IOP Conference Series: Earth and Environmental Science

PAPER • OPEN ACCESS

Grain Size Distribution of Copper Ore as Means for Qualitative Evaluation of Its Lithological Composition

To cite this article: Maksymilian Ozdoba and Robert Krol 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **221** 012100

Grain Size Distribution of Copper Ore as Means for Qualitative Evaluation of Its Lithological Composition

Maksymilian Ozdoba [1], **Robert Krol** [1]

[1] Faculty of Geoengineering, Mining and Geology, Wroclaw University of Science and Technology, Wybrzeze Wyspianskiego 27, 50-370 Wroclaw, Poland

robert.krol@pwr.edu.pl

Abstract: Information about the grain size distribution of a material plays an important role in optimizing production systems in various branches of industry. Analysis of particle size distribution in the run-of-mine material is frequently employed to verify the quality of drilling and blasting operations. Adequate software and improved grain size identification technologies not only help to monitor and evaluate the results of blasting operations, but also inform the selection of blasting methods which best correspond to particular geological and mining conditions both in surface mining and in underground mining. The accuracy of indirect, image-analysis methods used in the identification of grain size distribution motivated some pilot works aimed at using the grain size to evaluate the quality of a lithological complex copper ore deposit. Describing the run-of-mine material fed to the Ore Enrichment Plant (OEP) with the use of its grain size distribution may improve the techniques currently employed to optimize the energy efficiency of ore treatment processes. A model of ore flow in the underground transportation system, developed in the FlexSim environment, as part of the DISIRE research project, may prove a valuable optimization tool. This paper presents the results of preliminary research aimed at verifying whether grain size distribution of the run-of-mine material correlates with its lithological composition. The examinations covered grain size distribution in copper ore transported on belt conveyors in two mines in which the extracted ore has different lithology. The research was performed with the use of photogrammetric techniques and the Split Desktop 4.0 computer application. The advantage of the proposed technique is that it can be used at any location in the mine. The analysis was performed on the photographic material collected in situ at the "Lubin" mine. This material was supplemented with qualitative data stored in the Run-Of-Mine Ore Monitoring system (further: MOPRONA), as defined on the basis of channel samples collected on the day of tests.

1. Introduction

A mining operation and copper production must be profitable. The profitability is influenced by the price of material and the production cost. For this reason, particular attention is paid to researching methods for the optimization of the production line and for lowering the production cost [1]. Research focuses both on new solutions and on improvements to the already existing solutions. For example, the EU-funded DISIRE project is aimed at optimizing ore processing operations by providing in advance qualitative information about the lithology of the ore fed to the enrichment plant [2, 3]. The DISIRE project focuses on the processing operations, as their further optimization may translate into reduced processing cost and increased metal yield in the concentrate [4]. This goal has been pursued by annotating the stream of run-of-mine material with data-carrying sensors. The sensors included information about both the quality and quantity of the mined copper ore. The information from the sensors was subsequently read and processed in order to control ore processing operations. [2, 5, 6]. One of the results produced by this research is a model of ore flow generated in the FlexSim environment. FlexSim reconstructs the transport network in a mine and allows monitoring the flow of ore, which has variable metal grade levels due to three lithology types existing in the mining region operated by KGHM Polska Miedz S.A. (further: KGHM) (Figure 1).

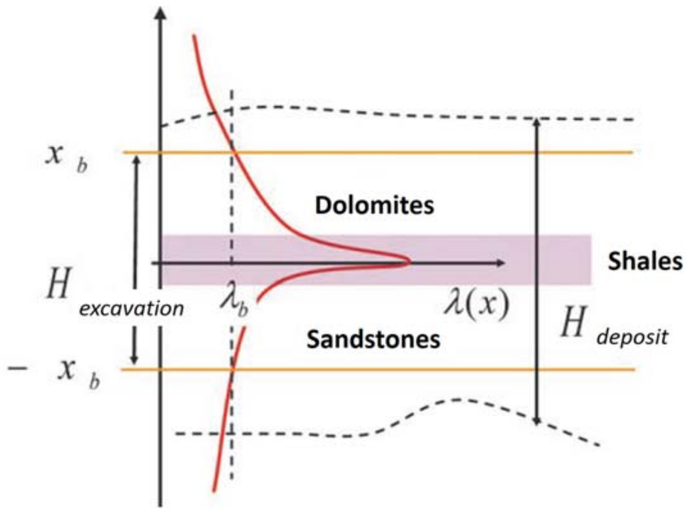

Figure 1. Model of copper ore grade distribution in the deposit profile $H_{excavation}$ – face height, $H_{deposit}$ – deposit thickness, λ_b – cut-off copper grade [7]

In the proposed empirical ore flow model, qualitative information about the deposit is retrieved from the MOPRONA system [8], which contains the results of in-situ measurements and channel samples collected from each of the mines. The authors of the model are aware that it may be viewed as a simplification to assign an ore lithology identified by channel sampling to the part of the ore extracted from the surface adjacent to the channel sample, but no other methods are presently available. Apart from the above fact, the process is time-consuming (it lasts approximately 24 hours) and expensive, as it necessitates qualitative tests performed in a specialist external laboratory equipped with optical microscopes. Therefore, it seems rational to search for new, more automatized methods in which data obtained in-situ will enhance the mobility of ore processing operations by enabling modifications of the processing parameters. Developments in computer technology allow easy and quick implementation of software for grain size identification based on the collected photographic documentation. This fact led to the authors to attempt finding a correlation between grain size distribution of the run-of-mine material and its lithological composition. Photogrammetry techniques have been found useful in evaluating grain size distribution of the run-of-mine material in both surface and underground mining [9, 10]. Literature mentions numerous examples of research into rock size in the run-of-mine material on the blast pile, belt conveyor or in the box of a haul truck [9, 11]. Such research proves useful in the monitoring and evaluation of blasting results and allows the selection of accurate blasting methods which best correspond to particular geological and mining conditions [11-17].

The Highland Valley Copper mine may serve as another example. The on-line grain size distribution monitoring coupled with rock hardness monitoring, which were implemented in the mining operation, increased the efficiency of the autogenous mill by 10% [11]. Based on literature and on the findings reported by researchers from Poland and from abroad, the authors suggest a method of grain size distribution measurement in Polish copper ore mines with the use of the Split Desktop 4.0 software.

2. Test Methodology

Grain size distribution slopes for ore extracted in different mining regions have been generated on the basis of photographs taken over belt conveyors receiving material from the division discharge points. The photographs were taken at even time intervals, during one full shift (4 hours). They were taken as the conveyor belt was moving. The camera was positioned on a stand, in perpendicular to the direction of belt movement, and the shutter was released with a remote control connected to the camera (Figure 2b). Relative width of the belt in the trough was used as a reference to provide an appropriate scale to the photos (Figure 2c). This width was averaged (due to local edge defects) on the basis of three measurements performed on various belt conveyor sections. A proper light source was also provided, which is an important prerequisite in an underground mine and which helped ensure that the photographs had an adequate contrast (Figure 2a).

a) b) c)

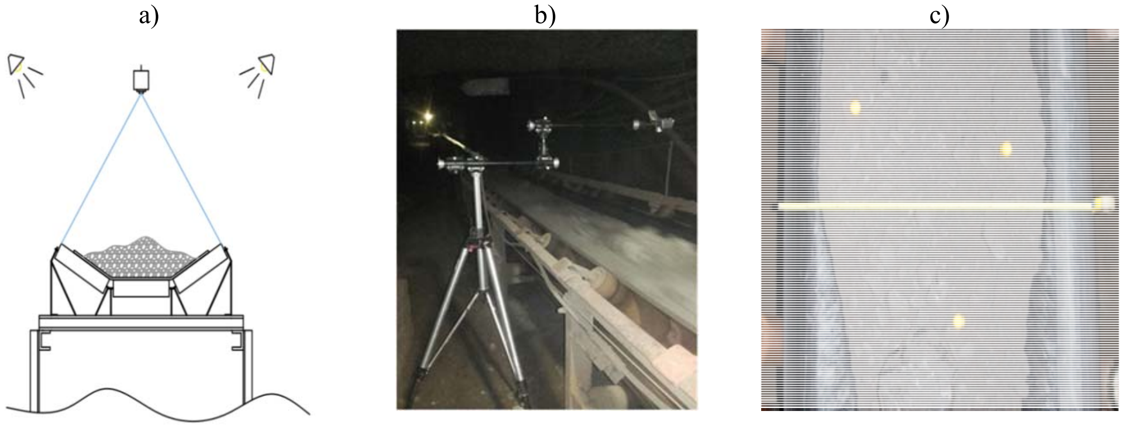

Figure 2. Measurement stand, a) schematic diagram, b) measurement stand in the mine, c) image from the camera positioned over the belt, during belt width measurements required for scaling purposes; (Source: own materials)

Measurement results in the form of grain size distribution curves for the ore transported on belt conveyors T5 (mining division G2) and W522 (division G5) were compared with the information on the quality of the deposit on the day of in-situ measurements, as obtained from the MOPRONA system. Belt conveyors used in the measurements are circled in red on the transportation system scheme of the KGHM mine selected for the tests. (Fig .3). The lithological data obtained from the MOPRONA system included thicknesses of individual layers in the mining face and mean copper grades. After photographs of satisfactory quality had been acquired, they were processed in the Split Desktop 4.0 software. The software uses built-in image thresholding functions to identify contours of rock fragments in the mined material [18]. Two diagonals are marked on the identified contour, which later serve to form a solid body. The solids are dimensioned on the basis of a scale defined with the use of an object of known dimensions. Subsequently, the Gaudin-Schumann distribution or the Rosin Rammler distribution are used to determine the percentage share of fractions whose contours cannot be identified.

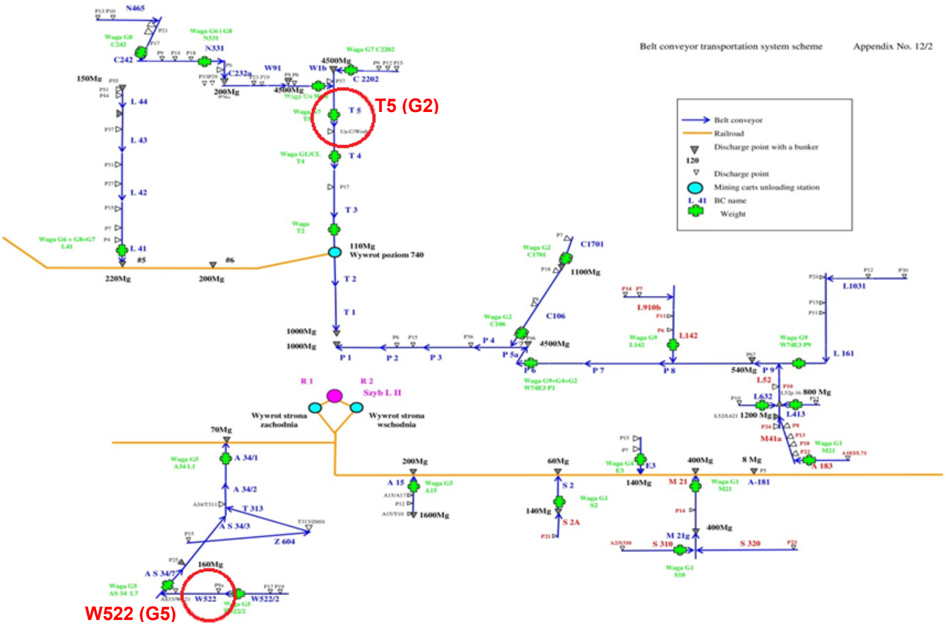

Figure 3. Schematic diagram of the belt conveyor transportation with circled points in which run-of-mine material was measured on the conveyor belt (Source: Lubin Mine)

The determination of the fines cut-off (FCO) level is influenced by the surface area of fine particles and by the dimensions of larger fractions. The procedure can be manually controlled by editing the solids and adjusting the delineation coefficients.

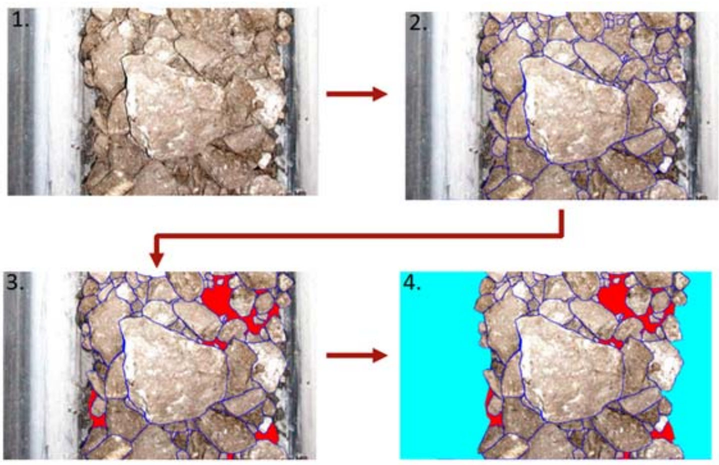

Figure 4. Data processing stages

Figure 4 shows subsequent photograph processing stages. Stage one consists in uploading a photograph to the application, stage two – in delineation, i.e. in identifying rock contours. Stage three consists in marking the locations where rock particles are too fragmented to be identified by the software. In the last, fourth stage, an image is processed by excluding areas in which no solid bodies are found. In this case, it was the area of the conveyor belt. The result is a particle size distribution curve, which describes the percentage shares of of individual fraction sizes. The software enables the user to generate combined curves on the basis of multiple photographs and thus to obtain mean particle size distributions for the analyzed time period.

3. Test results analysis

The quality of the material transported on belt conveyors T5 and W522 was described primarily on the basis of the data on the geological composition and Cu content stored in the MOPRONA system. The data were from channel samples collected at mining faces on the day of the in-situ measurements. The percentage shares of individual lithology types and mean Cu grades are shown in Figure 5.

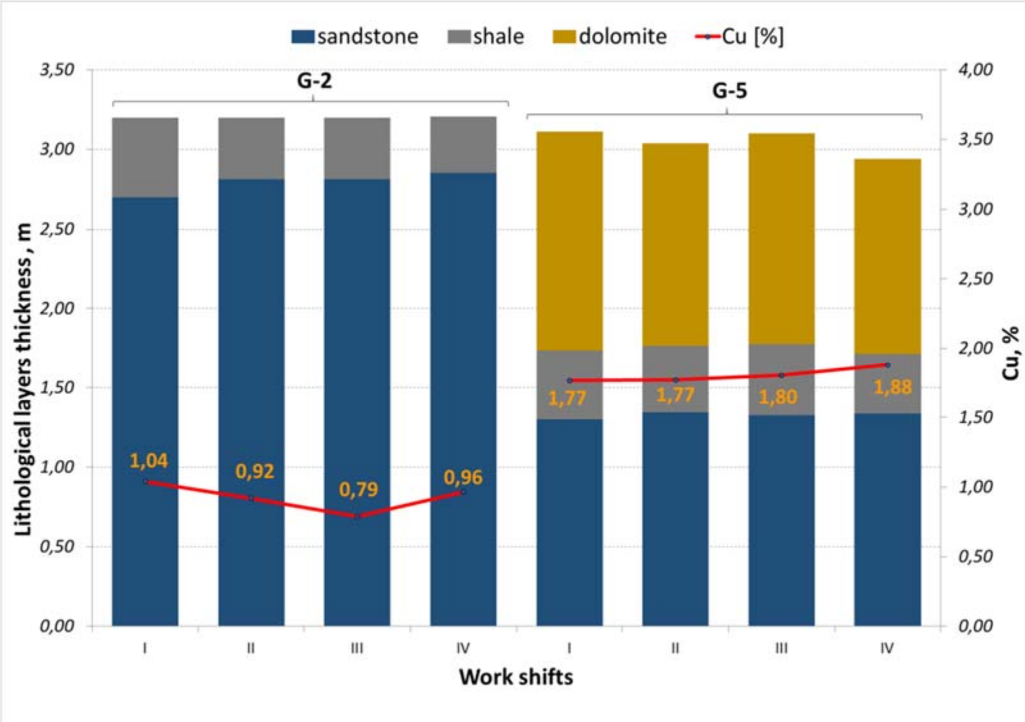

Figure 5. Percentage share of individual lithological layers in the mined height, based on data from the MOPRONA system acquired on the day of the in-situ measurements for the T5 (G2) and the W522 (G5) belt conveyors

The run-of-mine material from the analyzed mining divisions was extracted from faces of similar heights, but has different Cu content. The copper ore from the G2 division consisted of two lithological types (sandstone and shale), while Cu content in the ore from the G5 division is additionally increased owing to the dolomite part. In order to determine whether lithological differences may influence the particle size distribution in the run-of-mine ore, the authors proposed photogrammetry tests with the use of Split Desktop 4.0 software. Individual series of photographs were taken for both cases, and subsequently particle size distribution curves were plotted. Observation under the microscope was already sufficient to notice significant differences in the size and in the colour of rock fragments. Figure 6 shows sample photographs representing various fragmentation levels of the ore transported on both conveyors.

a)
b)

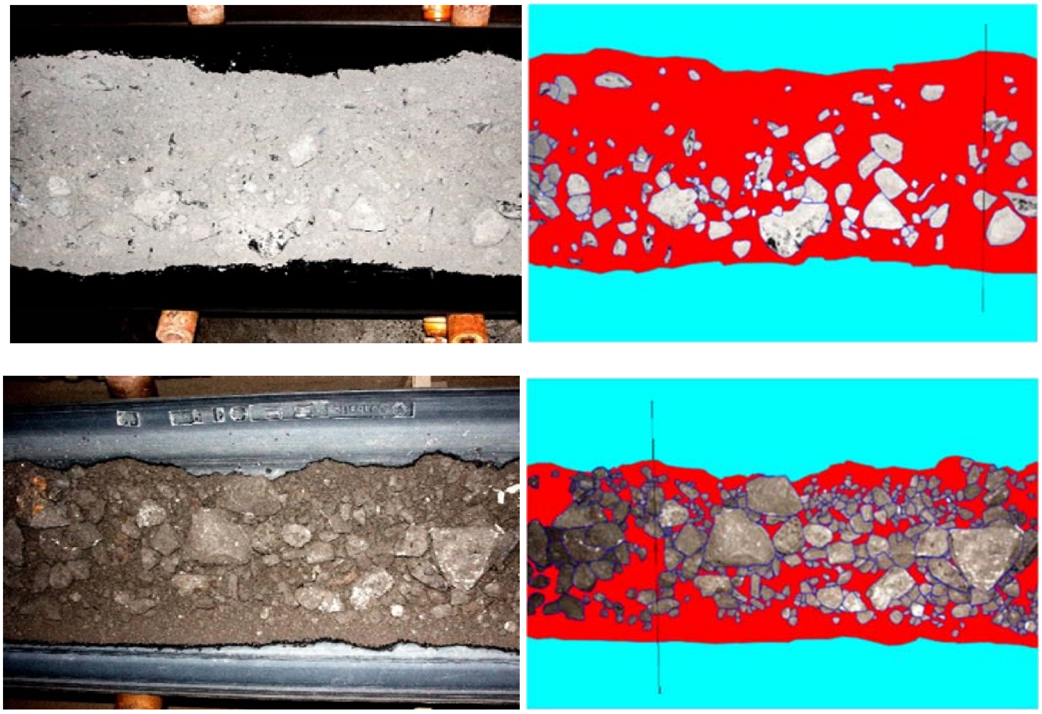

Figure 6. Example of size differences between various fragments of rock transported on conveyors: a) T5 – division G-2, b) W522 – division G-5

The above observations were confirmed in fragmentation tests, whose results are shown as particle size distribution curves. The curves plotted on the basis of the acquired photographic documentation correspond to the sizes of all rock fragments which constitute a representative sample of the material transported on both belt conveyors used in the examinations (Figure 7). The distribution curve for the ore with dolomite fraction (W522) has a slope which indicates higher percentage share of coarse fraction. This fact allows a conclusion that dolomite has greater strength [19] and shows smaller susceptibility to crushing when mined or transported [20]. The slope of the curve for the sandstone-shale ore has a reduced inclination angle due to prevalent fine fraction. This in turn is caused by the presence of sandstone – a low strength rock type composed of quartz grains bound with illite.

The analysis demonstrates a connection between the particle size distribution curves plotted for copper ore and its lithological composition described on the basis of data from channel samples. However, an accurate image-based qualitative description of ore requires a measurement methodology based on automated procedures for particle size identification with algorithms allowing fast processing of acquired photogrammetric data. Classification of the size and colour of rock particles may be performed for example with the use of artificial intelligence methods, already successfully employed in chemical engineering [22], agricultural engineering [23] or in medicine [24].

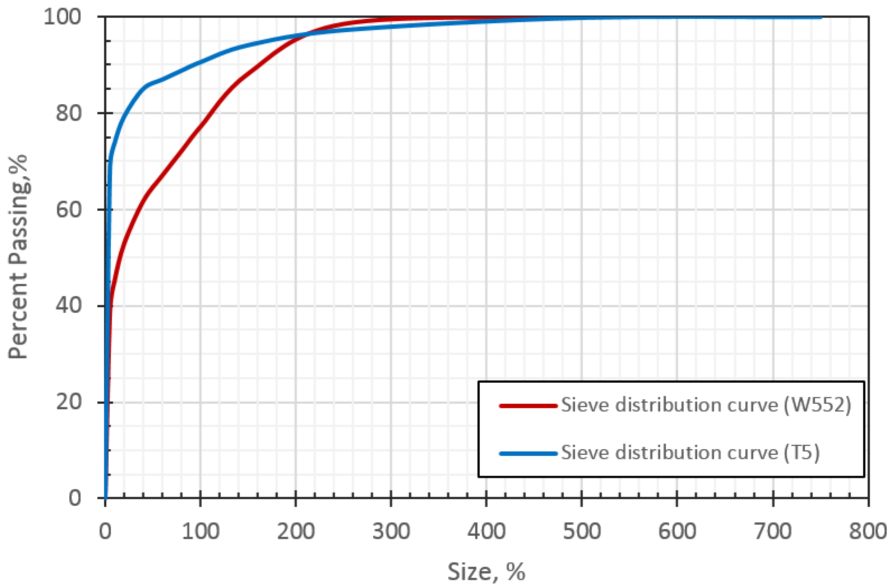

Figure 7. Cumulative particle size distribution curves for copper ore in the analyzed cases
Curve designations in the legend: T5 (division G-2) and W522 (division G-5)

4. Conclusions

The study presents the analysis of particle size distribution with the use of an indirect, image-based method. For this purpose, a series of photographs were taken of the ore transported from mining divisions having different deposit lithology. The research results were shown in the form of cumulative particle size distribution curves based on the acquired photographic documentation. The curves were compared with the information on the geological composition and Cu content obtained from the MOPRONA system. As a result, a relationship was observed between the identified the particle size distribution in the run-of-mine material and its lithology. This fact confirms that the quality of ore may be successfully described with the use of rock particle sizes. The strength of individual lithology types has been demonstrated to affect the degree of size distribution of the particles in the transported material. Copper ore extracted from the G2 division, where sandstone is prevalent, showed greater susceptibility to crushing. Owing to the presence of carbonate rocks, which typically have greater strength, the grain size distribution curve for the ore fed from the G5 division shows increased percentage share of coarse particles.

Moreover, the study revealed differences in the colour of copper ore extracted in different divisions.

Although the research here presented was performed on a small scale, its results are promising and confirm that it is sensible to pursue further research into a technology for acquiring additional information on the quality of ore fed to the processing plants.

Acknowledgment

This work was supported by the Polish Ministry of Science and Higher Education as scientific statutory project No. 0401/0131/17

References

[1] Saramak D. (2006). Analiza efektywności wybranych grup operacji wzbogacania z uwzględnieniem ich kosztochłonności na przykładzie technologii wzbogacania rud miedzi [Analysis of efficiency for chosen groups of enrichment operations with respect their cost-consumption on example of copper ore enrichment technology]. Gospodarka Surowcami

Mineralnymi [Mineral Resources Management], vol. 22, 1, 2006.
[2] Jurdziak, L., Kaszuba, D., Kawalec, W., & Król, R. (2016). Idea of identification of copper ore with the use of process analyser technology sensors. IOP Conference Series: Earth and Environmental Science, , 44(4) doi:10.1088/1755-1315/44/4/042037
[3] Kawalec, W., Krol, R., Zimroz, R., Jurdziak, L., Jach, M., & Pilut, R. (2016). Project DISIRE (H2020) - an idea of annotating of ore with sensors in KGHM polska miedz S.A. underground copper ore mines. Paper presented at the E3S Web of Conferences, 8 doi:10.1051/e3sconf/20160801058.
[4] Konieczny, A., Bazan, B., 2012. Challenges and difficulties of comminution processes in KGHM PM S.A. Division of Concentrators (MEI Conference Comminution 2012)
[5] Jurdziak L., Kawalec W., Król R. Application of flexsim in the disire project; Studies & Proceedings of Polish Association for Knowledge Management Nr 84, 2017
[6] Bardziński P. J.; Król R. 2018 Ilościowa ocena urobku na potrzeby symulacji procesu jego rozpływu kopalnianą siecią transportową' [Quantitative evaluation of run-of-mine material in the simulation of ore flow in the underground transport network] Transport przemysłowy i maszyny robocze {Transport in Industry and working machines] no. 1/2018.
[7] Pactwa K., Malewski J.: Opis koncentracji miedzi w profilu złoża i propozycja jego wykorzystania w planowaniu produkcji [Description of copper grade in the deposit profile and its application in production planning]. Przegląd Górniczy [Mining review] 69.7, 2013 pp. 75–82.
[8] Kulbacki A., System MOPRONA – Monitoring Produkcji Nadawy – ważny element w strategii realizacji zadań produkcyjnych w kopalniach rud miedzi [MOPRONA system – Run-Of-Mine Ore Monitoring system – an important element in the strategy of meeting production goals in copper ore mines]. Szkoła Eksploatacji Podziemnej [School of Underground Exploitation], Szczyrk 2007,
[9] Maerz, N.H., 2007. Optical sizing analysis of blasted rock: lesson learned, Materiały konferencyjne 4th EFEE World Conference of Explosives and Blasting in Vienna, s. 75-83.
[10] Katterfeld, A. & Wensrich, C. : Understanding granular media: from fundamentals and simulations to industrial application, Granular Matter (2017) 19: 83. https://doi.org/10.1007
[11] Maerz, N.H., 2001. Automated Online Optical Sizing Analysis, SAG 2001. 250- 269.
[12] Batko, P., Sołtys, A., 2007. O sposobach określania składu ziarnowego po strzelaniu [Methods for Estimating Grain Size Distribution After Blasting], Magazyn WUG [WUG Magazine]: "Bezpieczeństwo Pracy i Ochrona Środowiska w Górnictwie" [Industrial Safety and Environmental Protection in Mining] no. 9/1, pp. 125-139.
[13] Bessikirski, A., Bessikirski, R., 2012. Wpływ warunków geologiczno-górniczych na fragmentację urobku w kopalniach wapienia [Influence of Geological and Mining Conditions on Rock Fragmentation in Limestone Mines], Magazyn WUG [WUG Magazine]: "Bezpieczeństwo Pracy i Ochrona Środowiska w Górnictwie" [Industrial Safety and Environmental Protection in Mining] no. 12, pp. 18-27.
[14] Bessikirski, A., Dworzak, M., Pyra, J., 2016. Pośrednia analiza fragmentacji urobku otrzymanego w wyniku robót strzałowych wykonywanych w kopalni dolomitu [Indirect Analysis of Grain Size Distribution in the Material Obtained from Blasting in a Dolomite Mine], Przegląd Górniczy [Mining Review] no. 7
[15] Sanchidrian, J.A., Segarra, P., Ouchterlony, F., Lopez, L.M., 2009. On the accuracy of fragment size measurement by image analysis in combination with some distribution functions, Rock Mech Rock Engng 42: 95-116.
[16] Maerz, N.H. & Zhou, W., 1998. Optical digital fragmentation measuring systems – inherent sources of error, FRAGBLAST, The Int. Journ. for Blasting and Fragmentation, 2:415-431.
[17] Boujila, A., Bartolacci, G., Koch, N., Cayouette, J. and Cote, C., 2000. Toward the Improvement of Primary Grinding Productivity and Energy Investigation Consumption Efficiency, Mine to Mill 2000, Finland 5.

[18] Siddiqui F.I., Ali Shah S.M., Behan M. Y, 2009, Measurement of Size Distribution of Blasted Rock Using Digital Image Processing; Eng. Sci.,Vol. 20No. 2, pp: 81-93

[19] Butra J.: Metoda doboru systemu eksploatacji złóż rud miedzi w polach o jednorodnej charakterystyce geologicznej [Method for Selecting a Copper Ore Production System in Fields Having Uniform Geological Properties]. Kraków, IGSMiE PAN, Studia, Rozprawy i Monografie [Studies, Dissertations, Monographes], no. 89, 2001

[20] Krzemińska M., Malewski J., 2011, Energochłonność operacji przygotowania rud do wzbogacania w kopalniach LGOM [Energy Consumption of Ore Pre-Processing Operations in the LGCB Mines], Przegląd górniczy [Mining Review] No. 7-8 pp. 143-147.

[21] Spalińska B., Stec R., Sztaba K., 2007 „Miejsce i rola przeróbki rudy w kompleksie technologicznym KGHM polska miedź S.A. [The Position and Role of Ore Processing in the KGHM Polska Miedz S.A. Technological Complex]. Monografia KGHM Polska Miedź S.A. Lubin. 2.14: 142-144.

[22] Aleksić, I., Crossed D Signuriš, J., Ibrić, S., & Parojčić, J. (2015). An investigation into the usefulness of different empirical modeling techniques for better control of spray-on fluidized bed melt granulation. International Journal of Pharmaceutics, 496(2), 627-635.

[23] Koszela K., Weres J.: Neuronowa klasyfikacja obrazów suszu warzywnego [Neural Classification of the Images of Dried Vegetables]. Inżynieria Rolnicza [Agricultural Engineering], 2009, No. 8 (117).

[24] Ojha, V. K., Schiano, S., Wu, C. -., Snášel, V., & Abraham, A. (2018). Predictive modeling of die filling of the pharmaceutical granules using the flexible neural tree. Neural Computing and Applications, 29(7), 467-481.