the systems' interoperability capability: an anthropomorphic approach", Taylor & Francis - Enterprise Information Systems 11.3 (2017): 389-413

[42] H. Panetto, et al. "New perspectives for the future interoperable enterprise systems", Elsevier - Computers in Industry 79 (2016): 47-63

[43] The Global Open Data Initiative (GODI) Online: http://globalopendatainitiative.org/