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Analysis of changes in the length of belt sections and the number of splices in the belt loops on conveyors in an underground mine

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A B S T R A C T

Belts and their splices, during operation, perform many cycles around the conveyor. The process of their destruction occurs both at the feeding points and along the conveyor route. Belt destruction at the loading points has rapid and random character related to the impact of falling lumps of the load. In effect, the numerous punctures of the belt and damage to covers, edges and core occur as well as abrasions caused by load acceleration. Damage and wear along the route is related to the process of friction of the belt with the construction, rollers, and load and repeated belt bending on the idlers and drums having fatigue character. The abrasion wear process is cumulative and proportional to the conveyor length. Fatigue processes are proportional to the number of belt cycles (nc). Analyzing belt durability, you can calculate the proportions of the point and linear factors influence on belt and joints durability. In the absence of such data, you can indirectly determine them by analyzing the length of the belt sections in the loops.

Belt splices are the weakest link in the loop forming a serial structure from the reliability point of view. Due to the small size of splices in comparison to the length of the loop, the joints are less prone to punctures, and their durability and reliability is reduced by fatigue processes. Therefore, the belt loop is assembled from the longest possible sections to limit the number of splices in the loop. During operation due to belt damage, their fragments are replaced or shortened, what leads to an increase of their number.

The paper presents a statistical analysis of the length of belt sections and the number of splices in loops and conclusions that flow from it to improve belt loop reliability in the mine and costs of emergency stops.

1. Introduction

A belt loop consisting of belt sections and their splices (Fig. 1), during operation, travel many cycles around the conveyor. The process of their destruction occurs both at the feeding points (chutes) where ore (and any other transported material) fall onto the belt [22] and along the conveyor route [17]. Belt destruction at the loading points has rapid and random character related to the impact of falling lumps of load [2,9,10]. The results are numerous punctures of the belt and damage to covers, edges, core, as well as abrasions caused by load acceleration [15,26–28,31]. Damage and wear along the route are related to the process of friction of the belt against the conveyor structure, the rollers, and the load and of repeated bending of the belt on the idlers and drums. These are fatigue processes [1,14]. The abrasion wear process is cumulative and proportional to the conveyor length [31]. Fatigue processes are proportional to the number of belt cycles (n_c). By analysing belt durability on conveyors having different length [5,21], it is possible to calculate the proportions of point and linear factors which influence the durability of belts and splices (joints) [17,19]. In the absence of such data, it is possible to indirectly determine them by analysing the length of belt sections in the loops. During belt operation worn belt fragments are replaced by new ones [18]. The initial belt section length supplied by belt manufacturer on special reels and mounted inside belt loops is reduced many times due to belt splices and worn out belt fragments replacements, the creation of new joints inside belt sections in place of big failures weakening belt strength in the cross-section. Observations of changes of average belt sections length with time elapse can give indications about a number of belt splices – the weakest chain in belt loops

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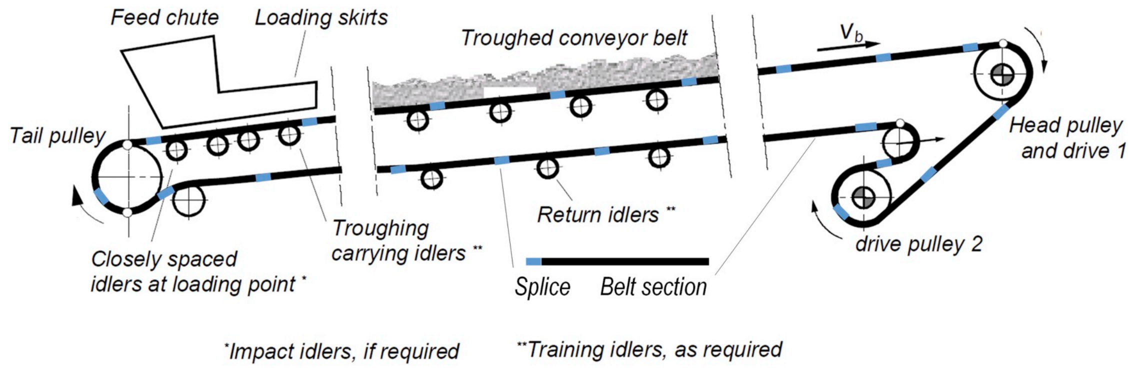

Fig. 1. Scheme of a conveyor with a belt loop consisting of belt sections and their splices [32].

from the reliability point of view.

2. Problem definition

The analysis of changes in the length of belt sections and the number of splices was based on the data collected for belt loops operated on conveyors in the Rudna underground copper ore mine and for belt sections disassembled from the conveyors in the same mine during the period of 2011–2016 [8], as documented in disassembly reports. Over the analyzed period, the mine in question operated 66 conveyors having a total length of 50.4 km. The length of an individual conveyor varied from 29 m to 2106 m. Conveyors are functionally linked at nodal (distribution) points with ore retention bunkers, which play an important role in the continuity of the weft (Fig. 2) [24]. Their capacity varies and ranges from several hundred to 6000 Mg. The total retention is 54,000 Mg (68.5% in shaft bunkers and 31.5% in divisional bunkers)). The annual output of the mine is about 15 million Mg of copper ore so the size of ore retention can cover one day of mining [24].

This solution ensures high reliability of system operation and optimal use of the transport system. The transport system is based on the so-called the "square" of conveyors, which transports ore from individual mining units to production shafts (R-I, R-II and R-III), and then after winning (hoisting) to the surface to the Ore Enrichment Plant. This solution, in contrast to linear systems, ensures a large use of transport capacity of conveyors [24]. Reliability of ore delivery is important due to lack of ore output from the mine can reduce copper production. Therefore, also the reliability of belt loops is a key factor for a mechanical department due to the replacement of splices and belt fragments usually take several hours but can also take several shifts and days. In severe cases, ore bunkers capacity (1 day) can be too small, and the mine can lose its revenue (about $ 3 millions per day). Reversing of ore flow direction on the "square" conveyors (Fig. 2) [24] is therefore crucial to avoid such losses. Nevertheless, too many splices in belt loops is a threat to continuous ore delivery.

Such type of mines utilises the room-and-pillar system, in which ore is extracted from the mined height of the deposit by blasting operations in many mining faces and then transported to the division conveyors. Loaders and haulage trucks (up to 50 Mg capacity) feed the ore to the so-called screens having 20 or 24 apertures sized 450 × 450 mm. Oversize ore lumps, which do not pass through the screen, are further crushed with hydraulic hammers [29]. Sharp-edged lumps of ore, sometimes having a section area up to 45 × 45 cm and a length of as much as 1 m, fall on the belt and cause extensive damage and belt cuts [23,28].

As ore accelerates on the belt to the speed of 2.5 m/s (v_b), abrasion of covers occurs [15]. The ore from the mining divisions is fed to main haulage conveyors, which transport it to the shafts. On its way, the ore may be temporarily stored in retention and shaft bunkers, which serve to ensure continuous operation of the horizontal and vertical transportation systems. The mixing of ore from many sources (from different divisions and mining fields) over time (due to ore retention in the bunkers) renders tracing its composition difficult [16], as individual lithological types form different-size lumps, from sand-size grains to large rocks of various density and edge sharpness, which pass through the apertures in the screen. Belt wear (abrasion on the covers and edges, fatigue processes in the core and the splices as the belt is frequently bent along the conveyor route) and the damage done to the belt at the feed points are lengthy processes, in which many factors overlap. Some of these factors result from the effects which accumulated over many years of operation, and some other factors have a more violent and rapid character, being difficult to predict.

A closed belt loop comprises belt sections delivered by manufacturers on special reels, each having a straight belt section. The reels are delivered to the site in which the conveyor is operated and where the sections are connected using adhesive or vulcanised splices. Depending on the length of the conveyor and of the belt sections, the loop may comprise one or many sections, sometimes as many as several tens of them. Users prefer the number of sections and splices to be possibly small, as splices are the weakest link in a serial arrangement formed by the loop, the conveyors and their routes considered from the perspective of their reliability. In open-cast mining, some manufacturers offer single sections having lengths of several hundred meters, reeled on specially designed reels (e.g. the PHOENIX firm has supplied to the Collahuasi mine, a PHOENOCORD® St 630, the heaviest conveyor belt, in the longest roll lengths ever produced 415 m. The belt reels were 5.2 m long, 4.2 m high and weighed 58 tons) [25]. In underground mining, the length of belt sections is limited by the dimensions of the excavations (e.g. of the shaft) which limit the size of the reels used for belt transportation. The longer and the stronger the belt, the higher the size of the reel. In the analyzed mine, the lengths of the delivered

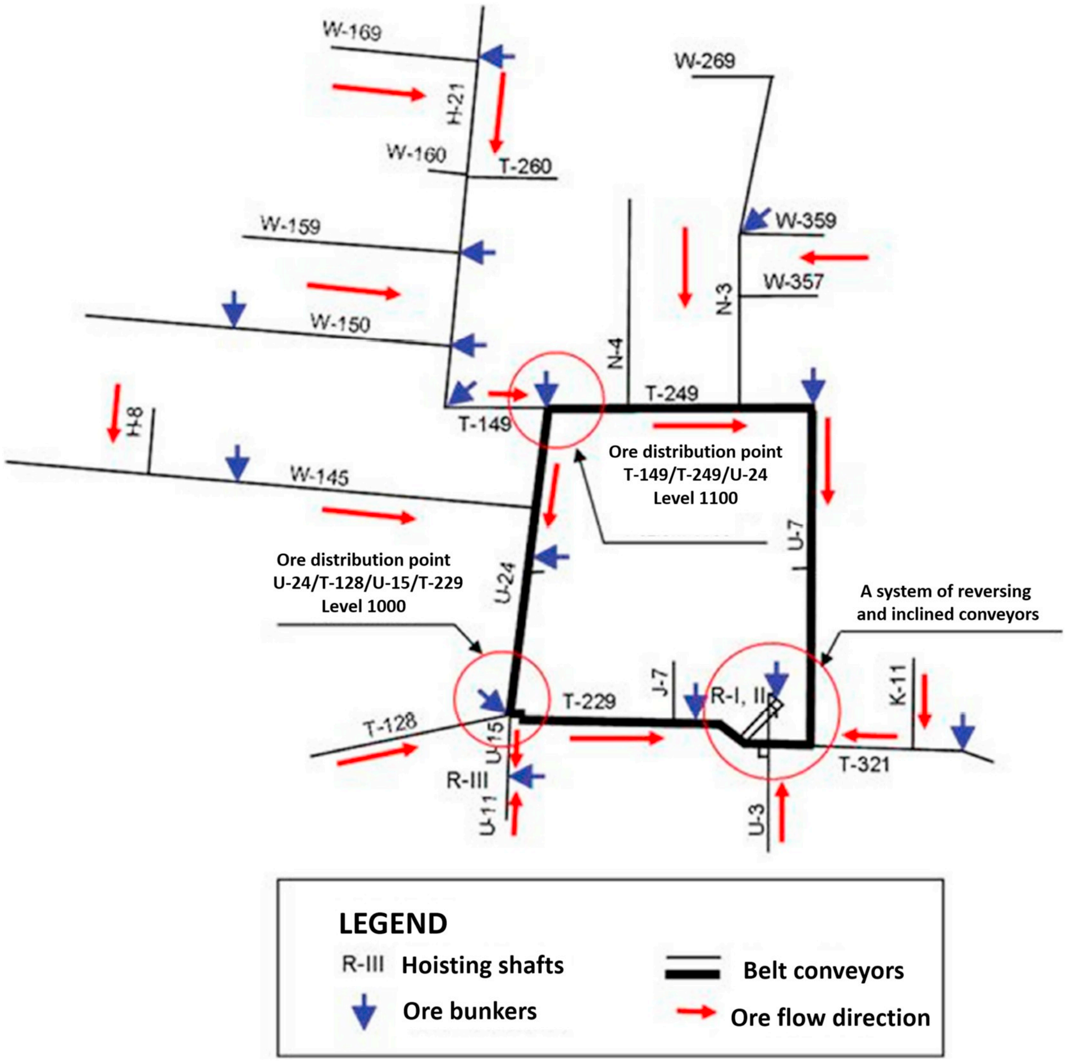

Fig. 2. The schema of the „Rudna" copper mine conveyor system (over the area of 78 km^2). Bold lines represent the "square" of conveyors ensuring reliable operation of the belt transporting system [24].

belt sections were 100 m, 250 m and 200 m. One belt section was 250 m in length.

After the belt sections are spliced to form a closed loop, the belt is tensioned and put to motion due to frictional contact. The reinforced belt core transfers longitudinal stresses. The drive mechanism is responsible for transporting ore and for overcoming the resistance to motion. It is related to the rotation of pulleys and idlers, the indentation of pulleys and idlers in belt covers and flexure resistance. Ore is loaded on the belt from feeding hoppers and transported on the belt, whose trough-shape is achieved by a specific arrangement of idlers which support the belt on the conveyor. In order to protect it from the damage caused by the transported material, the belt core is covered with a layer of rubber, which forms the carrying cover. Sometimes protecting breakers are inserted into the cover for better protection. The cover is resistant to abrasion and puncture. On the idler side, the core is protected by the bottom cover, which provides sufficient friction to enable belt movement. Much effort has been recently invested to design a pulley cover, which absorbs little energy, as much of this energy is then wasted (by rolling and friction resistances).

The energy provided by the drive mechanism and ore falling on the belt results in belt abrasion and the destruction of the covers, the core and the splices. The most significant defects and splices prone to failure are replaced with new belt sections or the belt section is shortened by introducing a splice in place of the damaged part. As a result, the number of sections and splices in the loop increases over time, and so does the risk of the conveyor being taken offline due to belt failure [3,30].

2.1. Analyzed data

The data regarding belts installed and disassembled in an underground copper ore mine were used to prepare analysis [8]. The paper attempts to describe how belt ageing processes and the need to replace or repair worn belt fragments influence the decrease of

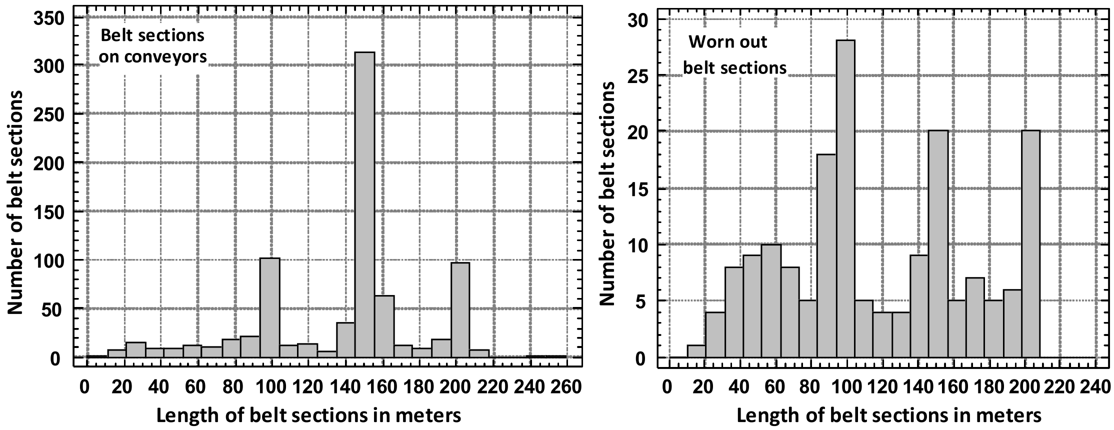

Fig. 3. Histogram of belt section lengths in loops operated on the conveyors and of belt sections disassembled between 2011 and 2016.

mean belt section lengths, the increase of the number of belt sections and splices, and the resulting decrease of the system's reliability.

The research also focused on how the increasing length of conveyors in the system affects the life of conveyor belts and how it translates into increased section lengths in the loops. The most recent results are shown against prior theoretical considerations the results of research performed in the same mine in the 1980s and at the turn of the century.

The analysis was based on the data regarding the length of all belt sections in the loops installed and operated in 2016 in the "Rudna" underground copper ore mine, as well as on the data regarding the distribution of the lengths of belt sections disassembled from the conveyors in the mine between 2011 and 2016 (Fig. 3).

A total number of 790 belt sections were operated on the conveyors. The lengths of the sections varied from 10 to 255 m. The disassembled sections included 176 sections from 19 to 200 m in length. Very short belt sections typically indicate a failure which needed to be repaired in a possibly short time. In such cases, instead of adequately replacing the worn belt section into a new one, the section is shortened by introducing a splice in the damaged location [3]. Belt shortening is possible if the belt tensioning system has sufficient belt surplus, and a new belt section is unavailable. If the damage is located near the edge of the belt section, such makeshift measures lead to dividing the old section into two parts of unequal length. One such part was only 10 m in length. When analysing the histogram of belt section lengths, it is possible to notice 3 indicated section lengths which occur more frequently than other lengths. The occurrence frequencies for belt sections of different lengths are represented in 20-m classes. In the case of lengths different than original (100, 150, 200 m) all other length classes are equally represented by 10–20 sections. Except for the original length sections (100, 150, 200 m), slightly shorter sections dominated. They were formed from original sections and resulted from several splice replacements.

The installed belts had a total length of 110,283.50 m and mean belt length was 139.60 m. During the analyzed period, 20,635 m of the belt was disassembled and mean section length was 117.24 m.

The distribution of the lengths of belt sections operated on and disassembled from the conveyors is compared in the graphs (Fig. 3). As it can be observed, some belt section lengths prevail. These lengths include 100 m, 150 m and 200 m. One belt section 255 m in length was identified. However, it was probably the result of a mistake, as a reel containing a belt of such length would not lend itself to transportation via the shaft. The most likely explanation is that a splice was not identified between a 100 m section and a 150 m section. The expected result was to observe that belt sections operated on the conveyors had original lengths. This is because belt joints, especially adhesive and mechanical joints, demonstrate lower durability than the belt itself and therefore belt users intentionally form the belt loop of possibly longest sections. The length of the original sections (as in the specification +/− 2 m) should be identical to the length on the reel with accuracy down to splice length, which has such a length. Therefore, the sections classified as original had original length +/− 2 m. The change in this value significantly affects the number and length of the original sections (Fig. 4).

Interestingly, the disassembled belts also include sections which have an original length within the boundary range. This fact implies that some belt sections were operated since installation without being shortened by more than 2 m and then were disassembled as a whole, from splice to splice. Such original length sections accounted for 32.39%, i.e. ca. $^{1}/_{3}$. Significantly more such sections were operated on the conveyors (57.01%). If original lengths of belt sections were assumed to be only exactly 100 m, 150 m and 200 m, their share would be significantly smaller, at 32.11%, and only at 23.3% of the disassembled sections (Fig. 4).

Also, it is important that the 150 m sections account for the majority of belts installed on the conveyors – their number is 256 for the +/− 2 m range, i.e. 61% of all original length sections. Apparently, at the time when this research was performed, sections of this length dominated. Such domination is not observed in the case of the disassembled sections – the number of original length sections was comparable in all groups. The 200 m sections prevail (38.6%), followed by the 150 m sections (33.3%), with the smallest number of the 100 m sections (28.1%). However, the differences are not significant, being only 3 sections (22, 19 and 16 belt sections, respectively). The distribution histogram of disassembled sections (Fig. 1) may seem not to confirm this observation, as it indicates that the 100 m and 90 m sections dominate. However, it indicates that such sections were most frequently installed, but splices had to

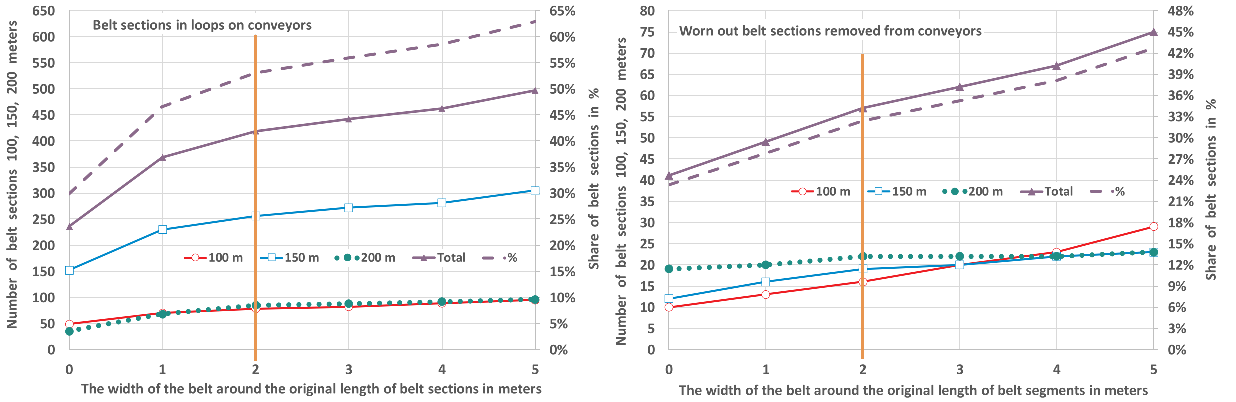

Fig. 4. Changes in the number of belt sections having original length and in their % share in the total number of sections depending on the width of the boundary range.

be replaced, as there was a similar number of them in the original length for disassembly as other original lengths. The existence of a great number of sections slightly shorter than 98 m (dominating class of 100 m and 90 m sections) indicates that splices had a significantly shorter life than the life of the belt. The disassembly of a 90 m section means that it was shortened five times by ca. 2 m in order to replace splices at its ends. Of course, a possibility exists that during the operation of a 200 m section it was divided into two parts (110 m and 90 m) with a splice, or that the 60 m worn fragment shortened a section having the original length of 150 m. Unfortunately, such questions cannot be answered without tracing individual histories of each of belt sections. Mines do not have a computer database of disassembled belts and splices, and the disassembly procedure is only recorded in paper reports. Tracing the individual histories of all belt sections and splices would require a tremendous amount of work, and there is not enough time to do it in common mining operations. However, it may be attempted to draw indirect conclusions based on random investigations being part of research and diploma works [8].

2.2. *Estimated changes of average belt section length and number of splices*

Of the installed belt sections, 78 were 100 m in length, accounting for ca. 9.87% of the number of sections not subjected to modification and ca. 12.29% of the length of these belts. Belts were classified as not subjected to modifications if they were 98–102 m in length. A total number of 256 belt sections were 150 m (148–152 m) in length, and they accounted for 32.41% of the number of sections not subjected to modifications and ca. 60.52% of the length of these belts. 85 belt sections were 200 m (198–202 m) in length were identified, accounting for 10.76% of the number of sections and ca. 26.79% of the length of these sections. Only 1 section was 255 m in length, accounting for 0.4% of the length of belts not subjected to modifications. Thus, based on an assumption that original sections had lengths in the same proportions, mean length of original section was 157.67 m (=12.29%*100 m + 60.52%* 150 m + 26.79% * 200 m + 0.4%*255 m). These sections remained in operation for a significantly shorter period, with (length) weighted mean life of 54.2 months, as compared to 70.92 months for all installed belts.

Estimations of mean original section length in new belts, in installed belts and disassembled belts may demonstrate how mean section length changes with time (Fig. 5). Upon installation, mean section length was 157.7 m (according to the preserved proportions of the share of original sections in the total length of installed belts). Mean length of all installed sections was 139.6 m, and their age was 70.9 months. Mean length of all disassembled belts between 2011 and 2016 (as documented in disassembly reports) is 119.0 m, and their age is 117.24 months.

The presented estimations are based on the analysis of the length and age of both the installed and disassembled sections. Instead of the estimated, actual changes could be presented on the basis of current condition records from the mine. Unfortunately, mines usually do not keep such records, and even if they occasionally perform such analyses, they do not reveal either the results or the conclusions. The estimations must, therefore, be done using the data available from random belt condition analyses performed in the mine and from historical data related to disassembled belts and prepared for other purposes.

3. The influence of conveyor length on belt durability

Belt durability can be estimated on from the energy used for belt wear and degradation caused by fallen lumps of ore or other transported material. In the energy model of belt wear, developed by prof. T. Zur [33], wear factors were divided into „linear" – placed along the conveyor's route, e.g. rubbing against the rollers and the side frame, etc. (proportional to belt travel distance) and „local" – in particular locations on the conveyor such as: the feed, the cleaning devices, the drive, etc. (proportional to number of belt cycles). Assuming that the sum of "local" damage is proportional to the number of runs of the belt loop around the conveyor (cycles around a conveyor) and the sum of "linear" damage is proportional to the distance covered by a specified cross-section of the belt, he proposed the following formula for belt durability measured over total belt operating time t_t and transformed by Jurdziak [17] into

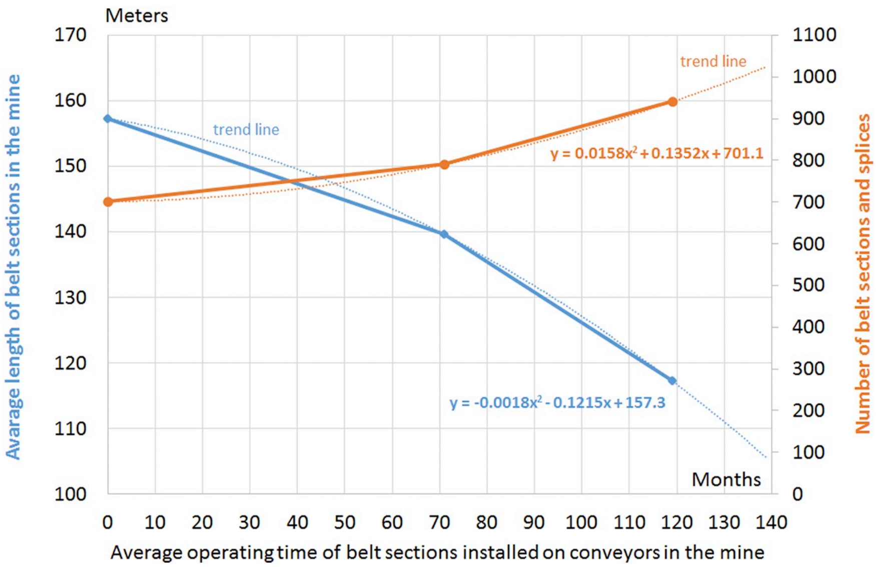

Fig. 5. Changes in the mean length of belt sections in the mine and the consequences for the increase in the number of sections and splices.

total belt cycles n_c till belt damage or wear:

$$n_c(L_l) = \frac{A_t}{\sum_{p=1}^{P} A_p + L_l A_l} \quad n_c(L_l) = \frac{1}{\frac{\sum_{p=1}^{P} A_p}{A_t} + L_l \frac{A_l}{A_t}} \tag{1}$$

$$n_c(L_l) = \frac{T_t}{t_c} = \frac{T_t}{L_l/v} \tag{2}$$

$$T_t(L_l) = n_c \frac{L_l}{v} = \frac{A_t L_l}{v\left(\sum_{p=1}^{P} A_p + L_l A_l\right)} = \frac{L_l}{v\frac{\sum_{p=1}^{P} A_p}{A_t} + v\frac{A_l}{A_t} L_l} = \frac{L_l}{va_p + vb_l L_l} = \frac{1}{vb_l + \frac{va_p}{L_l}} \tag{3}$$

where:

n_c total number of belt cycles during belt operation till it is damage or wear,
L_l the length of the belt loop (m),
A_t total work required for belt wear (J),
A_p unit work generated by particular point wear factor during 1 belt cycle (J),
P the number of point (local) wear factors,
A_l unit work of linear wear factors generated for 1 m of belt during one cycle (J/m),
T_c total time of belt operation till it's wear or damage (s),
t_c duration of one belt loop cycle around a conveyor (s),
L_l the length of the belt loop (m),
L_l belt loop length (m), $L_l \approx 2\ L_p$, where L_p is the length of belt conveyor,
v belt speed (m/s),
a_p, b_l point and linear coefficients of the double reciprocal model.

Belt durability, measured by the number of cycles n_c, was thus expressed as a function of belt loop length and coefficients specifying the shares of "point" damage work and "linear" damage work in the wear of the belt loop per its one cycle around the conveyor.

The relationships were verified and the two coefficients were calculated on the basis of operating data. Results obtained at the beginning of the new century from the same mine in which tests had been performed in 1988 (Fig. 6) have proven that even significant increases of belt durability (roughly of about 60%) have not changed the character of their influence on belt wear [19].

The influence of conveyor length on belt life was analyzed for the most recent data on the belts disassembled between 2011 and 2016.

Regardless of the reason for disassembly, the regression model (2) selected in Statgraphics Centurion v.18 did not provide good correlation (R^2 = 35.61%, R^2 adjusted for d.f. = 35.21%) for the data, as the dispersion of values was significant irrespective of conveyor length (Fig. 7). The range for the 95% prediction limits is vast, and still, seven sections fall below the lower limit.

$$T_t = (0.399027 + 1.47222\ \ln(L_p))^2 \tag{4}$$

The fitting of the model improves significantly when it includes only belts disassembled due to cover wear (120 sections). It was

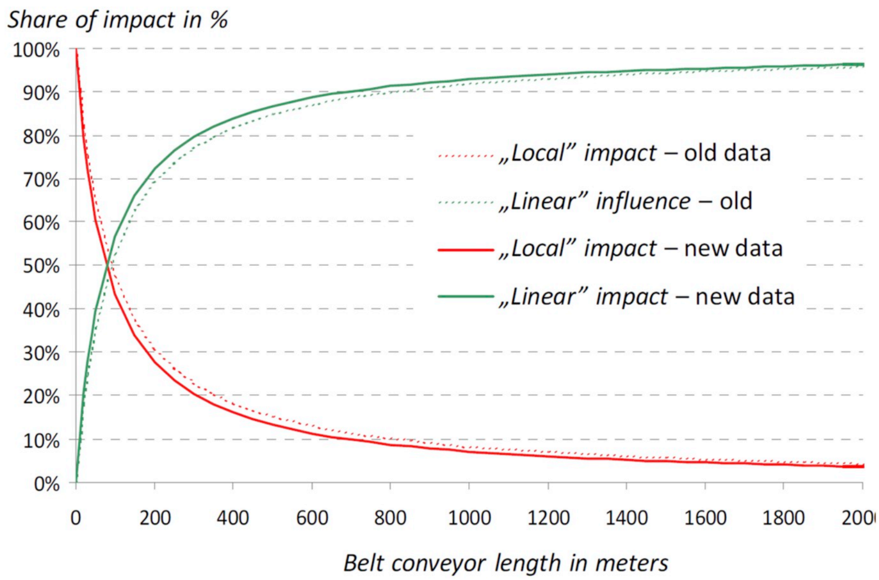

Fig. 6. Variation of the percentage contribution of "local" and "linear" damaging agents (wear factors) in the conveyor belt wear process as a function of conveyor length [19].

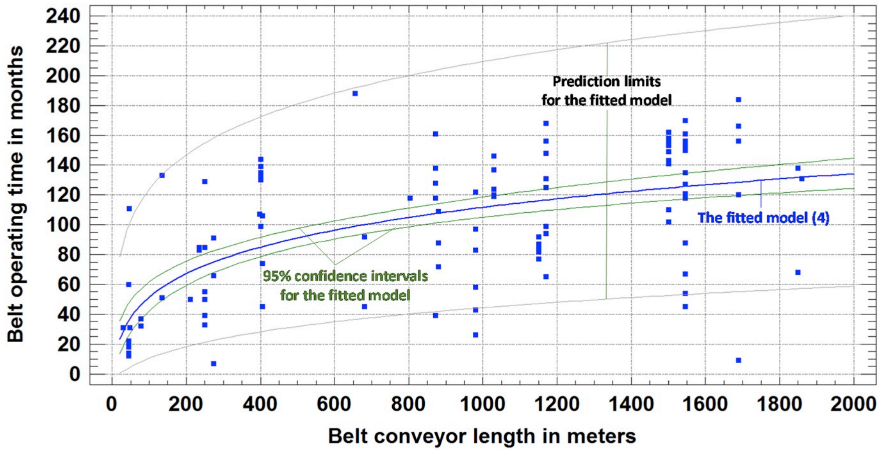

Fig. 7. The plot of fitted model (4) to describe the relationship between belt operating time and conveyor length.

found that in the case of belts subjected to natural wear processes, the fitting of the model measured with the R^2 indicator is higher than previously ($R^2 = 69.1\%$, R^2 adjusted for d.f. $= 68.8\%$). Besides, Eq. (3) has importance from the physical point of view, as the double reciprocal model (5) may be transformed into (3), which describes the relationship between belt durability and the energy related to belt wear processes occurring locally and along the belt conveyor route (1).

$$T_t = \frac{1}{0.00689091 + \frac{1.8109}{L_p}} \tag{5}$$

The ANOVA variance analysis was performed for 120 registered operating times of belt sections disassembled due to belt cover

Table 1
Coefficients.

	Least squares	Standard	T	
Parameter	Estimate	Error	Statistic	P-Value
Intercept	0.00689091	0.00067803	10.1631	0.0000
Slope	1.8109	0.111578	16.2299	0.0000

Table 2
Analysis of variance.

Source	Sum of squares	Df	Mean square	F-ratio	P-value
Model	0.0112687	1	0.0112687	263.41	0.0000
Residual	0.00504804	118	0.00004278		
Total (Corr.)	0.0163167	119			

wear. The results are shown in Tables 1 and 2.

Since the P-value in the ANOVA table is less than 0.05, there is a statistically significant relationship between belt operating time and belt conveyor lengths at the 95.0% confidence level.

The R^2 statistic indicates that the model as fitted explains 69.1% of the variability in belt operating time. The correlation coefficient equals 0.831, indicating a moderately strong relationship between the variables. The standard error of the estimate shows the standard deviation of the residuals to be 0.00654064. The mean absolute error (MAE) of 0.00341142 is the average value of the residuals. The Durbin-Watson statistic (DW = 2.15341, P = .7985) tests the residuals to determine if there is any significant correlation based on the order in which they occur in the analyzed data file. Since the P-value is greater than 0.05, there is no indication of serial autocorrelation in the residuals at the 95.0% confidence level. Lag 1 residual autocorrelation = −0.0789624.

Fig. 9 shows the changing relationship of belt operating time in the “Rudna” copper ore mines over a significant period. The first results were obtained in the 1980s, the next results – at the beginning of this century and the most recent results come from the 2011–2016 period. As can be seen, belt durability increases and the character of the relationship due to the distribution of point and linear factors remains constant.

An attempt was also made to verify whether a relationship exists between the durability of sections subjected to natural wear (disassembled due to cover wear), the length of conveyors and the length of the disassembled sections. The results showed no significant correlations. The only confirmed relatively strong correlation was observed between the operating time of belt sections and the belt conveyor length. The significant Pearson Product-Moment Correlation is 0.68 (Fig. 10). The correlation coefficient for all sections was smaller (0.53). The relatively strong correlation (0.68) shows that we can try to find the best model to fit the data. It has been already done by fitting a double reciprocal model (5) to data about worn out belt sections (Fig. 8). The advantage of this model is that it is not only the best from a statistical point of view, but it also has the theoretical background linking the total belt durability T_t with the length of the conveyor L_p (=0.5 L_l) on which the belt loop was operated by the formula 3.

The collected data also indicate that the length of the belt conveyor does not affect the length differences between the disassembled sections. This means that there are no differences between the length of belt sections disassembled from short and long conveyors. The belt maintenance regulations used in the mine (regarding belt repairs and replacements) does not differentiate belt services according to the length of conveyors. All failures of belt sections are treated in the same way. The only difference which can be observed is the slower degradation process of belt sections operating on long conveyors. So with the increase of conveyors length, the rate of new failures is a bit slower. So belt sections operating on long conveyors attain the same lousy condition qualifying them for replacements but later than on short conveyors and this process can be described by the double reciprocal model (3 and 5).

4. Conclusions

The identified decrease of mean belt section length observed as a result of belt operation, and the forecast of future changes based on the analysis of the lengths of disassembled sections are both estimated values based on selected trend line. They demonstrate the

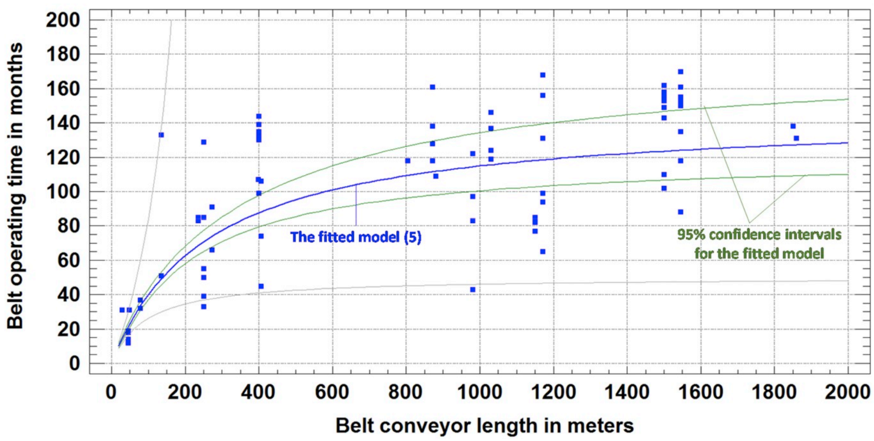

Fig. 8. The plot of fitted model (5) to describe the relationship between belt operating time and conveyor length for belt sections disassembled due to the wear of the covers.

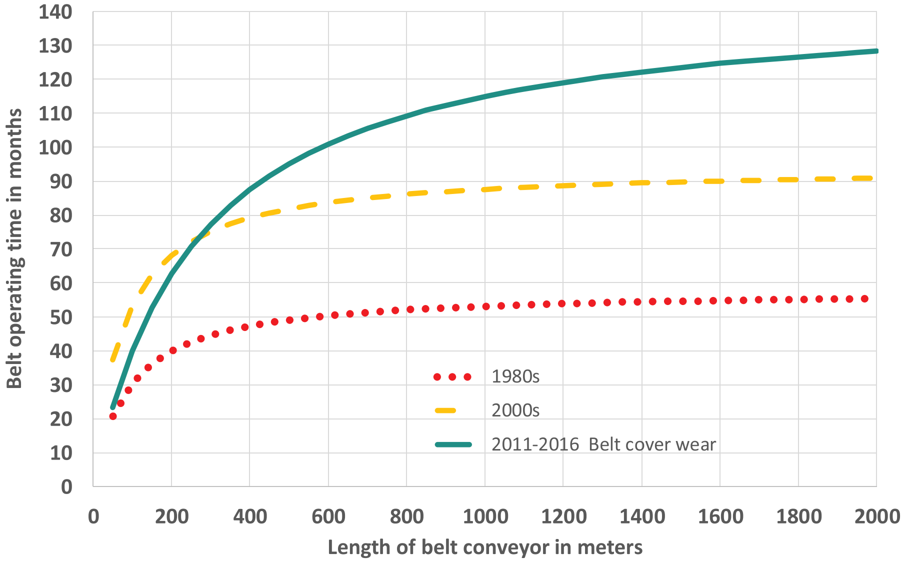

Fig. 9. Comparison of the results from different periods (the 1980s and 2010s).

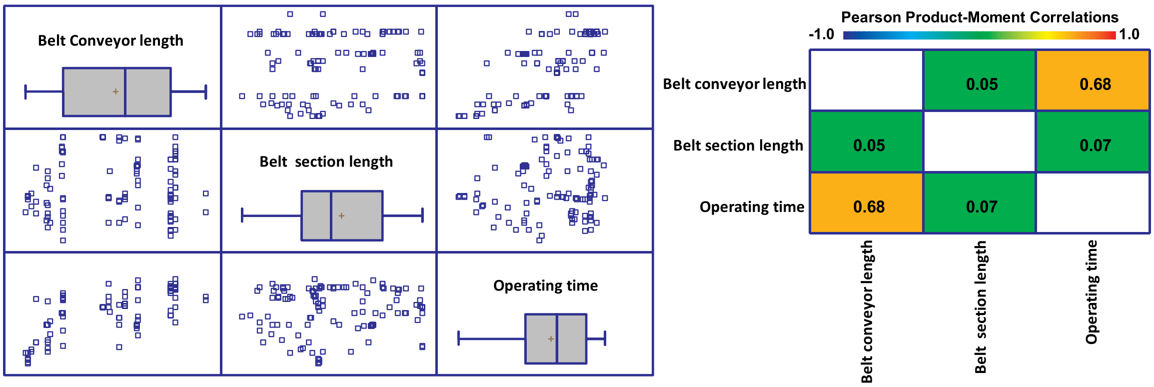

Fig. 10. Multiple variable analysis for belt conveyor length, belt section length and belt operating time, Box and whiskers and scatter plots plus Pearson Product-Moment Correlations Matrix for belts sections disassembled due to worn belt covers.

rate of the expected changes.

Decreasing length of belt sections in the loop entails an increase in the number of sections and splices on individual conveyors and the mine as a whole. The result is decreasing the reliability of the transportation system, which leads to increased operating costs and more frequent emergency downtimes, and significant financial losses due to decreased production [3]. The mines still fail to provide sufficient data on the transportation system's downtimes and the related costs. However, the growing risk can be estimated indirectly by forecasting the growth in the number of splices accompanying belt wear processes. The belt loop is a serial system from the reliability point of view, and any additional splice decreases the reliability of the whole belt due to splice durability is much lower than belt durability and so the risk of downtimes [4].

The growth of mean belt section age from 0 to 71 months (mean belt age installed in the mine during the measurements) resulted in the growth of the number of sections and splices (concerning the estimated original number) by 89, i.e. by 12.7%. If mean belt age reached the age of the disassembled belts (119 months), the number of splices and sections would increase to 940 – a further growth by 150 (19%) concerning the condition in 2016 and by 240 (34%) with the original condition.

As splices are replaced more frequently than the belt [4], the maintenance costs of the transportation system would increase even more than by 13% and a further 19% (34%).

This tendency may be counteracted by implementing a proper policy for replacing the belt in the loop. Instead of increasing the number of sections and splices by introducing fragments of new belts in the middle and leaving two fragments of used belts on both sides, users may replace complete belt sections or their fragments from the splice to the damaged location. The resulting decrease of belt reliability is thus smaller, but such a policy entails increased costs. The mines place so much stress on resuming production as quickly as possible that instead of vulcanised or adhesive splices, mechanical joints are used, which can be made more quickly, and new belts are inserted only in the areas of defects, without considering the consequences of such actions.

More detail study is required in order to estimate losses caused by emergency stops. As it is seen downtimes caused by belt failures (average duration of 70.71 min) usually can be solved within 1 shift. However, it is possible to have stoppages longer – up to 10 h. Repairs of belt splices have 2 times higher frequency as belt failures and require more minutes to come back to operation (average duration 93.9 min). Taking into account that splices durability is smaller than belt durability, more attention is required to analyse the main causes and economic consequence of splices malfunctioning.

Reliability of large quantities of material supply is more and more critical in times of the growing number of mass production and transportation in mines, harbours, bulk terminals, chemical and metallurgy plants. This paper aims to demonstrate the result of such decisions for the increase in the number of sections and splices and the decrease of reliability.

The growing risk caused by increasing belt age and a higher number of splices may be limited by introducing belt and splice diagnostics [6,11–13]. Mines start to notice the advantages of such solutions [4,7,20].

The analysis of the data on the disassembled belt sections also allowed determining the influence of conveyor length on the increase in conveyor belt operating time until disassembly [17]. It was confirmed that an increase in the conveyor length translates into slower belt degradation (increased belt durability). The observed changes are well described by the derived equations linking belt durability to conveyor length by establishing a relationship between the work needed for belt wear and the energy transmitted to the belt in various locations and along its length [33]. A higher fitting degree was observed for belts subjected to natural wear processes than for the whole population of the disassembled belts.

The length of the belt conveyor has not been found to affect the length differences between the disassembled sections. This fact indirectly confirms the uniform policy of belt repairs and replacement, irrespective of conveyor length. Only in the case of long conveyors, the belt section is disassembled later and allows identifying a functional relationship between mean belt durability and conveyor length. Importantly, the selected empirical models are following the relationships derived theoretically.

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