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Estimation of Purchase and Replacement Costs of Conveyor Belts and their Splices in an Underground Mine Based on their Durability

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Abstract. A cost model for the purchase and replacement of conveyor belts using the average durability of belts and splices of various types (including adhesive and vulcanized splices) was developed for a hypothetical underground mine which uses continuous belt transport. Variant cost models of belt maintenance were developed for the given belt purchase prices and costs of splicing belt segments in the loop. The investigations focused on how the total costs of belting are influenced by various factors, including: belt prices, splicing costs, durability of belts and their joints, type of splicing, time and costs of planned and emergency belt replacements. The analyzes were performed without taking into account random differences in durability, and therefore the confidence interval for total costs for the given confidence level was not presented. The calculations were based on data obtained from users. They were not preceded by any statistical analyzes of actual operating times for either belts or splices. The results are therefore of qualitative rather than quantitative nature. Nevertheless, they should accurately reflect the level of costs and the impact of the analyzed factors on its changes.

1. Introduction - Aim and basis of the research

The purpose of this research is to examine how different costs of vulcanized and adhesive splices and their different durabilities affect the costs of belting in an underground mine. The belting costs were assumed to include all costs related to the purchase and replacement of belts and to assembling vulcanized and adhesive splices. This analysis does not include mechanical connections. They have been excluded due to their temporary character and comparatively short durability, which has not been reliably tested in a comparative study.

The analysis was based on several assumptions regarding the hypothetical mine in question. Firstly, the analyzed mine was assumed to have 10 km of installed belts, i.e. the conveyors have a length of approximately 5 km. Secondly, mean length of an individual segment in the loop was assumed to be 100 m. This assumption determines the number of splices. With time, as the belt is operated and subjected to wearing processes and defects, the damaged fragments are replaced by a service crew. This process leads to increased number of segments and splices. The locations in which new belt is inserted determine the number of segments and splices. If the replaced fragment is located at an end of the belt segment and the new splice is inserted in place of the old splice, only 1 new segment and only 1 new splice are formed. If, however, the replaced fragment is inserted in the middle of a belt segment, 2 new splices are formed, and the number of segments grows to 3 (instead of one). The method of belt fragment replacement (minimum length of the inserted belt and splicing method) remain of importance for the reliability of the belt loop [1, 2]. However, the issue of reliability remains beyond the scope of this analysis and the increasing number of segments will be allowed for by investigating the influence of the length of mean belt segment on the costs of belt replacement and splicing. Evidently, replacements of belt segments lead to an increase in the number of splices, a decrease in the mean segment length and also to increased costs, as will be demonstrated later. However, the calculations will not include potential losses related to emergency downtimes and lowered production caused by increased belt loop failure rate due to the growing number of unreliable splices. The strength of adhesive joints is analyzed as part of a research grant in which various parameters of belts and adhesive rubber are tested for their influence on splice strength [3, 4, 5].

The purchase costs of textile belts were assumed at 300 pln/rm. (69 EUR/rm), the costs of vulcanized joints – at 2 800 pln (643.7 EUR), and the costs of adhesive splices – 1 800 pln (413.8 EUR). Mean belt life was assumed to be 3 years. The same life was assumed for vulcanized joints, as they reach 100% of belt strength. The above fact means that vulcanized joints are replaced only when the belt is replaced and no need exists to replace them due to their deteriorated condition. With 100 splices and their life not shorter than 3 years, approximately 34 vulcanized joints will be replaced every year (34≈100/3).

Adhesive joints in textile belts were assumed to have lower strength (up to 60% of belt strength) and therefore their life was assumed to be 1 year. This means that every year 100 splices will be replaced (100=100/1), and this number corresponds to the total number of splices in the mine.

The analysis allowed for additional downtime costs, although at a different level than the level accepted in the United States [6]. The financial losses that American underground hard coal mines incur due to downtime caused by belt failures are estimated at $ 240 000, i.e. approx. $ 1 000 per minute, as mean repair time was 4 hours. Losses of this scale, which occurred due to emergency downtimes in the period of increased coal demand, were the reason behind developing a machine vision system which monitors splice and belt condition and which prevents failure [7].

The scale of downtime costs and the related losses are difficult to be estimated, as they depend on the location of the defective conveyor. Downtimes on main haulage conveyors will always generate greater losses than the division conveyors. Scheduled replacements may generate no losses, as they are performed during non-production periods (e.g. weekends or non-production shifts). Emergency downtimes may be related not only to production losses (production stopped during the downtime) which cannot be compensated as the mine already uses its full production capacities, but also to the costs of eliminating the consequences of the failure, e.g. removal of the spilled material, repairs of the damaged route, replacement of damaged belt. Emergency downtime may be prevented through belt diagnostics and application of devices which prevent the damage from developing [8, 9]. Due to insufficient data on the number of emergency downtimes in Polish mines, an assumption was made that the analyses focus only on additional downtime costs related to each splice replacement. Their level was analyzed from 0 pln to 20 000 pln (0 - 4598 EUR) per one replacement, and the readers will be able to choose a number which corresponds to their individual conditions.

Additional downtime costs have been considered in two variants. In the first variant, both strategies – the vulcanization method and the adhesive splice method (cold vulcanization) – are equally time-consuming and generate identical additional downtime costs. In the second variant, the time required to assemble an adhesive splice is three times shorter and therefore the costs are three times lower.

The costs related to the downtime of a conveyor may be treated as costs related to the replacement of belts and splices which are covered by the mine. Splices are typically assembled by external companies which specialize in belt maintenance. However, the mine still bears own costs related to belt maintenance, such as the costs of additional and preparatory activities (e.g. turning the belt loop in such a manner that the splice is in a location judged convenient for repairs, clearing the route, supervising the splicing procedure) or the costs of acceptance inspection. Additional personnel and equipment must by assigned to such jobs and thus they generate costs.

2. Estimations of belting costs

Calculations based on the above assumptions demonstrated that in the case of both strategies the replacement costs for belts and splices exceed 1 000 000 pln (229 885 EUR per 10 km of installed belts). The annual costs of vulcanized splices are 94 700 pln (21 779 EUR) lower than the costs of adhesive splices. The cost of vulcanized splices is 1 100 000 pln (252 874 EUR), while the cost of adhesive splices is 1 195 000 pln (274 712.6 EUR).

Belt replacements account for the greatest part of these costs (90.88% and 83.66%, respectively). The annual cost of vulcanized joints was 95 200 pln (21 885 EUR), which accounted for 8.65% of the total costs. The annual cost of adhesive splices was 180 000 pln, (41 379.3 EUR) and accounted for 15.06% of the total costs. The costs additionally included belt losses due to splice assembly. 1 m of belt was assumed to be lost for each splice. The share of these costs was 0.46% (5 100 pln, 1 172.2 EUR) in vulcanized splices and 1.26% (15 000 pln, 3 448.3 EUR) in adhesive splices (Figure 1).

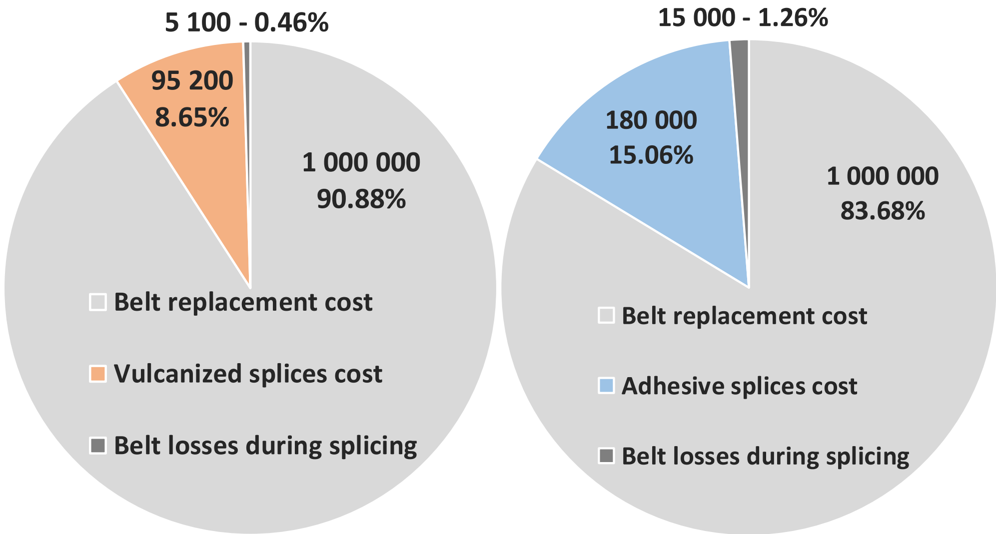

Figure 1. Share of component costs in belt and splice replacement costs

3. Influence of mean segment lengths (number of splices) on belting costs

A sensitivity analysis was performed in order to assess the influence of changed baseline parameters on the belting costs. One of the baseline parameters was mean belt segment length in the mine, equal to 100 m. This length determines the number of splices, and with given splice life – also the number of replaced splices and the resulting costs. The influence of this parameter is shown in Figure 2. The points in the graph correspond to the calculated costs, and the dotted/dashed lines correspond to selected trend lines (4^{th} degree polynomial function).

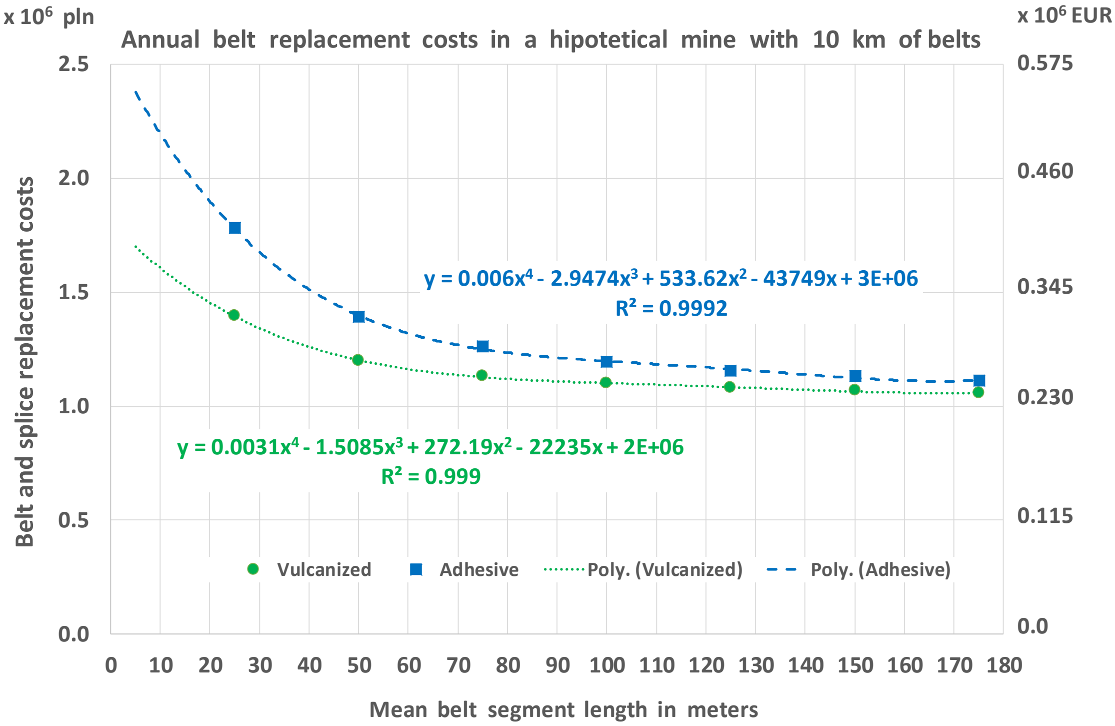

Figure 2. Impact of mean belt segment length in a mine on belt and splice replacement costs

As can be seen, this influence is not significant: in the case of twice shorter segments (twice the number of splices), the cost for vulcanized splices increased by approximately 97 350 pln (22 379.3 EUR), and for adhesive splices – by 195 000 pln (44 827.6 EUR). The percentage increases were respectively: 8.85% for vulcanized splices and 16.32% for adhesive splices. Savings due to increased segment lengths are even smaller. An increase of the segment length to 150 m would affect savings of approx. 3% for vulcanized splices and 5.44% for adhesive splices. The limited scale of savings is related to the fact that the costs of new belt are the most significant cost component, and the cost of splices remains within 8-15%. Doubling the number of splices entails doubled splicing costs in absolute terms, although in percentage terms this is still a small component of the total costs. However, the analysis did not include the costs of emergency downtimes, which depend on the reliability of the belt loop. This reliability decreases with the growing number of adhesive splices, whose reliability is reduced in comparison with the reliability of vulcanized joints.

4. Influence of belt durability changes on belting costs

Belt price was another factor mentioned by users and suppliers in their questionnaires. The investigations also covered the influence of changes in adhesive splice durability on the change of total annual costs of belt and splice replacements (Figure 3). An increase in adhesive splice life from 12 months to 18 months has been found to practically equalize the total costs in both strategies.

Unfortunately, increased competition in the market of belt maintenance and splicing services causes the cost of adhesive splice covers only the marginal cost of its assembly. Splice durability cannot be expected to grow when the earnings of workers who assemble splices decrease. Low salaries translate into high rotation of workers and their resulting lack of experience. Additionally, mine management insists on limiting the lengths of belt downtimes, and haste affects the expected belt durability. It is worth considering whether the price of splicing procedures should be related in the tenders to the warranty period on splice quality, as in the case of belt tenders. Splices which are slightly more expensive but are assembled with higher care and by more experienced workers may show greater durability. Higher price will be in such case compensated to the user by savings due to increased splice life (Figure 5) or by avoiding extra costs due to warranty repairs if belt life targets are not met.

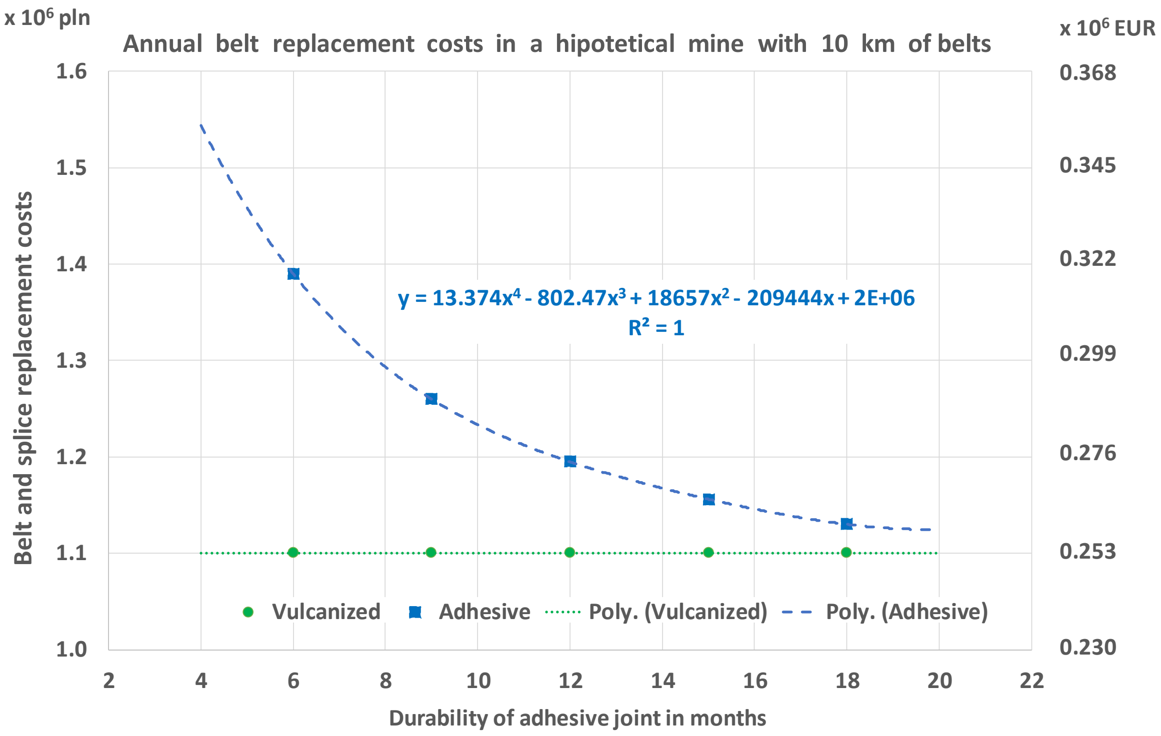

Figure 3. Impact of average durability of adhesive belt joints on total belt and splice replacement costs

The splice maintenance company may compensate the risk of increased warranty costs with higher tender prices. Such contractors will be also more interested in ensuring high quality of splices, using improved splicing materials and improving splice designs so that the warranty repairs did not increase their costs despite higher price.

5. Influence of changes in splicing costs on belting cost

Increases in the costs of adhesive splices translates directly into increased total belt and splice replacement costs (Figure 4). Price increase by 33.(3)% (from 1 800 pln to 2 400 pln, 413.8 EUR - 551.7 EUR) causes an increase of annual costs only by 60 000 pln (13 793.1 EUR), i.e. by approx. 5%. If the relative increase in the cost of adhesive splice is accompanied by an analogous relative increase in the durability, then the total costs of belt and splice replacement in a mine should not grow, while profits will result from increased reliability.

The additional splicing costs covered by the mine were assumed to be identical in the case of both splicing strategies (vulcanized and adhesive splices). These costs may be own costs due to conveyor downtime, its preparation to the splice replacement procedure, assisting in and/or supervising of the procedure, as well as the use of additional equipment (e.g. the costs related to the transportation of the splicing crew to the repair location). The costs do not include emergency splice replacement and production losses.

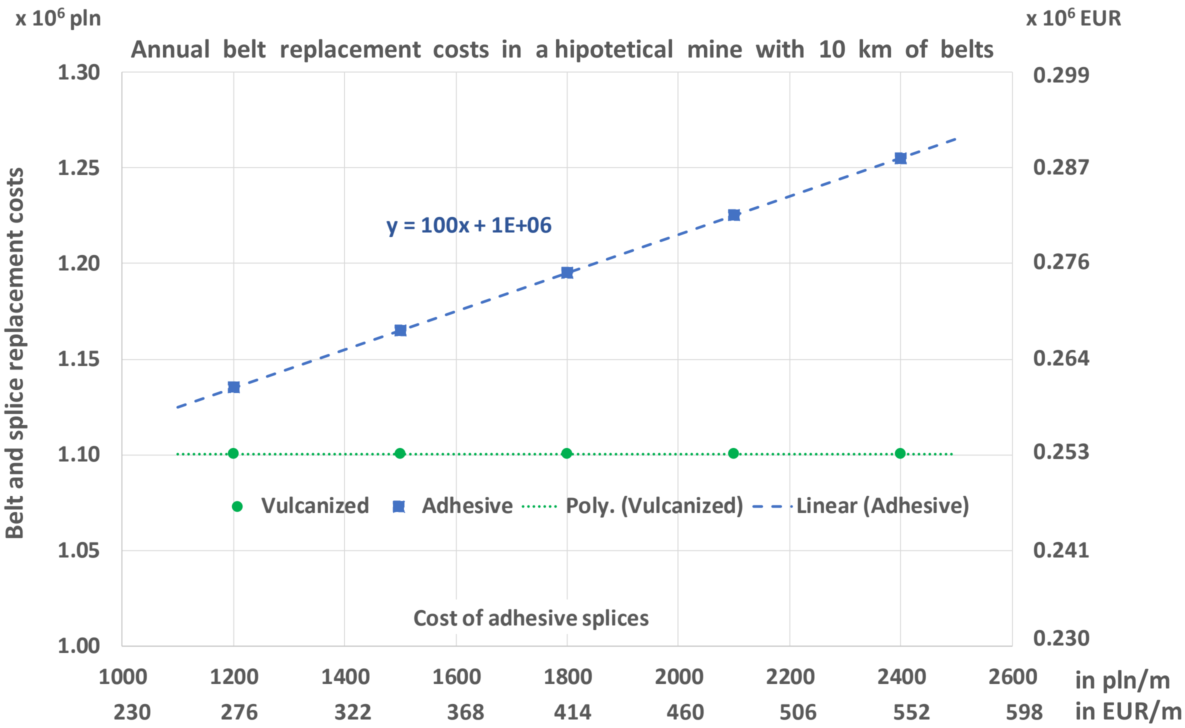

Figure 4. Impact of the price of adhesive belt splices on the total belt and splice replacement costs

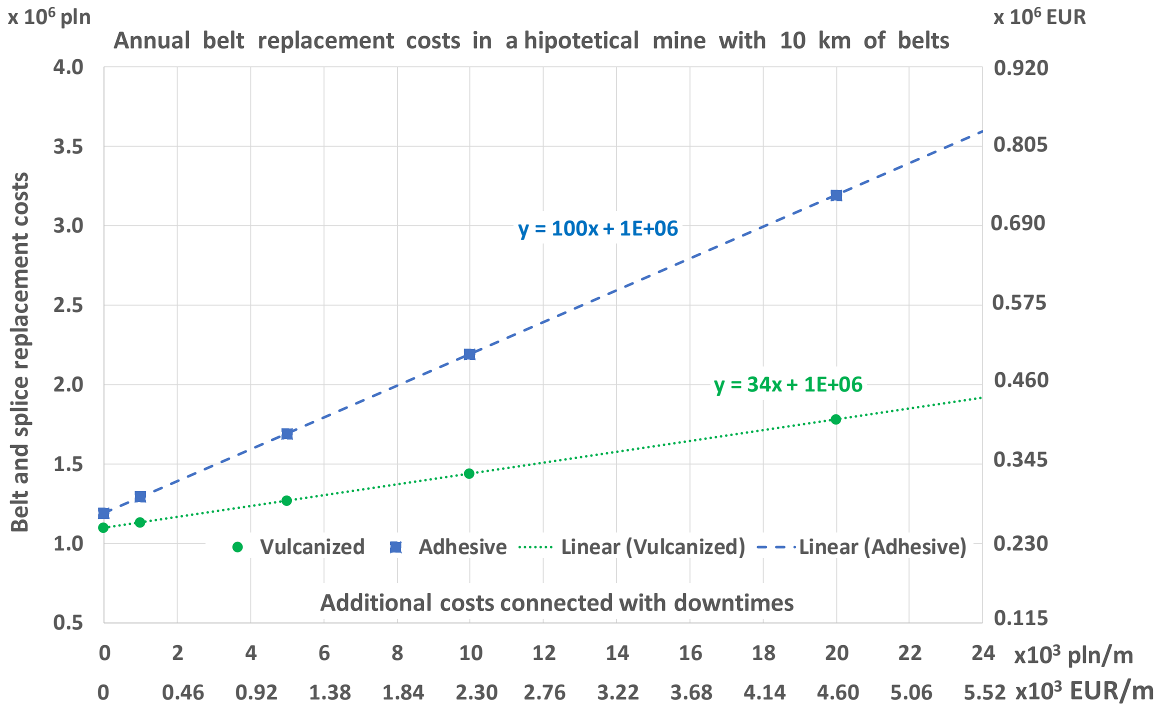

Figure 5. Impact of the additional costs of downtimes on the total belt and splice replacement costs

It remains unknown what part of splice replacements are emergency procedures and what losses they entail. As can be seen, any additional costs immediately translate into increased total costs of belt and splice replacement, leading to increased cost differences in both replacement strategies. The differences result from much greater frequency of replacement procedures in the case of adhesive splices, whose life is one third of the life of vulcanized joints. If the downtime costs for adhesive splices are assumed to be threefold lower in comparison to vulcanized joints, the initial difference of costs for all levels of additional downtime costs is maintained. Figure 5 shows additional downtime-related costs being included in the analyses.

6. Conclusions

The analyses confirmed that belt durability is a parameter of key importance for the annual total costs of belt and splice replacement. Mine management should pay much attention to their proper operation and monitor their wear degree. Belt durability introduces difference to the total costs in both strategies.

Belt price remains another factor of great importance for the total costs of belt and splice replacement. It does not, however introduce difference to the costs in both strategies. Importantly, price increase by 50 pln/rm (11.5 EUR/rm, by 16.67%) with analogous increase in mean durability entails a reduction in the total costs in the case of vulcanization by 9.1%. Increasing durability decreases costs more effectively in the vulcanization strategy, as the life of vulcanized splices is identical to the life of the belt. The total costs in the adhesive splice strategy remain at an almost identical level – their increase is insignificant. The proportional relative increase in belt prices and durability is practically neutral in this strategy. The vulcanized splice strategy leads to significant profits, as the relative cost reduction reaches approx. 10%. The potential linking of belt price growth with the warranty of longer life (proportional to the increase in price) is advantageous for mines only on condition that they use vulcanized splices.

Splice durability has a significant influence on the reductions of cost differences in both strategies. Lower price of adhesive splices does not compensate their much lower durability. The assumed relative price difference for adhesive splices is approx. 36%, while the assumed relative decrease in durability was 66.7%. An increase in adhesive splice life to 2 years practically eliminates the differences in both strategies.

Low durability of adhesive splices entails low reliability of the belt loop and high cost of emergency downtimes, as well as production losses due to such downtimes. These have not been included in the analysis. It may be reasonable to perform estimations of the costs related to the two strategies with allowance for the stochastic properties of the durability of belts and splices, e.g. by simulating their replacements with the Monte Carlo method.

The results of the deterministic analysis here described do not fully represent the risk and the costs of replacement procedures performed with the two methods, even with allowance for the analysis results of the sensitivity of the total costs to the influence of multiple changing parameters. The results of both strategies on the reliability of the transportation system can be easily allowed for in a simulation analysis. Such an analysis may also aid evaluations of the financial consequences of the warranties offered by belt manufacturers and service contractors, and also indicate who gains and who loses on the warranties. The warranties are not necessarily a zero-sum game. Even the deterministic analysis has demonstrated that an equal relative increase in the belt price and in its durability generates savings, and hence the sum is positive.

The annual belt and splice replacement costs for different splicing strategies, costs and durability, as estimated in this paper, may be adjusted to the conditions in a particular mine. For this purpose, the values presented in this analysis should be multiplied by the actual length of the installed belts, given in kilometres, and divided by 10, which is the number of belt kilometres assumed in the cost estimations presented in this paper.

Although this analysis was focused on the costs for the adhesive splice and vulcanized joint strategies considered in separation, actual mines may operate both types of splices simultaneously. The actual costs may be therefore calculated as a weighted mean of costs for both strategies, based on the proportions between the two types of splices operated in the mine.

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