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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

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Abstract. In this paper the methodology of ore sampling on a belt conveyor in one of KGHM Polska Miedz S.A. mines was presented together with the results of analysis of the variation of ore tonnage and quality. The ore was transferred from one mine to another one through the analysed transfer conveyor on the route from the mine Division of Mining to copper plants. The transported ore was sampled in person from Division of Concentrators on a regular basis for metal accounting purposes between both mines. The ore quality control became a significant problem since it is impossible to predict with satisfactory advance both Cu content in the feed as well as its lithology composition which is required to improve and optimise the enrichment efficiency.

1 Introduction

In SW Poland near Lubin town, KGHM Polska Miedz S.A. operates 3 underground mines that is Lubin, Rudna and Polkowice-Sieroszowice, 3 Ore Enrichment Divisions of Concentrators (OEDs) and two copper smelter/refinery complexes.

Copper is extracted by using a room-and pillar method by drilling and blasting, cyclically loaded and hauled by low-profile LHDs and by continuous horizontal transport to shafts and stores using belt conveyors. Conveyors are also used to transport ore to concentrator plants.

The deposit comprises three different rock types, that is dolomite and sandstone separated by a main layer of copper-bearing black shale. The height of extracted seam (different in different mines) is established by channel sampling in the grid from 20x20 to 40x40 m. In each mining area both copper content and proportion of different rock types can substantially vary. The variability of ore excavated in different locations and transported in a complicated network of about 130 km of belt conveying systems, with many mixing and switching points as well as stores, causes the ore quality control to become a significant problem [1].

For improving the enrichment process, the identification of both copper content and proportion of type of rocks supplied are important. In fact, the latter one is the most important and never controlled on conveyors. The Cu content measurements from samples on a conveyor are done on a regular basis

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on one conveyor linking two mines. The samples are taken in order to make financial accounting between both mines after each shift.

In this paper one month measurements data were used to analyse the variability of Cu content in ore transported by one of KGHM Polska Miedz S.A. mines [2]. The results can be compared with Cu content variability of ore proceeded in the enrichment plants [3] as well as in ore supplied from mining face on divisional conveyor [2].

2 Methodology of ore sampling on a belt conveyor

A sampling station led by staff from the Centrum Badan Jakosci Sp. z o.o. (shortly CBJ) is placed on a transfer belt conveyor linking two KGHM Polska Miedz S.A. (shortly KGHM) mines. The ore is weighed on the conveyor by weightometer and is manually sampled in person by CBJ for metal content determination. These measurements and sampling/assay dictate the commercial payment between the mine, which supplies ore through this conveyor, and the mine, which receives and sends it together with its own ore to the ore processing plant.

The following description come from the QA/QC audit provided to KGHM by Wroclaw University of Science and Technology and SRK Consulting from UK [2].

The ore from the supplying mine was loaded into four bins from which the ore was fed onto the gathering conveyor and then transported ore from four sites of potentially different grade levels. The operations personnel advised that the finer fractions were generally with higher grade. The loading of material onto the analysed gathering conveyor was controlled by supplying the mine operators while the sampling regime was selected independently by CBJ personnel based on an agreed protocol.

The ore in the supplying mine was fed after blasting onto sectional conveyors by loaders through a 400 x 400 mm grille limiting the maximum lump size fed forward onto the analysed gathering conveyor linking both mines. Cumulative sampling was carried out exactly on this conveyor on each shift. It consisted of a dozen of partial samples drawn from equal masses (or periods) according to a special procedure described in the protocol.

The loading station comprised four 300 Mg ore bins fed by a single conveyor. The first three bins were filled via three moveable heavy duty ploughs on the conveyor. The local operator either raised or lowered the ploughs to push ore off the conveyor to discharge into the bins in order to maintain ore levels in the bins. The final bin received the ore from the discharge of the conveyor and did not incorporate a plough. The height of the plough was adjusted allowing partial removal of solids from the conveyor and consequently selective filling of different bins with either finer or coarser material was possible. The ore in the bins exhibited some degree of size segregation. The bins incorporated the level measurement instrumentation.

The bins were discharged via feeders onto the transfer conveyor to feed ore to the receiving mine conveying system via the CBJ weightometer and ore sampling point. The local operator, employed by the supplying mine, selected the plough position and bin discharge point. The procedure indicated that one feeder should be used at any time but also two feeders could be used if required. The first feeder was larger than the others. The operator recorded the timing/usage of the feeders but did not record the bin loading times.

The conveyors in the receiving mine were shut down one hour earlier than the supplying mine conveyors and during this time the bins at the load out point were usually filled. The conveyor tonnage was measured by two weightometers located upstream of the sample point. One weightometer was maintained by the supplying mine, which used the results, and the other was used and maintained by the receiving mine.

The sample cut was 0.3 m wide marked on the conveyor structure. This represented a 30 kg sample. The sampling process, from stopping the conveyor, breaking larger lumps, removing the sample, screening, crushing of oversize, mixing, splitting through labelling – was satisfactory. The CBJ sampling operators, seemed well-drilled in the procedures. The summarized protocol was as follows.

- Based on total planned tonnage to be transferred over the shift, the sampling procedure defined the number of samples to be taken, the sample interval in terms of tonnage and the minimum tonnage between successive samples.
- The sample was 300 mm wide and was taken from the conveyor between two defined marks.
- The conveyor was stopped and samples were taken at tonnages selected by the CBJ operators within the parameters described below. This procedure introduced randomness to the sample timing in order to reduce any potential bias in the type of material fed onto the conveyor at any particular time and to prevent the sampling exercise from being predicted (by loading operators).
- Pieces of ore lying across the sampling width were manually broken.
- The sample was removed and screened at 10 mm. The oversize was removed and crushed to -10 mm. The undersize and crushed solids were mixed in person on a steel plate. The mixed sample was collected and riffled to produce an approximately 4 kg sample. The sample was added to the mixer. All samples were combined and mixed and then riffled to produce the final sample.

The parameters for selecting sample intervals are given in Table 1.

Table 1. Sampling interval protocol.

The planned supply of dredged material [Mg]/shift	Mass range (layer) [Mg]	Minimum interval by mass [Mg]	Number of incremental samples/shift
to 999	75	37.5	10-13
from 1000 to 1499	100	50	10-15
from 1500 to 1999	125	62.5	12-16
from 2000 to 2499	150	75	13-16
from 2500 to 2999	175	87.5	14-17
over 3000	200	100	15 and more

At the start of the shift, the planned tonnage to be transferred from the supplying mine was used to define the sampling plan. The CBJ sampling team identified the number of samples and the sampling tonnage interval. Then the team then identified the random tonnages at which the conveyor would be stopped. These figures are noted on a log sheet. During the shift the actual tonnage transferred as measured by the CBJ weightometer is noted. For each sample were a unique sample reference number was given which then was noted on the sheet.

The sample size was reported to be approximately 30 kg per cut depending on loading of the conveyor. The particle size was mostly smaller than 300 mm. Larger particles commonly occurred.

The sample size taken from the belt appeared to be too small considering the maximum particle size on the conveyor. Observation indicated that some particles in excess of 250x250x100 mm were possible, which would be 30% of mass contained in a typical 30 kg sample cut. Typically, a sample of this size should not contain particles greater than 40 mm. Increasing the sample width even to 1 m would not significantly improve this situation and would probably result in a unrealistic sample size for manual processing.

The final sample was split into four separate samples: one for i) the supplying mine, ii) receiving mine, iii) assay and one as a control sample.

Similar sampling procedures were used for sampling the ore on other conveyors e.g. irregular control sampling for establishing Cu content in the ore supplied from mining faces on the divisional conveyors. The check of dilution level was the aim of control sampling.

3 Results and discussion

Figures 1 and 2 show the change of the quantity and quality of ore during 120 subsequent shifts. On Saturday and especially on Sunday the analysed conveyor belt was practically not used for ore transportation, and therefore some studies excluded the "zero" shift from the analysis.

Ore quality variations were random, what can be seen from the results of the process test run recorded above and below the median, as well as from the change of the increase and decrease directions (Table 3). In the case of ore quantity, a statistically important data clustering was observed with a 95% confidence level (Table 2).

Out of 120 shifts, ore was transported only during 77 shifts (the quantity of ore was greater than zero). The quantity range was between 560 and 3500 Mg. The median was 3000 Mg. The *P* value for values above and below the median was below 0.025 (0.00978), and therefore a statistically significant clustering exists of the sequence value, with statistical significance of 95%.

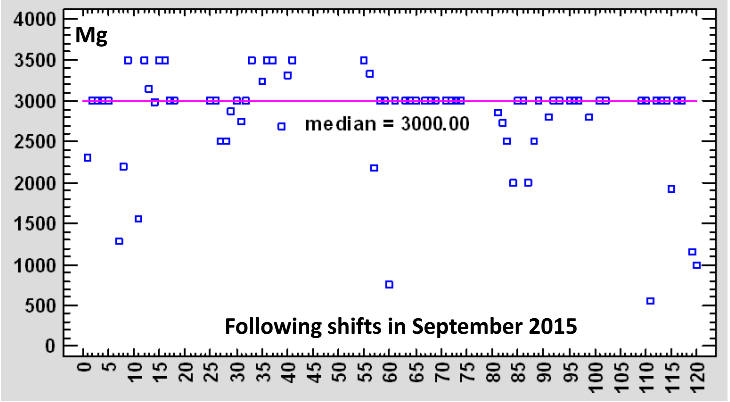

Figure 1. Variations of ore quantity on the conveyor analysed in 120 subsequent shifts in September 2015.

Table 2. Results of the Wald-Wolfowitz test of time sequence for the quantity of run-of-mine material.

Test	*Observed*	*Expected*	*Longest*	*P(>=)*	*P(<=)*
Values above and below the median	11	17.8649	44	0.996549	0.00977954
Increase and decrease of the sequence value	32	29.6667	4	0.254099	0.846738

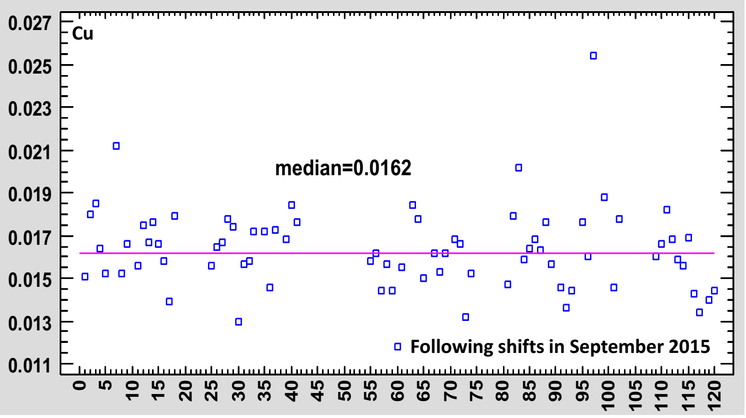

Figure 2. Variations of copper content in the ore transported on the analysed conveyor in September 2015.

Table 3. Results of the Wald-Wolfowitz test of time sequence for the copper content in the ore.

Test	Observed	Expected	Longest	P(>=)	P(<=)
Values above and below the median	35	37.973	7	0.792076	0.281171
Increase and decrease of the sequence value	49	50.3333	3	0.693159	0.409252

Numerous instances of shift output at the level of 3000 Mg indicated that this was the target value and probably such tonnage was usually planned for transportation from one mine to other one using a underground transport. Maintaining control of this value was possible, while maintaining control of quality could be difficult and quality variations might be random.

The ore grade was determined for 77 of 120 shifts, as the discussed conveyor was not used to transport ore during the rest of the shifts. The grade varied from 0.0118 to 0.0254 and the median was 0.0162. As none of the *P* values in Table 3. was below 0.025, non-random patterns were not observed at the significance level of 95%.

A further part of this work included description of the variations in copper quantity and content in the ore transported on the analysed conveyor, depending on the shift and the day of the week, supplemented by the analysis of their significance.

In September 2015, the quantity of the ore transported on the analysed conveyor varied depending on the day of the week (Fig. 3), shift number and day of the week/shift number combined. The variation of the weight of the transported run-of-mine material was significantly smaller if idle shifts were excluded.

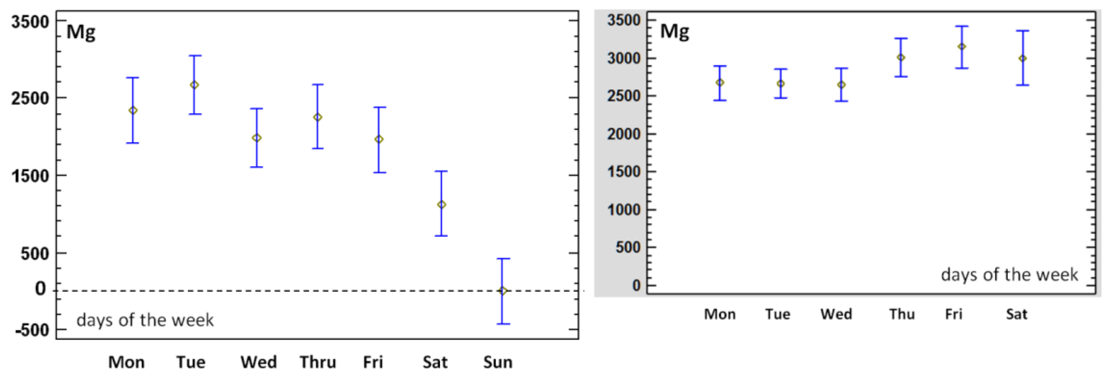

Figure 3. Variation of the average quantity of the transported ore with 95% confidence intervals depending on days of the week (including idle shift on the left and excluding idle shift on the right).

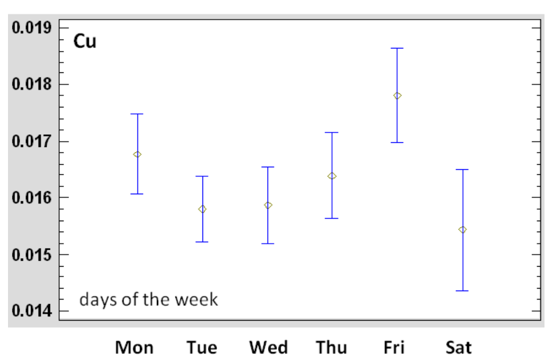

Figure 4. Variation of the average copper content in the ore transported on the analysed conveyor with 95% confidence intervals depending on days of the week.

Such statistical differences, occasionally significant especially if idle shifts with zero transportation were included, were not reflected in grade variations, which showed to be more stable in the discussed subgroups. As far as days of the week were concerned, two homogeneous but not disjoint groups were formed (Mon-Thu + Sat and Thu-Fri + Mon), with significant differences for the following pairs: Tue-Fri, Wed-Fri and Fri-Sat. Such differences may be difficult to explain, without the knowledge on the extent to which the production plans were followed.

Although some variations of copper content may be observed depending on the shift number, they did not seem statistically significant. This was confirmed in the quartile graph (box and whiskers type – Fig. 5, left side). Similar statistically insignificant variation of average grade values may be observed, if they were grouped depending on days of the week (Fig. 5, right side). Although average grade variations seemed to be considerable, especially on Saturday, when represented in the quartile graph, they proved to have a similar variation range for all days of the week. Two non-homogenous but joint groups may be identified (Mon-Thu + Sat and Thu-Fri + Mon). Significant differences can be observed for the following pairs: Tue-Fri, Wed-Fri and Fri-Sat.

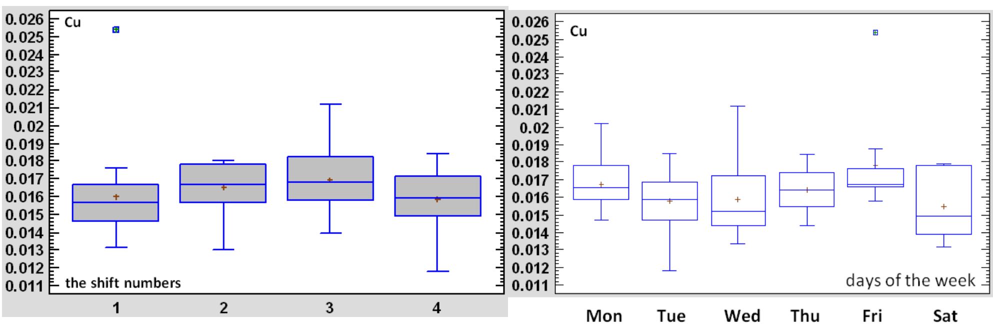

Figure 5. Variation of average copper content in the transported ore shown as a quartile graphs depending on the shift number (left) and days of the week (right).

Another comparison can be made depending on the days of the week and shift number (Fig. 6). The statgraphics Centurion XVII computer software, which was used in the calculations, identified as many as 4 joint homogeneous subgroups based on 17 significantly different pairs.

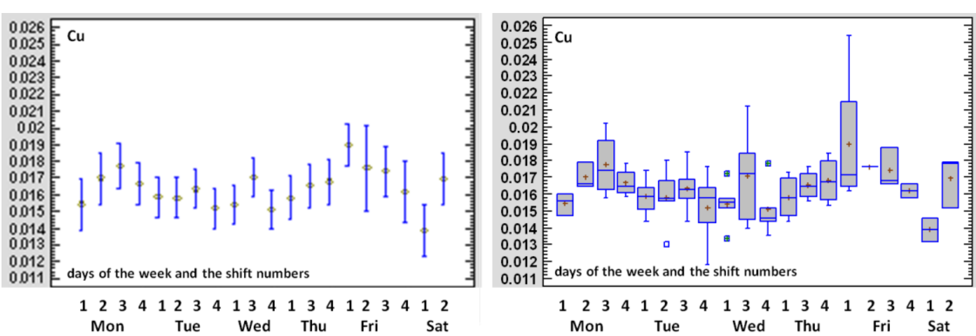

Figure 6. Average copper content in the ore transported on the analysed conveyor with 95% confidence intervals and with quartile graph depending on the day of the week and on the shift number.

These differences can't be logically explained without establishing a connection with production plans and mining face location. However, in the future, a record should be kept and analysed of metal grades in the output stream of mixed ore on the analysed conveyor and/or at the feeding point to Division of Concentrators, as the identified statistical differences may be explained by variation in the quality of ore from different parts of the deposit. Such procedure may serve a base for using statistical methods to forecast variation as related to mining face location (feeding point). The procedure may also be used in the DISIRE project.

If neither the shift number nor the days of the week have a significant influence on metal grade in subgroups, the time sequence of ore grade may be possibly analysed as a random sequence.

4 Conclusions

The analyses of ore transported on the transfer conveyor analysed in September 2015 showed that the quantity of the material in separate shifts was not a random process. The most frequent value and median was 3,000 Mg per shift, what indicated that the quantity of material sent from one mine to another one via the underground transport system was planned and controlled.

The run-of-mine tonnage changed significantly depending on days of the week, number of shifts and days of the week/shift numbers. Eliminating the idle shifts (without ore transport: Wed2, Thu2, Sat2, Sat3, and Sun1-4) allowed to limit the variations. It indicated that during work shifts the attempts were made to follow the plan. Reasons for the lack of transport during the second shift on Wednesday and Thursday are not known. Zero load during two shifts on weekends was due to lack of production.

The preliminary analysis of ore grade changes on the analysed conveyor indicated that grade variations may be considered as a random process. Significant grade differences depending on days of the week and shifts may be the result of conducting mining operations in different parts of the mine.

Detail description of the sampling procedure showed that the Cu content in all ore transported during one shift (circa 3,000 Mg) was estimated based on composite of about a dozen of small subsamples taken randomly during one shift. The subsample size taken from the belt appeared to be too small considering the maximum particle size on the conveyor. Observation indicated some particles in excess of 250x250x100 mm were possible, which would be 30% of mass contained in a typical 30 kg sample cut. Typically a sample of this size should not contain particles greater than 40 mm. Increasing the sample width even to 1 m would not improve this situation significantly and would probably result in a sample size unrealistic for manual processing. An automatic belt sampler should be considered if physical samples are required.

Taking into account variable size of ore lumps sometimes greater than 30 cm in diameter and possible big variation of Cu content in extracted ore: from 0.7% Cu in sandstone and dolomite (cut-off grade) up to even 15% Cu in rich shale layer indicated that both the sample mass as well as frequency of subsampling can hardly be representative.

Therefore, there is a need to introduce another ways of estimating ore quality (both Cu content as well as composition of ore lithology) what has not been measured till now. A belt analyser (neutron technology) could be considered as on application of special pellets with the ore quality information input into ore streams at their beginning in a DISIRE project.

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