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INFLUENCE OF THE SAMPLING FREQUENCY FROM THE CONVEYOR ON THE DISTRIBUTION OF AVERAGE CU CONTENT VIA MONTE-CARLO SIMULATION FOR COPPER ORE OF VERY VARIABLE QUALITY

WPŁYW CZĘSTOTLIWOŚCI POBIERANIA PRÓBEK Z PRZENOŚNIKA NA ROZKŁAD ŚREDNIEJ ZAWARTOŚCI CU ZA POMOCĄ SYMULACJI MONTE-CARLO DLA RUDY MIEDZI O BARDZO ZMIENNEJ JAKOŚCI

Reconciliation between two copper ore mines transferred ore from one mine to another for processing in enrichment plants generated the need to regularly study the amount and composition of the ore on the conveyor connecting these two mines. To ensure the objectivity of the study, taking composite samples and their analysis was entrusted to a specialized outside laboratory. However, the managing staff of both mines still have doubts whether sampling results reflect correctly content of transported ore especially when the fed is highly variable. In order to investigate how the relatively low sampling rate affects the accuracy and precision of the measurement, the article investigates the hypothetical situation on the linking conveyor with the ore having extremely differentiated mineralization: 80% of almost barren rock (below 0.7% Cu) and 20% of the richly mineralized shale (around 10% Cu). Such ore occurs in some areas of the mine, from which it is fed onto a connecting conveyor. Through simulation techniques it was examined how the frequency of sampling can influence the distribution of the pooled sample results. It turned out that for 16 randomly selected samples in the following 15 minutes time intervals of a working shift, the spread of results around the simulated value is very large. A satisfactory accuracy level for the estimations of mean Cu content in the transported ore is achieved when the samples are collected at 30-second intervals. Only with sampling frequency close to on-line scanner parameters the probability of obtaining estimations with deviation exceeding 10% drops to the level of 2%. In the case of extremely differentiated ore doubts about confidence in the described measurements are fully confirmed, because with over 50% probability a single measurement could be deviated by 50% up and down from the true value.

Keywords: DISIRE, ore grade variation, frequency of sampling, belt conveying, simulation

Uzgodnienia pomiędzy dwiema kopalniami rud miedzi dotyczące przekazania urobku z jednej kopalni do drugiej spowodowało potrzebę regularnego badania jej ilości i składu na przenośniku łączącym obydwie kopalnie. Aby zapewnić obiektywność badania, pobieranie próbek złożowych i ich analizę powierzono

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wyspecjalizowanemu laboratorium zewnętrznemu. Jednak personel zarządzający obydwoma kopalniami nadal ma wątpliwości, czy wyniki kontroli wyrywkowej odzwierciedlają stan faktyczny. W celu zbadania, w jaki sposób stosunkowo niewielka częstotliwość pobierania próbek wpływa na dokładność i precyzję pomiaru, przeprowadzono symulacje dla transportowanej przenośnikiem rudy o zróżnicowanej mineralizacji: 80% prawie jałowej skały (poniżej 0,7% Cu) i 20% bogato mineralizowanego łupku (około 10% Cu). Ruda taka występuje w niektórych obszarach kopalni, z której jest podawana na przenośnik łączący. Dzięki zastosowanym technikom symulacyjnym zbadano, w jaki sposób częstotliwość pobierania próbek może wpływać na rozkład zbiorczych wyników próbek. Okazało się, że dla 16 losowo wybranych próbek w kolejnych 15-minutowych przedziałach czasowych zmiany roboczej, rozrzut wyników wokół symulowanej wartości jest bardzo duży. Zadowalający poziom dokładności dla oszacowania średniej zawartości Cu w transportowanej rudzie uzyskuje się, gdy próbki są zbierane w 30-sekundowych odstępach. Tylko przy częstotliwości próbkowania zbliżonej do parametrów skanera on-line prawdopodobieństwo uzyskania szacunków z odchyleniem przekraczającym 10% spada do poziomu 2%. W przypadku niezwykle zróżnicowanej rudy wątpliwości co do ufności w opisane pomiary są w pełni potwierdzone, ponieważ przy ponad 50% prawdopodobieństwie pojedynczy pomiar może być odchylony o 50% w górę iw dół od wartości rzeczywistej.

Słowa kluczowe: DISIRE, zmienność okruszcowania, częstotliwość próbkowania, transport przenośnikowy, symulacje

1. Introduction

Only few research publications were dedicated to identifying the composition of ore transported on belt conveyors in underground copper mines in the KGHM "Polska Miedz" SA and of the material transported from the mines to the processing plants in this company. These publications focused on analyzing the changes in grade during subsequent work shifts (Drzymała & Kowalczuk, 2010; Tasdemir & Kowalczuk, 2014), as well as on the changes in grade on the belt conveyor which connects two mines (Jurdziak et al., 2016, 2017b). They pointed to the difficulties in forecasting future grades on the basis of historical data (Tasdemir & Kowalczuk, 2014; Jurdziak et al., 2018). Information on mean Cu content in the ore during one shift was required to perform the reconciliation between two mines (Jurdziak et al., 2016) and to estimate the fluctuations of the composition of ore fed to the ore processing plants (Drzymała & Kowalczuk, 2010; Tasdemir & Kowalczuk, 2014). These research works, however, did not include the analysis of the accuracy and precision of grade estimation based on samples collected during a single work shift (Mucha et al., 2008). In the case when samples are collected manually from a belt conveyor, doubts occur as to whether such measurements are accurate and precise (Jowett, 1952). Employees of both mines question the reliability of measurements, although these are performed by workers of the Centrum Badania Jakości sp. z o.o. (CBJ Ltd.) – an independent external company which is hired by mines to assay ore samples.

More precise information on ore feed quality is obtained from a composite sample of ore feed, as regular samples are collected automatically from the pulp in the flotation machine. At this stage, ore is milled and blended, and samples are collected with high frequency. A cumulative aggregated sample from the shift is reduced several times and analysed in the CBJ laboratory. The results of these measurements are used for long-term reconciliation, while the results obtained from sampling ore on the connecting conveyor serve for current reconciliation. The content of ore after preliminary crushing may be also identified in the process of automatic sampling from the whole ore stream passing through the discharge chute over the crushers. Samples in the mine are collected manually from a 30 cm wide zone marked on the conveyor housing, after the conveyor is stopped (Jurdziak et al., 2016). At belt speed of approximately 2.5 m/s, this means that although the sample is collected correctly from the whole stream (it is representative), it is still representative for a very short period of only 1/7 of a second. The size of rock fragments which can be fed to the conveyor through a grizzly with 40-45 cm mesh may cause the samples to be of insufficient mass. This mass is typically approximately 30 kg. Additionally, samples of so small size are collected from the stream of mined ore, which in extreme cases may be composed only of two types of rock: barren rock and high grade shale. Some parts of the deposit in the operating area of the connecting belt conveyor described in (Jurdziak et al., 2016, 2017b, 2018) comprise ore of this type. The above fact may significantly influence inaccuracy when estimating mean grades at low sampling frequency.

The influence of the number of collected samples was investigated using simulation performed in ModelRisk program. The quantity and qualitative composition of the ore stream divided into portions were simulated. Each portion was drawn from the ore with the most diverse composition (20% of reach shale and 80% of barren rocks). The simulation was carried out at the request of the mine management to check the accuracy of ore sampling from a conveyor for the extreme case, the exploitation of the ore from the field with the most diverse composition. It was assumed that the conveyors operated continuously for the whole work shift, so that the irregularities resulting from cyclical conveyor loading on the grizzly did not additionally contribute to the spread of results (Polak et al., 2016; Kruczek et al., 2017). In a similar manner, it was assumed that the mined ore was a uniform, random blend of a number of homogeneous portions having limited mass (ca. 105 kg) and in random proportions corresponding to the presence of barren rock and shale.

Simulation was also used by Snopkowski (2005) as a tool for identification of the function of coal output probability density and to model of the longwall face excavation using two-way shearer mining technology (Snopkowski, 2009). In these papers, however, the author concentrated mostly on stochastic modelling of variability of the quantity of coal stream rather than variation of its quality. The geological information has its value (Krzak & Panajew, 2014) and variability of quality parameters has the impact on the risk of mining projects (Kopacz, 2017), also in the context of deposit accuracy estimation (Mucha et al., 2008). For simplicity, sampling errors as well as detail quantity modelling of ore stream changes due to cyclical loading (Kruczek, 2017) were not taken into account in further analysis.

2. Simulation of grade fluctuations on a conveyor connecting two mines

Ore fed from the mining faces to the screen has variable grade, as the mined ore contains lumps of dolomite and sandstone whose grades are close to cut-off grades (as they come from areas at the roof and floor – on the margins of the mined seam deposit), as well as fragments of high grade shale. This variability poses problems as far as mined ore sampling is concerned (due to significant differences of lump sizes and blending of the mined ore). Therefore, apart from trench samples taken in advance from side walls or mining faces, the mined ore is not regularly sampled in situ. In some locations, however, ore transported on the conveyor is sampled.

An example of such location is the conveyor connecting two mining plants, in which samples of mined material are randomly collected at regular intervals defined by the transported mass or by the passage of time (Jurdziak et al., 2016, 2017b). Further problems result from the fact that ore delivered to the conveyor from individual mining faces has variable grade. Copper-bearing shale ore is very rich in copper but its thickness is less than 0.5 m. Extraction of barren rock surrounding thin shale deposit, in such case, causes significant dilution of ore. The minimum room height of approximately 2 m is necessitated by the dimensions of mining machines and therefore both sandstone and dolomite are worked using blasting method with various room-pillar systems with roof settlement. The excavation cycle includes drilling, bolting, blasting and loading. Barren rocks together with rich shale are delivered by loaders and haulage vehicles to the conveyor, as selective extraction in some places is not economically justified. Shale accounts there only for 20% of the mined rock. Nevertheless, mean Cu content in the mined ore remains on a similar level as compared to other mining faces. A doubt occurs, however, whether collecting cumulative samples from the conveyor (e.g. from 8 to maximum 16 times per shift, approximately every 15-30 minutes) does not significantly affect the precision of mean Cu content estimations in the ore transported over one work shift.

This problem has been addressed using simulation methods. It was assumed that ore portions delivered to the belt conveyor are randomly chosen from two different fractions of mined material. 80% was randomly chosen from the run-of-mine material (barren rock) having grades between 0.0% and 0.7% (with the modal value at 0.35%), while the remaining 20% was randomly chosen from shale ore described with triangular distribution from 0.7% to 14% (with modal value at 10%) (Fig. 1). The assumed distributions may be corrected and adjusted to better represent the actual values in further research taking into account also cyclical loading pattern (Bardzinski et al., 2019). The primary concern, however, are not the particular distributions but the fact that barren rock occurs with 80% frequency. This may be of great importance for the estimation of mean Cu content in the transported ore when partial samples are collected with low frequency.

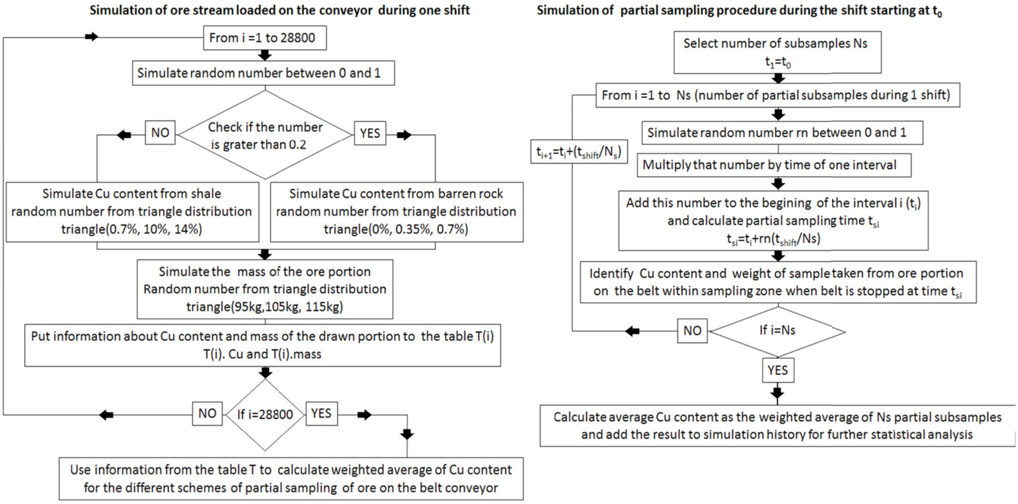

Fig. 1. Procedures to calculate ore stream loaded on the connecting belt conveyor and selection of random sampling times in following Ns intervals used for calculating average Cu content of ore transported by the transfer conveyor during one shift

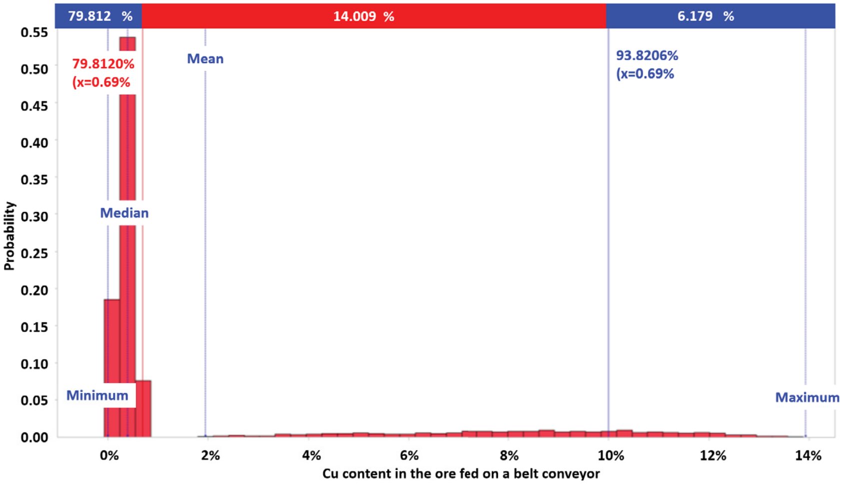

Fig. 2. Histogram of ore grades on the conveyor

The resultant distribution of ore content on the conveyor is a combined bimodal distribution (0.35% and 10.0%). It is presented on the Figure 2. As can be observed, the spread of results is considerable (14%) and apart from barren rock, high grade ore may be found on the conveyor, albeit not often. The above observation is confirmed in the scatter plot (Fig. 3) and in the bar chart of Cu content fluctuations for the first 300 portions (Fig. 4).

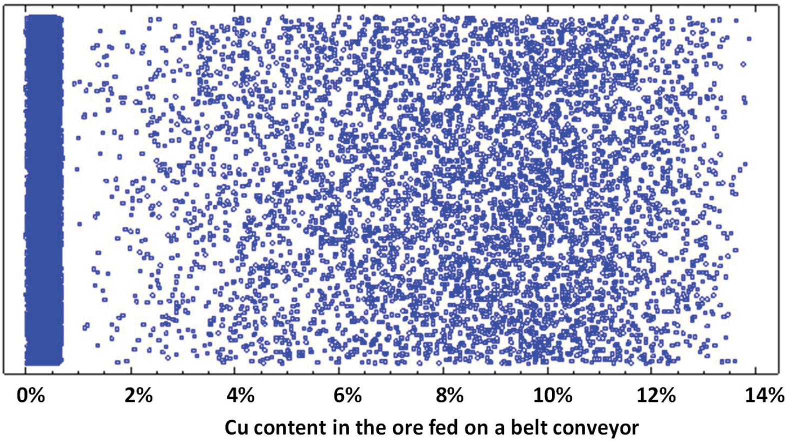

Fig. 3. Scatter plot of grade distribution for ore fed to the connecting conveyor.
Along the vertical axis, the points are "jittered" randomly up and down to prevent identical points from overplotting each other

In the simulation, mined ore portions were generated with the frequency of 0.5 second, so that the target efficiency of 3 000 Mg was achieved during the work shift. It was assumed that a single portion of mined ore weighs approximately 105 kg. Fluctuation was assumed in accordance with the triangular distribution with the following parameters: minimum = 95 kg, modal value = 105 kg, maximum = 115 kg (Fig. 1).

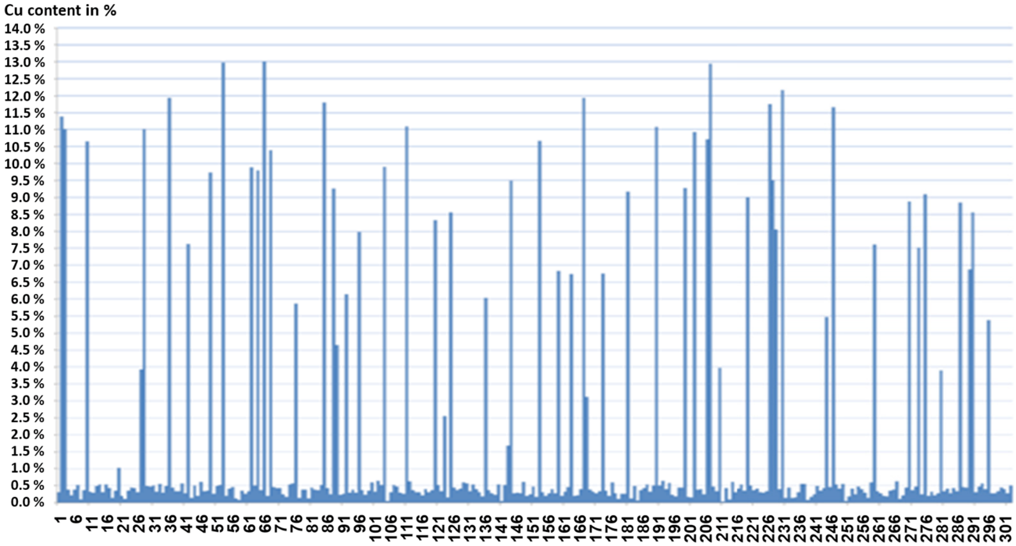

Fig. 4 Histogram of a grade distribution for ore fed to the connecting conveyor – simulation performed for first 300 portions (150 seconds)

During one work shift, 28 800 ore portions were randomly generated – each of the portions could be a portion of shale or barren rock with the assumed proportions (20% and 80%). With the belt speed at approximately 2.5 m/s, a single ore portion would be distributed on the conveyor belt having length of 1.25 m, which means that the distance of 30 cm (the marked sampling zone) would contain approximately 24 kg of ore which would be crushed, milled, blended and reduced to be incorporated in the cumulative sample. We do not know whether this method of randomly selected subsequent ore portions reflects real distribution of ore quality along the conveyor belt due to utill now there were no published results of such detail measurements. Only data of average Cu content between following shifts together with their variability analysis were presented (Jurdziak et al., 2016, 2017b). So, it is the first attempt to model quality of ore stream with so small time intervals. Further investigation will be carried out if simulation will be chosen as a tool to predict average quality of ore stream send from mine to the ore enrichment plants. Nevertheless, selected method ensures a comparatively well blended ore, as it assumes grade fluctuations in portions of approximately 105 kg, and on 1.25 m belt lengths. Current research works are performed to describe in detail the process of loading mined ore mass on the conveyor belt by observing the operating parameters of loaders and haulage vehicles which service the screen (Polak et al., 2016; Bardzinski et al., 2019). Portions of mined ore delivered to the screen in a single load far exceed the 105 kg value assumed in the simulation, as the capacity of buckets and haulage vehicles are within 5-11 m^3, the density of mined ore in the undisturbed rock is 2.6 Mg/m^3. Unfortunately, little is known about ore composition in these large portions, as sampling them is difficult due to the variability of rock lump sizes, lithology and the content of Cu and other valuable minerals in rocks ranging from barren rock to high grade shales with Cu content above 10%. Estimation of the composition of these portions is not easy as samples of the deposit are collected from the mining face or from the walls with an vertical interval of max. 20 cm, within the 16 identified lithologies. The pile formed after blasting is blended and contains a great number of various rock fragments and fine material. No information is also available on the composition of randomly collected portions of the material taken by loaders. Due to the varying sizes of fragmented rock and to the blending of ore, it is also very difficult to collect representative samples of blasted material.

In the simulation, sampling frequency could be freely adjusted. The frequency was increased from 1 sample per shift, through 2, 3, 4, 5, 6, 8, 10, 12, 15, 16, 20, 30, 32, 40, 48, 60, 80, 96, 120, 160, 240, until 480 samples per shift (every 30 s.). Thus, a total of 1 410 sampling procedures were performed for each of the 10 000 simulations. Sampling times were randomly selected from constant sub-periods (intervals) formed by dividing the 4-hour times (t_{shift} belt conveyor operating time during one shift) by a particular number of partial samples Ns. The highest frequency (480 samples collected every 30 s.) is already close to the frequencies of on-line scanners. These do not operate continuously either, but require several seconds to perform scanning and process the data. This means that scanners are capable of estimating ore portions greater than those used to generate the primary ore stream. Therefore, it may be assumed that mean ore stream parameters for the whole shift and from all generated portions correspond to the actual material stream, and the randomly selected samples indeed constitute its approximation. Metal-content measurement errors were also excluded from the simulation, as its aim was to determine the influence of sampling frequency on the accuracy and precision of estimations. The metal content in the generated portions was randomly selected and not assayed in the laboratory and therefore the confidence and bias were not included in the simulations. Obviously, in actual conditions the bias would additionally decrease grade estimation precision. Their presence was ignored in the simulation.

The very moment of sample collection (reading the data on the mass and grade of the individual portions from the table T, sampling time required to stop conveyor and take a sample from the belt is ignored in the simulation and put to 0 due to simulation was prepare to analyse ideal and hypothetical situation not the real procedure) were selected randomly within each time interval. Each second of the time period could be selected for sampling with equal probability. This allowed observing the basic rule of proper sampling: each fragment of sampled material has an equal chance of being collected. Sampling at uniform time periods was used, as it was assumed that the belt conveyor had a constant efficiency during the shift. When simulating the physical process of feeding mined ore to the belt conveyor (e.g. the cyclical operation of loaders in mining faces), it was necessary to substitute time intervals with mass intervals. Another simplifying assumption was made at this stage: that conveyors are uniformly loaded, which is not far from actual conditions as the conveyor under consideration is a cumulative conveyor, with ore being fed to it from many mine faces simultaneously. Thus, the variable values from a number of faces are averaged and the ROM material on the belt is appropriately blended. Maximum sampling frequency corresponds to the generation time, i.e. 0.5 second. In this scenario, all of the 28 800 portions were analyzed and this value was considered to be the actual mean metal content calculated as weighted average with allowance for the variable weights in all portions and for their variable randomly selected grades. Mean Cu content in the cumulative sample was also calculated as weighted average of Cu content in the total mass of the number of randomly selected portions (which constituted composite samples).

Mean value of Cu content in ore identified for all portions was considered to be an actual value in a particular simulation. Obviously, this value was also subject to fluctuations, as each of the 10 000 simulations constituted an equally probable version of actual conditions. Analytical errors of the laboratory and errors which occur during the sampling procedure were not included in the grade value of the cumulative sample in order not to blur the actual value fluctuations resulting from sampling frequency differences. Ore grades in particular portions on the belt were treated as accurate and reflecting the actual values.

At the highest sampling frequency (sampling in the scenario was performed every 0.5 s) Cu content in ore varied to a limited degree. 98% of the simulation results remained within the range (1.88%, 1.97%) and were symmetrically distributed around the mean value of 1.93%. 100% of 10 000 simulations for the cumulative sample remained within the range (1.86%, 2.00%).

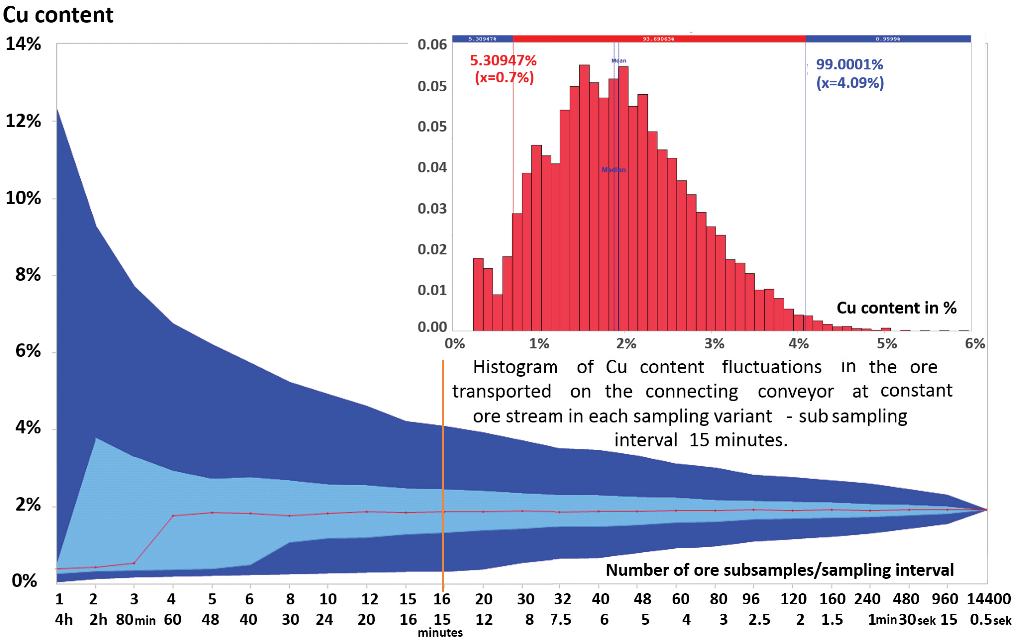

Fig. 5. Variability trend for ore grade estimations with alternating number of partial samples during one shift with details of Cu content distribution estimations based on 16 subsamples taken every 15 minutes

In the histogram of Cu content distribution in Cu content estimated based on 16 subsamples taken within every 15 minutes (Fig. 5), mean grade value was 1.94%, the spread was 5.62 percentage points (min. = 0.24%, max = 5.86%) and the median of 1.88% is a little below the mean value. The histogram has an asymmetrical shape (skewness = 0.43). The frequency of taking subsamples was twice higher than in reality but still estimation is very poor.

With limited number of samples, the histogram has a long right tail. For 1 sample, maximum Cu content reached 12%. The median is lower than the mean value (red line). The above can be observed in the trend line (Fig. 5). The median approaches the actual grade value no sooner than with 4 measurements (every 1 hour). For a smaller number of measurements, it is close to the modal value at 0.35%, as fewer than 4 measurements are randomly selected from a population, 80% of which comprises non-balance ore (waste). In Fig. 5, the light-blue colour indicates in which area 50% of grade estimations were located, and the dark-blue colour indicates 98% variation range. As can be observed, the variation range is far from the actual value. A lower spread, within the 20% range (+/–10%) is possible only with samples collected every 30 seconds. Sampling with so high frequency is possible only with an on-line scanner.

The simulation results can be compared with real measurements of ore quality on the transferred belt conveyor (Jurdziak et al., 2016 and 2017) (Fig. 6). Due to the aim of the simulation was not recreation of the real situation but analysis of extreme case, the quantitative data are different. Simulation results showed more frequently barren rock (Cu content below 0.7%) and higher Cu results (long right tail) but the shape of both histograms (asymmetric with long right tail) is very similar. Probably it is the result of not frequent sampling from ore stream with high variable quality. Such variable ore we can find in almost all mining faces due to it contains marginal ore (from roof and floor area) and rich copper-bearing schists. Mixing of ore during blasting and cyclical loading is not ideal so by manual sampling we can take subsamples that differs a lot. It influence high variability of average results.

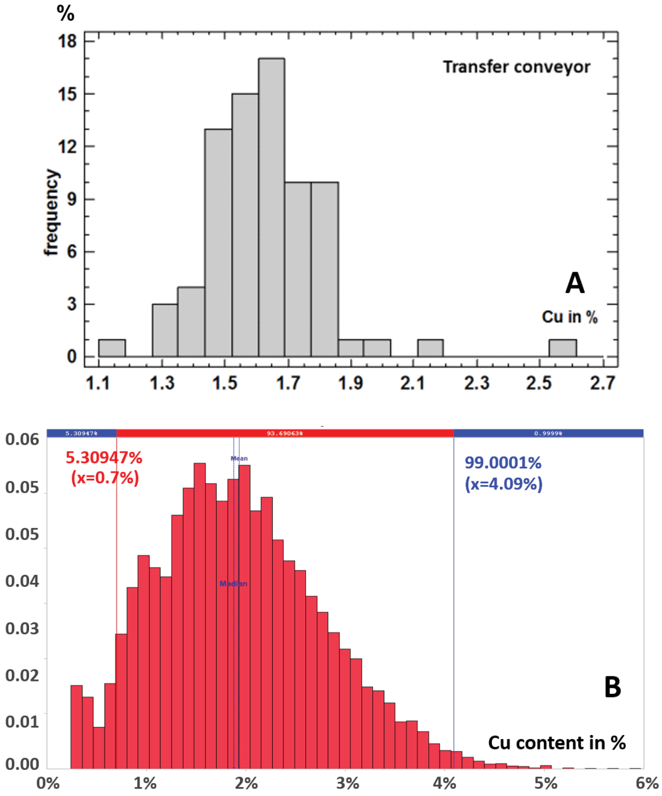

Fig. 6. Comparison of histograms of average Cu content in ore stream on the transfer conveyor calculated from cumulative sample taken from: A) the real conveyor in the mine (Jurdziak et al. 2016, 2017b), B) simulated ore stream

3. Conclusions

The analysis of the case in which ore has a highly varied distribution (20% of shale and 80% of barren rock) demonstrated that a large share of barren rock in the ore translates into high probability that waste rock will be found in partial samples and significantly influences the accuracy of individual estimations.

A satisfactory accuracy level for the estimations of mean Cu content in the transported ore is achieved when the samples are collected at 30-second intervals. Only with so high sampling frequency the probability of obtaining estimations with deviation exceeding 10% drops to the level of approximately 2%.

It is possible that with more varied ore, lower sampling frequency would provide sufficient accuracy, but Cu content in each mine face is different. It varies from the cut-off grade (0.7% Cu) to the maximum grade (several % Cu) in shale. The need to rip barren rock from either the roof or the floor causes waste to be blended with the ore (phenomenon known as dilution) and precludes selective exploitation (e.g. with a rock shelf). Barren rock rarely occurs with 80% frequency, as this is an extreme case, but when sampling is performed with low frequency the probability of collecting a sample from waste or from low grade ore would significantly affect the reliability of individual sampling procedures using this method.

The results of the analysis show satisfying accuracy and precision can be achieved only when ore is sampled on the conveyor with the use of on-line scanners and with a frequency of several seconds. Errors related to grade analysis methods would then be of greater importance, as sampling frequency would be already satisfactory. At this stage, however, it becomes interesting whether such information is valuable and whether the profits from more detailed knowledge of ore grades on the conveyor will outweigh the costs of scanner.

The samples collected from the connecting conveyor are analysed in order to allow reconciliation between the two mines. This research indicates that the probability of overrating or underrating the estimations is similar and close to 50% (the median is a little lower than the mean value, Fig. 5). Over long periods of time and for many measurements, estimations of mean values are close to the actual values. Over one month, the number of transport shifts approximates 100, and over one year it exceeds 1000. With so many estimations and an almost symmetrical probability of deviations to both sides, errors balance each other out and estimated mean values are close to actual values. This method may be accepted for long-term reconciliation (it is accurate), but individual measurements may show significant deviation from actual values (they are not precise), thus accounting for the impression, shared by the employees of both mining plants, that the sampling procedure is not reliable.

Information on grades in the ore fed to the processing plant, if provided in advance, may increase the efficiency of concentration processes. Information on Cu content alone is, however, insufficient. Optimization of ore concentration processes requires information on lithology and/or mineralogy of the ore. On-line scanners do not provide such data. Providing such information in advance is also difficult, as it requires knowledge of not only temporary mineral content but also of mean data collected for a longer period. Therefore, other methods of ore grade forecasting should be considered.

Smart pellets with ore content information from loading points is therefore a good and less expensive alternative. In order to prepare forecast of ore feed to processing plant a simulation of this process during the working shift can be helpful.

The results of the analysis are important in the context of the DISIRE project (Kawalec et al., 2016), in which the method of forecasting the composition of the ore being supplied to enrichment plants was developed. The simulation method was indicated in this project as a very good tool for this purpose (Jurdziak et al., 2017a).

All 10 thousands simulations were done within Microsoft Excel using the spreadsheet risk modelling program ModelRisk from Vose Software company.

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References

Bardziński P.J., Król R., Jurdziak L., Kawalec W., 2019. *Random Loading of Blasted Ore with Regard to Spatial Variations of Its Actual Lithological Compound*. In: Burduk A., Chlebus E., Nowakowski T., Tubis A. (eds) Intelligent Systems in Production Engineering and Maintenance. ISPEM 2018. Advances in Intelligent Systems and Computing **835**, 668-677, Springer, Cham.

Drzymala J., Kowalczuk P.B., 2010. *Problems with statistical evaluation of separation results*. Proceedings of the 12th International Mineral Processing Symposium 1191-1202, Cappadocia, Turkey.

Jowett G.H., 1952. *The Accuracy of Systematic Sampling from Conveyor Belts*. Journal of the Royal Statistical Society. Series C (Applied Statistics) **1**, 1 , 50-55.

Jurdziak L., Kawalec W., Król R., 2016. *Current methods and possibilities to determine the variability of Cu content in the copper ore on a conveyor belt in one of KGHM Polska Miedz S.A. mines*. Mineral Engineering Conference MEC2016, Swieradow-Zdroj, Poland, September 25-28. EDP Sciences, 2016. art. 01055, E3S Web of Conferences, **8**, 1-7. ISSN 2267-1242. doi: 10.1051/e3sconf/20160801055.

Jurdziak L., Kawalec W., Król R., 2017a. *Application of FlexSim in the DISIRE project*. Studies & Proceedings of Polish Association for Knowledge Management **84**, 87-97.

Jurdziak L., Kawalec W., Król R., 2018. *Autocorrelation Analysis of Cu Content in Ore Streams in One of KGHM Polska Miedź S.A. Mines*. Intelligent Systems in Production Engineering and Maintenance – ISPEM 2017. Advances in Intelligent Systems and Computing **637**, 189-198,. Springer, Cham.

Jurdziak L., Król R., Kawalec W., 2017b. *Variation of ore grade transported by belt conveyors to processing plants*. Physicochem. Probl. Miner. Process. **53** (1), 656-669 (2017). doi: 10.5277/ppmp170151.

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 (2016) E3S Web of Conferences, 8, art. no. 01058.

Kopacz M., 2017. *The impact of variability of selected geological and mining parameters on the value and risks of projects in the hard coal mining industry*. Arch. Min. Sci. **62**, 3, 545-564. DOI 10.1515/amsc-2017-0040.

Kruczek P., Polak M., Wylomanska A., Kawalec W., Zimroz R., 2017. *Application of compound Poisson process for modelling of ore flow in a belt conveyor system with cyclic loading*. International Journal of Mining, Reclamation and Environment, DOI: 10.1080/17480930.2017.1388335.

Krzak M., Panajew P., 2014. *Value of geological information in exploitation management: the case of exploitation units of the Polkowice-Sieroszowice mine*. Arch. Min. Sci. **59**, 1, 239-256.

Mucha J., Nieć M., Saługa P., Sobczyk E.J., Wasilewska M., 2008. *The risk of investments in bituminous coal mining as a function of the estimation accuracy of deposit parameters (in Polish)*. Gospodarka Surowcami Mineralnymi – Minerals Resources Management **24**, 2, Kraków, 161-173.

Polak M., Stefaniak P., Zimroz R., Wyłomańska A., Śliwiński P., Andrzejewski M., 2016. *Identification of loading process based on hydraulic pressure signal*. 16th International Multidisciplinary Scientific GeoConference SGEM 2016, www.sgem.org, SGEM2016 Conference Proceedings, ISBN 978-619-7105-56-8 / ISSN 1314-2704, June 28 - July 6, 2016, Book1 **2**, 459-466.

Snopkowski R., 2005. *The use of the stochastic simulation for identification of the function of output probability density*. Arch. Min. Sci. **50**, 4, 497-504.

Snopkowski R., 2009. *Stochastic model of the longwall face excavation using two-way shearer mining technology*. Arch. Min. Sci. **54**, 3, 573-585.

Tasdemir A., Kowalczuk P.B., 2014. *Application of statistical process control for proper processing of the Fore-Sudetic Monocline copper ore*. Physicochem. Probl. Miner. Process. **50** (1), 249-264.