TRANSPORT & *LOGISTICS:*
the International Journal

Article history:
Received 10th December 2022
Accepted 16th December 2022
Available online 19th December 2022

ISSN 2406-1069

Article citation info: Kimakova, Z., Andrejiova, M., Assessment of the lifetime of conveyor belts using the method of analysis of variance. Transport & Logistics: the International Journal, 2022; Volume 22, Issue 53, December 2022, ISSN 2406-1069

ASSESSMENT OF THE LIFETIME OF CONVEYOR BELTS USING THE METHOD OF ANALYSIS OF VARIANCE

Zuzana Kimakova [1], Miriam Andrejiova [2]
[1] Faculty of Mechanical Engineering, Technical University of Kosice, Letna 9, 042 00 Kosice, Slovak Republic, e-mail: zuzana.kimakova@tuke.sk

[2] Faculty of Mechanical Engineering, Technical University of Kosice, Letna 9, 042 00 Kosice, Slovak Republic, e-mail: miriam.andrejiova@tuke.sk

Abstract:
Conveyor belts are an important element of continuous material transport, which can be used in various operating conditions. For this reason, the research of belt conveyors and conveyor belts in terms of their lifetime, reliability and attrition is currently an issue that is increasingly coming to the forefront of interest not only for manufacturers of belt conveyors and conveyor belts, but also for their users. The article deals with the assessment of the lifetime of conveyor belts using statistical methods, primarily the method of analysis of variance and multiple comparison methods.

Key words: *conveyor belts, statistical data processing, ANOVA, multiple comparison methods*

1 INTRODUCTION

Transport of material and mineral raw materials is an important element of the transport system of every mining enterprise. From the point of view of the company's complex transport system, it belongs to intra-company transport. According to (Marasova et al., 2010), transport in the mining industry has its characteristic feature consisting in the fact that it works in significantly more difficult conditions than transport in other sectors of industrial activity.

Conveyors belong to continuous transport devices that continuously transport various types of material over distances from several meters to several kilometres. Some conveyors are used for horizontal, vertical or inclined, or combined transport. Belt conveyors are a highly efficient active element of transport. According to (Bigos, 1981), in general, these are continuously operating transport devices with a traction and bearing element in the form of an endless conveyor belt. They are characterized by high productivity, economic efficiency and ecological harmlessness with minimal impact on the environment. We can use them when transporting different types of material (bulk, piece) and in different operating conditions (Taraba et al., 2017). They make it possible to connect significant height differences and to overcome even long transport distances. Because conveyor belts are the structural element of belt transport that most often breaks down, great care must be taken. According to (Nouri et al., 2014), the conveyor belt is the element with the most probable failure. The cause of these failures is the large number of production, storage, handling and operational activities performed during the life cycle of conveyor belts. Likewise, the authors (Fedorko et al., 2015) state that the process of attrition and damage of the conveyor belt is a limiting condition that has a decisive influence on the operational life of the conveyor belt.

Monitoring the damage occurring to conveyor belts in real conditions has been discussed in several papers. The paper (Galkin, 2014) discussed issues regarding the monitoring of conveyor belts in the mining industry. The greatest risk of damage to the conveyor belt due to dynamic impact stress is at the point of the overflow, i.e. the point of fall of the material on the conveyor belt. Its investigation is dealt with by the authors in works (Ballhaus, 1983, Komander et al., 2014). Author (Mazurkiewicz, 2012, 2010) gathered knowledge about the operational characteristics of conveyor belts and their joints, which were made using different gluing methods. According to (Ilic, 2019), premature failures of conveyor belts and transfer chutes which are caused by their wear have a very significant impact on the success of conveyance operations. The consequent few hours lasting down times may result in an annual export loss amounting to as much as millions of tonnes. When determining the lifetime of conveyor belts, the author (Zur. 1996) is based on the effective working time of the conveyor belt, the number of revolutions of the belt around the conveyor and the total length of the conveyor belt. Author (Lutynsky, 2004) states: when analysing the wear process of conveyor belts, it is necessary to evaluate the lifetime of the conveyor belt, which is influenced by the design parameters of the conveyor belt and the conveyor, or properties of the transported material. The lifetime of the conveyor belt and the causes of damage to the conveyor belt are monitored by (Lihua, 2011, Andrejiova et al., 2016). Authors (Grincova et al., 2014, Bindzar et al., 2006) deal with the lifetime of conveyor belts from the point of view of resistance to punctures. The problem of the optimal lifetime of conveyor belts through the renewal theory is discussed in works (Andrejiova et al., 2014, Knezo et al., 2016, Pavliskova et al., 2006).

The article evaluates the lifetime of conveyor belts using statistical methods, primarily variance analysis and multiple comparison methods. The evaluated conveyor belts represent samples of conveyor belts obtained from the operation of a production organization engaged in the production of iron.

2 METHODS AND METHODOLOGY

2.1 Conveyor belts

At the present time, transport by belt conveyors (belt transport) is among the prospective continuous transport systems in various branches of industry (e.g. in engineering, metallurgy, mining, construction, agriculture and others). Conveyor construction is governed by many standards and regulations, and conveyor manufacturers themselves have developed their own complex construction methods. The basic elements of a classic belt conveyor include a conveyor belt (Taraba, 2017).

The conveyor belt is a closed element circulating around the end drums, which performs two functions during its circulation: carrying and pulling. Its task is to carry the material along the transport length, i.e. it is a carrying element. At the same time, it overcomes resistance to movement and thus fulfils the function of the traction element of the belt conveyor. The basic structural elements of the conveyor belt are the protective rubber cover, the frame and the covering layers, the thickness of which is influenced by the properties of the transported material (Fig. 1).

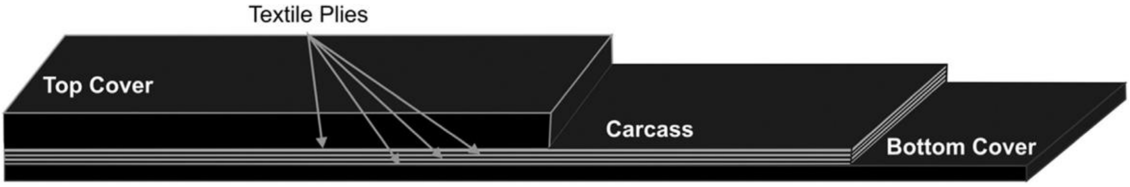

Fig.1 *Basic elements of the conveyor belt*

We distinguish several types of conveyor belts. From the structural point of view, their division depends on the type of frame, the method of covering, the material that covers the frame, the surface treatment, etc. The most commonly used conveyor belts include rubber textile (Fig.2) and steel cord conveyor belts (Fig. 3). Currently, the carcass frame can be made of different types of material: natural (e. g. cotton), synthetic (polyamide, polyester, aramid), chemical (glass) and steel.

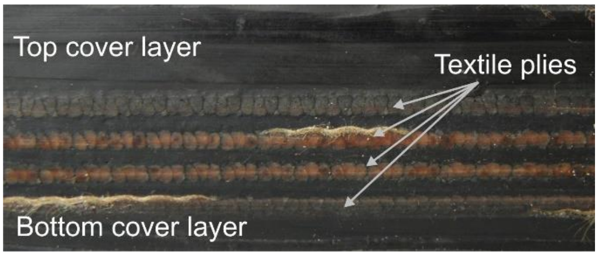

Fig. 2 Rubber-textile conveyor belt

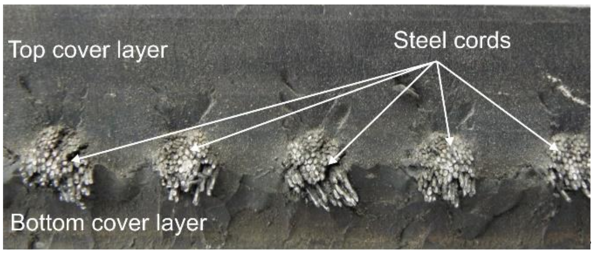

Fig. 3 Steel-cord conveyor belt

2.2 Statistical methods

Basic statistical methods (descriptive statistics, statistical hypothesis testing) were used to analyse the lifetime of the conveyor belts (Montgomery et al., 2011). When testing statistical hypotheses using statistical programs, the decision to reject or accept the null hypothesis is often made using the p-value, which represents the lowest possible level of significance at which it is still possible to reject the null hypothesis. For the decision on acceptance, or rejection of the null hypothesis applies: if $p - value < \alpha$ then we reject the null hypothesis at the significance level α, if $p - value \geq \alpha$, then we do not reject the null hypothesis.

Analysis of variance (ANOVA) is a method that allows you to compare the mean values of several independent basic sets. Its goal is to reveal whether the differences in the mean values of individual sets are statistically significant or just random. According to the number of investigated factors, we divide the analysis of variance into one-factor (single factor, one-way ANOVA), in which the influence of one factor is monitored, and multi-factor, in which the influence of several factors on a quantitative variable is monitored. According to the range of sample files, we distinguish a balanced model (the range of sample files is the same), an unbalanced model (a different range of sample files).

Rejection of the null hypothesis verifying the agreement of mean values provides information that there are statistically significant differences in mean values within the group.

But usually we are also interested in which two files these differences exist between. That's what multiple comparison methods, the so-called methods of subsequent testing (post hoc tests) are for. The most common methods include Scheffe's method, Tukey's method, and others.

Even before carrying out the analysis of variance, it is advisable to use exploratory analysis, which primarily uses graphic methods that enable the assessment of statistical peculiarities of the data (e.g. quantile graph, histogram, rankit plot, variance diagram, etc.). The basic graphs include the boxplot, which allows you to assess, for example, the symmetry or asymmetry of the distribution, to display the median, average, etc. Boxplot also helps to identify outliers that can cause inaccuracies in the analysis of variance. If there is one outlier, it is recommended to remove that value in some way. If we keep it in the file, it is better to perform analysis of variance using the non-parametric Kruskal–Wallis test.

When assessing the data, we worked with the R program, which is suitable for performing statistical calculations and creating graphic outputs. It is a free program that can be downloaded from http://www.r-project.org/. In addition to base sets, the program offers expansion packages *stat*, *nortes*, *fBasices*.

3 RESULTS

To investigate the dependence of a quantitative variable (lifetime of con conveyor belts) on one factor (conveyor type), we will use one-factor analysis of variance.

3.1 Data Characteristics

During 7 years, the replacement and lifetime of the conveyor belt was recorded on 4 conveyors CB1, CB2, CB3, and CB4. The reason for the replacement was the overall wear of the conveyor belt material. The characteristics of the conveyor belt and operating conditions are in Table 1. The descriptive statistics of the lifetime of conveyor belts is in Table 2.

Tab. 1 *Characteristics of the conveyor belts*

Conveyor belts	**CB1, CB2, CB3, C4**	**Transported material**	**Agglomeration mixture, coke**
Type	P 1000x3	Speed	1.25 m/s
The conveyor belt width	1000 mm	Power	300 t/h
The conveyor belt length	20 m	Electrical engine	1420 rpm

Tab. 2 *Descriptive statistics of the lifetime of conveyor belts (number of days)*

Characteristics	**CB1**	**CB2**	**CB3**	**CB4**
Mean	425.4	351.0	663.3	607.2
Standard deviation	159.9	162.0	117.5	209.0
Maximum	668	658	808	864
Minimum	287	189	520	375
Range (Max-Min)	381	469	288	489

We are interested in whether the differences in the lifetime of conveyor belts are caused by the different quality of the conveyors, or if we can attribute them to random influences. At the level of significance $\alpha = 0.05$, we test the hypothesis $H_0\colon m_{CB1} =$

$m_{CB2} = m_{CB3} = m_{CB4}$ against H_1: *at least one of the equalities is not fulfilled*. Fig. 4 shows a boxplots, which shows the concentration of data and indicates suspicious and outlier values.

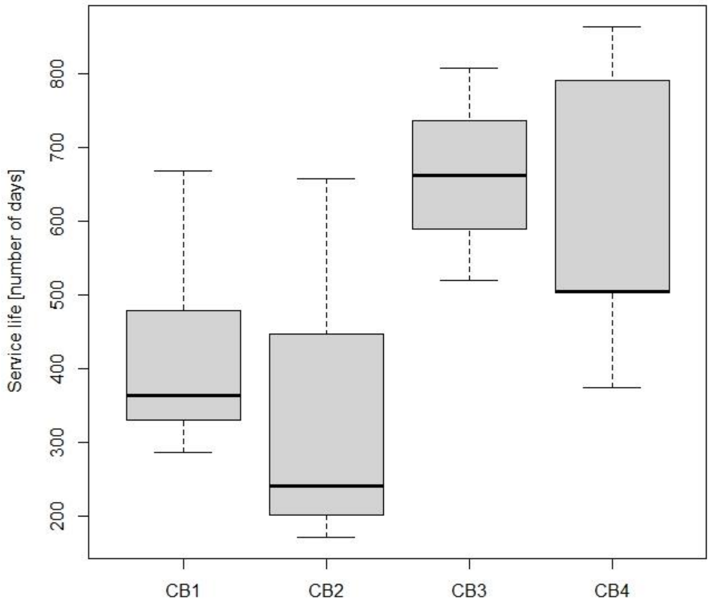

Fig.4 *Boxplots*

3.2 ANOVA analysis

The basic assumptions for the use of analysis of variance include: independence (individual selections are independent of each other), normality (selection sets come from base sets with a normal distribution), homoscedasticity (homogeneity, similarity of variances of base sets).

Verification of homogeneity of variances

First, we check whether the conditions of normality and homogeneity of variances are met at the level of significance $\alpha = 0.05$. We can verify the condition of the homogeneity of variances using Bartlett test, for example. We test $H_0: \sigma^2_{CB1} = \sigma^2_{CB2} = \sigma^2_{CB3} = \sigma^2_{CB14}$ against H_1: *at least one of the equalities is not fulfilled*. The results of the test show that we do not reject the hypothesis of equality of variances ($p - value = 0.795 \geq \alpha$).

Verification of normality

In practice, two main tools are used to assess normality: graphical representation of data and visual assessment of normality (e. g. histogram, Q-Q graph,), or testing using the statistical tests (e.g. Kolmogorov - Smirnov test, Pearson test, Shapiro-Wilk test, Anderson - Darling test and others).

To graphically assess the normality of the data, we used the Normal Q-Q graph. If the data comes from a normal distribution base set, then all points of the sample file should lie on a straight line. From the graphic representation (Fig. 5) it follows that the graphs do not always provide a clear answer about the normality of the basic sets.

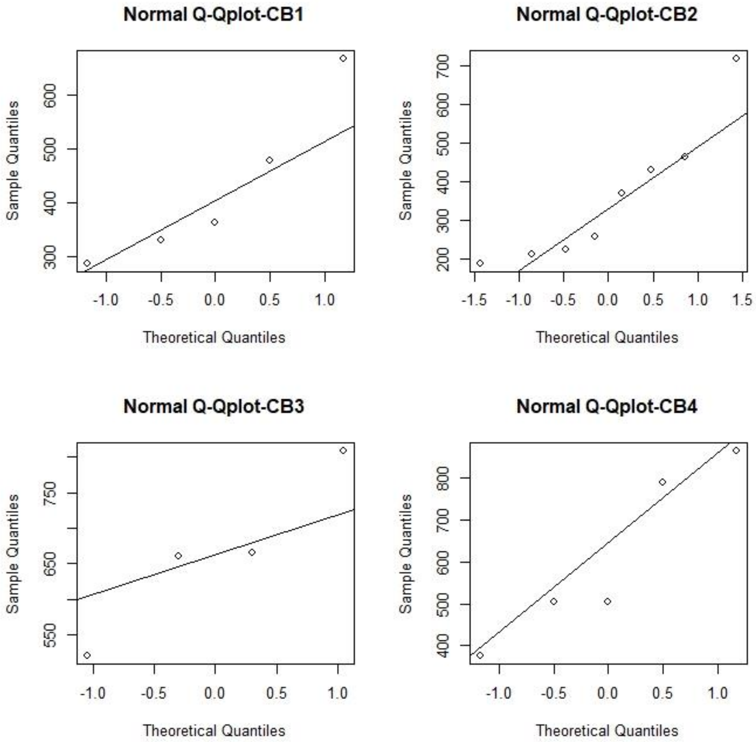

Fig.5 *Normal Q-Q graphs*

We will use one of the tests to assess normality, e. g. *Shapiro-Wilk normality test*, which is the most commonly used test of normality in the case of small to medium range up to 2000. We test H_0: *a random sample comes from a base set with a normal distribution* against H_1: *a random sample comes from a base set with other than a normal distribution*. Table 3 shows the calculated p-values for individual conveyor belts. Since for each sample set the p-value is greater than the significance level ($\alpha = 0.05$), we do not reject the null hypothesis about the normality of the individual base sets. We can assume that all samples follow a normal distribution (Table3).

Tab. 3 *Shapiro-Wilk test (α=0,05)*

Conveyor belt	p-value	Conclusion for null hypothesis
CB1	0.361>α	Not rejected
CB2	0.081>α	Not rejected
CB3	0.730>α	Not rejected
CB4	0.354>α	Not rejected

Analysis of variance

The conveyor belts represents the factor A, whose influence on the lifetime of the conveyor belt we are investigating, and the types of the conveyor form the levels of the factor A. At the level of significance $\alpha = 0.05$, we test the hypothesis $H_0: m_{CB1} = m_{CB2} = m_{CB3} = m_{CB4}$ against H_1: *at least one of the equalities not being fulfilled*. The resulting values of the analysis of variance are in Table 4.

***Tab. 4** Analysis of variance table - summary*

A source of variability	Sum of squares	Degrees of freedom	Average square	Test characteristic	p-value
Factor A	$SS_A = 363069.1$	$df_A = 3$	$MS_A = 121023$	$F = 4.413$	0.0171
Residual	$SS_R = 493608.8$	$df_R = 18$	$MS_R = 27422.7$		
Total	$SS_T = 856677.8$	$df_T = 21$			

where SS_A is variability between groups, SS_R is a variability within groups, SS_T is a total variability and F is a test characteristic. Since the p-value is lower than the significance level $\alpha = 0.05$, we reject the null hypothesis of equality of mean values of the basic sets. The results of the analysis of variance show that there are statistically significant differences between individual conveyors. The proportion of variability (factor effect) explained by the conveyor type is determined by the coefficient $\eta^2 = \frac{SS_A}{SS_T} = 0.424$. This means that the lifetime of the conveyor belts depends approximately 42.4% on which conveyor they are on and 57.6% on other factors.

3.3 Multiple comparison methods

We have rejected the null hypothesis of the equality of the average lifetime of the conveyor belts and it is necessary to decide which pairs of belts differ significantly from each other. We are testing the null hypothesis in which we consider the differences in mean values between a pair of groups to be insignificant against the hypothesis that there are statistically significant differences between the mean values of a pair of groups, i.e. $H_0: m_{CBi} = m_{CBj}$ against $H_1: m_{CBi} \neq m_{CBj}$ for each pair $i, j = 1,2,3,4,\ , i \neq j$, while we will perform successive testing of 6 hypotheses. We will use the Scheffe's method and Tukey-Cramer's method, which is modification of Tukey's method. We reject the null hypothesis at the level of significance $\alpha = 0.05$, if $|\bar{y}_i - \bar{y}_j| \geq TS_{ij}$(Scheffe's method) or $|\bar{y}_i - \bar{y}_j| \geq TT_{ij}$ (Tukey-Cramer's method) where

$$TS_{ij} = \sqrt{(k-1)\frac{SS_R}{(n-k)}F_{1-\alpha}(k-1, n-k)\left(\frac{1}{n_i} + \frac{1}{n_{ij}}\right)} \tag{1}$$

or

$$TT_{ij} = q_{1-\alpha}(k, n-k)\sqrt{\frac{SS_R}{2(n-k)}\left(\frac{1}{n_i} + \frac{1}{n_{ij}}\right)} \tag{2}$$

where $F_{1-\alpha}(k-1, n-k)$ is the quantile of the Fisher distribution, $(k-1)$ is the between groups degrees of freedom, n_i (resp. n_j) is sample size in group j (resp. j) and $q_{1-\alpha}(k, n-k)$ is the tabulated critical value of the studentized range The results of Scheffe's method (resp. Tukey-Cramer's method) which was used to determine pairs of measurement sites with statistically significant differences, are shown in Table 5.

***Tab. 5** . Multiple Comparisons result*

CB	Absolute mean differences			TS_{ij}			TT_{ij}		
	CB2	**CB3**	**CB4**	**CB2**	**CB3**	**CB4**	**CB2**	**CB3**	**CB4**
CB1	74.40	237.85	181.80	290.67	342.03	322.47	240.98	283.57	267.35
CB2	-	**312.25***	**256.2***	-	312.23	290.67	-	**258.86**	**240.98**
CB3	-	-	56.05	-	-	342.03	-	-	283.57

Scheffe's method is advantageous for its generality, but on the other hand, it is less sensitive than Tukey-Cramer's method. According to Scheffe's method, we do not reject the null hypothesis, that is, there are no significant differences between individual levels of factor A. According to the Tukey-Cramer's method, there are statistically significant differences in belt lifetime (marked *) between CB2 and CB3 conveyors and between CB2 and CB4.

4 CONCLUSIONS

Belt transport is widely used for the transportation of material. It is used to transport various types of material and is exposed to a whole series of surrounding's conditions, weather and environment. The issue of increasing the technical and economic level of belt transport is related to increasing the lifetime of the conveyor belts and operational reliability of conveyor belts and technological devices of belt transport. The results of the analysis of variance show that there are statistically significant differences between individual conveyors. According to the Tukey-Cramer method, there are statistically significant differences between the average lifetime of the conveyor belt. From all the processed empirical outputs, it follows that the variance analysis method is a suitable method for evaluating and comparing the lifetime of conveyor belts.

Acknowledgement

This article was prepared with the support from the project titled VEGA 1/0168/21 and project titled KEGA 012TUKE-4/2022.

REFERENCES

Andrejiova, M., Grincova, A., Pavliskova, A., 2014. Mathematical model for determining the lifetime of conveyor belts depending on some selected parameters. *Applied Mechanics and Materials* 683, pp.147–152.

Andrejiova, M., Grincova, A., Marasova, D., 2016. Measurement and simulation of impact wear damage to industrial conveyor belts. *Wear* 368, pp. 400–407.

Ballhaus, H., 1983. Stress and Wear of Conveyor Belts by Loading Point Impact. *Bulk Solids Handlings* 3 (1), pp. 347–353.

Bigos, P., 1981. Theory and construction of conveyors Belt transport, TU Kosice.

Bindzar, P., Grincova, A., Ristovic, I., 2006. 3D mathematical model of conveyor belt subjected to a stress loading. *Podzemni Radovi* 13(15), pp. 179–188.

Fedorko, G., Molnar, V., Kopas, M., Tomaskova, M., 2015. Dynamic damage of rubbertextile belts in pipe conveyor application. *Bulk Solids Handling* 35, pp. 44–49.

Galkin, V.I., 2019. Assessment of conveyor belt monitoring systems in mining. *Mining Informational and Analytical Bulletin* pp. 166–174.

Grincova, A., Marasova, D., 2014. Experimental research and mathematical modelling as an effective tool of assessing failure of conveyor belts. *Eksploatacja i Niezawodnosc-Mainteneance and Reliability* 16 (2), pp. 229–235.

Ilic, D., 2019. Development of design criteria for reducing wear in iron ore transfer chutes. *Wear* 434, pp. 1-13.

Knezo, D., Andrejiova, M., Kimakova, Z., Radchenko, S., 2016. Determining of the optimal device lifetime using mathematical renewal models. *TEM Journal* 5 (2), pp. 121–125.

Komander, H., Hardygora, M., Bajda, M., Komander, G., Lewandowicz, P., 2014. Assessment methods of conveyor belts impact resistance to the dynamic action of a concentrated load. *Eksploatacja i Niezawodnosc* 16, pp. 579–584.

Lihua, Z., 2011.Typical Failure Analysis and Processing of Belt Conveyor, *Procedia Eng*. 26, pp. 942–946.

Lutynski, A., 2004. Service life of conveyor belts used in conveyors being in operation at coal preparation plants. *Inzynieria Minerala* 1, pp. 29–38.

Marasova, D., Zimmermann, V., Gurecka, J., 2010. Belt transport as part of the integrated transport system of a mining enterprise (in Slovak). *Transport and Logistics* 7, pp. 462–466.

Mazurkiewicz, D., 2012. A Knowledge Base of the Functional Properties of the Conveyor Belt Adhesive Joint for FEM Simulation of Its Stress and Strain State. *J. Adhes.Sci. Technol* 26, pp. 1429–1442.

Mazurkiewicz, D., 2010. Tests of extendability and strength of adhesive-sealed joints in the context of developing a computer system for monitoring the condition of Belt joints during conveyor operation. *Maint. Reliab*., 12, pp. 34–39.

Montgomery, D. C., Runger, G. C., 2011. Applied Statistics and Probability for Engineers, John Wiley & Sons, New York 2011.

Nouri G. A., Mokhtarei, A., Khodayrei, A., Ataei, M., 2014. Fault tree analysis of failure cause of crushing plant and mixing bed hall at Khoy cement factory in Iran. *Case Studies in Engineering Failure Analysis* 2, pp. 33–38.

Pavliskova, A., 2007. Deterministic strategies and the lifetime of conveyor belts (in Slovak). *Acta Montanistica Slovaca* 12(3), pp. 265–269.

Taraba, V., Marasova, D., Miku1ová, N., Burget, M., 2017. Belt transport (in Slovak), Kosice.

Zur, T., Hardygora, M., 1996. Przenosniki tasmowe w górnictwie, Sllask Publishers, Katowice.