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Reliability Analysis of Conveyor Belt System of Crushing Department

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ABSTRACT

This paper describes reliability analysis of conveyor belt system in Azarabadegan Khoy cement factory. For this purpose, initially the general algorithm presented and then related subsystems and their relationship with each other in terms of various types of networks were evaluated. The required data collected and sorted in chronological order. The results of trend and autocorrelation tests revealed that the assumption of independent and identically distributed is not contradicted for time between failures of CBS1 (CBS: conveyor belt subsystem) and CBS3, but this assumption is valid for CBS2. Thus, classical statistical methods used to analyze the reliability of trend free subsystem and power low process selected for analyzing subsystems with trend. Finally, for CBS1 and CBS3 Reliability-based maintenance proposed to achieve the 90% level of operational reliability. In CBS2 evaluation of system condition is carried out by using total time on test plot and corrective maintenance is suggested.

KEYWORDS: Conveyor belt, Power low process, Reliability-based maintenance, Total time on test plot.

1. INTRODUCTION

The conveyor belt is one of the widely used, interconnected transportation system in the today industry. Conveyor belt, which is a permanent means of transportation, has higher power and cargo transportation ability than the volume it needs. Moreover, in many cases conveyor belt is the only economic means of transporting material from one point to another, and is generally used on horizontal surfaces (slopes less than 23 degrees), where the stevedore is constant.

In the cement industry, because of the continuity of the production cycle and the fixed nature of loading and unloading areas, transfer of materials between departments and various sections of production carried out by conveyor belt. Therefore, proper functioning and reliability of this system of transportation has an essential role in the stability of production. This will gain double importance with regard to the fierce market competition, the existence of several plants (68 plants) and high capacity production (61 million tons per year) in Iran, which puts Iran among the first fifteen countries of the world [1], [2]. Consequently, research in the field of reliability, maintenance of conveyor belt to identify and eliminate problems associated with it is essential.

The reliability issue at first was discussed in the mid-1980s as a standard method in the design and operation of automatic and complex systems. Moreover, numerous studies have been done in various fields such as: LHD machines ,[3], [4], chrushing planet [5], reliability and maintainability analaysis of drum shearer machine at mechanized longwall mines [6], [7]. These studies help us to identify the behavior of failure occurrence, which is effective in the decision-making process for maintenance policy.

- Increase understanding of the failure behavior occurred in conveyor belt
- Estimating quantitative properties of reliability power of the system
- Determine the critical subsystems of conveyor belt systems, in order to provide appropriate maintenance strategies for improving reliability and prevent damages.

2. Reliability-based maintenance policy

The general algorithm to calculate reliability and the suggested appropriate maintenance policy used in this article is presented in Figure 1, and tisabbreviation used here are as follows:

- F.T.M.: Fix Time Maintenance
- C.M.: Corrective maintenance
- T.B.M. Time-based maintenance
- C.B.M.: Condition-based Maintenance
- ECP: Expected costs of implementing preventive maintenance

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- ECC: Expected costs of implementing corrective maintenance

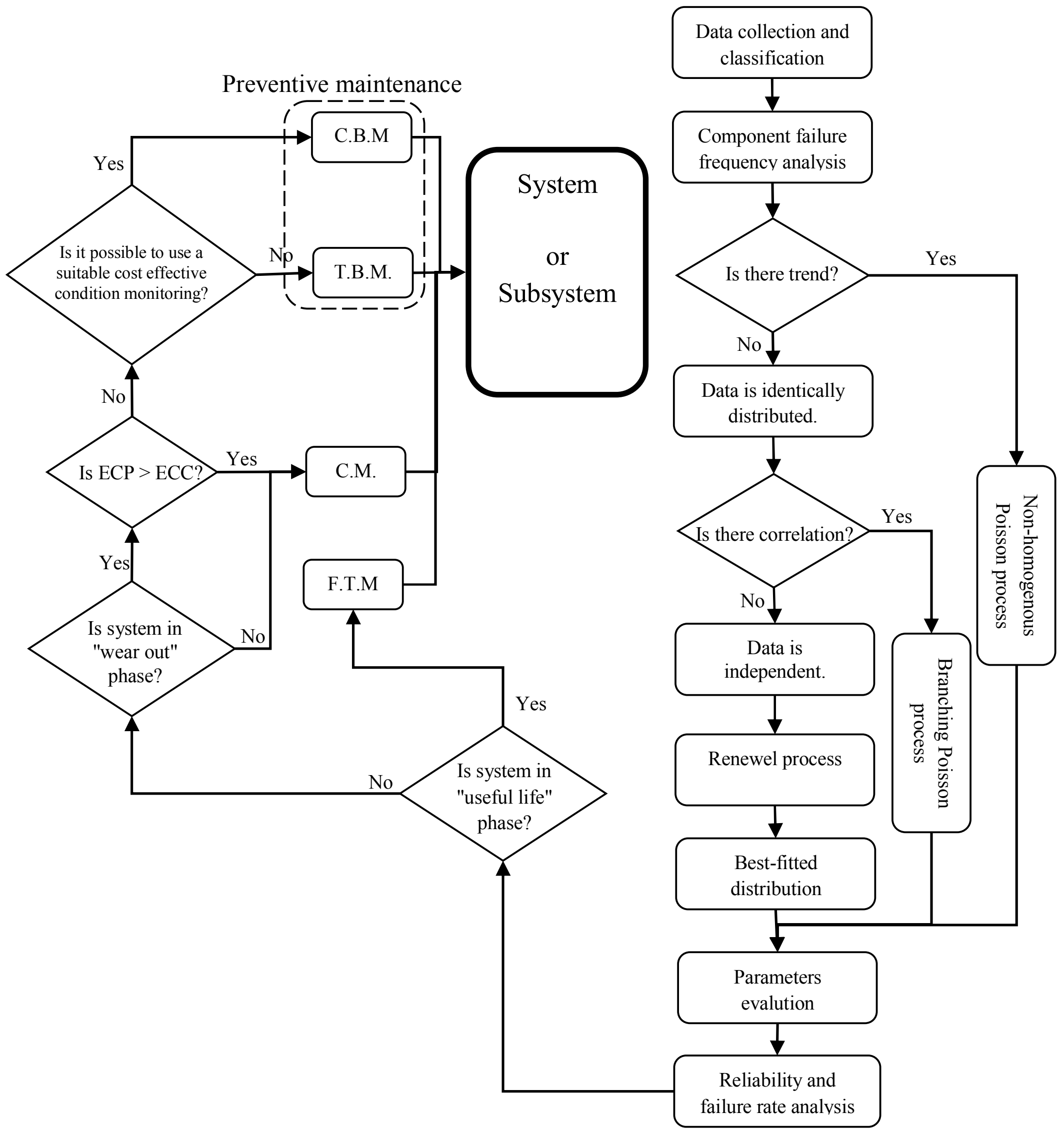

Fig 1. Algorithm for determining appropriate maintenance policy based on the reliability [5], [7], [8]

In this approach after collection of the appropriate data from different sources (Department of Mechanics reports, daily reports, maintenance reports, and the data from the sensors...) analysis and evaluation phase of reliability will be carried out. Reliability analysis is prepared generally with the assumption that the time between failures (TBF) is independent and identically distributed. In this case, the resorting of TBFs is possible based on their value, in order to fit proper distribution among the various distributions to show the behavior of TBFs and this is known as a renewable process. However, before analyzing the data, trend test and serial correlation test should be conducted to determine the proof of independent and identically distributed (iid) hypothesis. If the hypothesis of iid is rejected, statistical methods for analyzing reliability are not appropriate. Therefore, the non-stationary models such as "Non-homogeneous Poisson process" should be used. Fitting of a non-homogeneous Poisson process technique for non-stationary data is very different from the iid assumption of distribution functions. The functional form commonly used in fixable systems is the Non-Homogeneous Poisson Process following a Power law process [5], [6], [9]–[11].
In the following, the life cycle of industrial systems, including three stages (Fig 2) and the appropriate maintenance policies for the proposed algorithm (Fig 1) in each stage is presented:

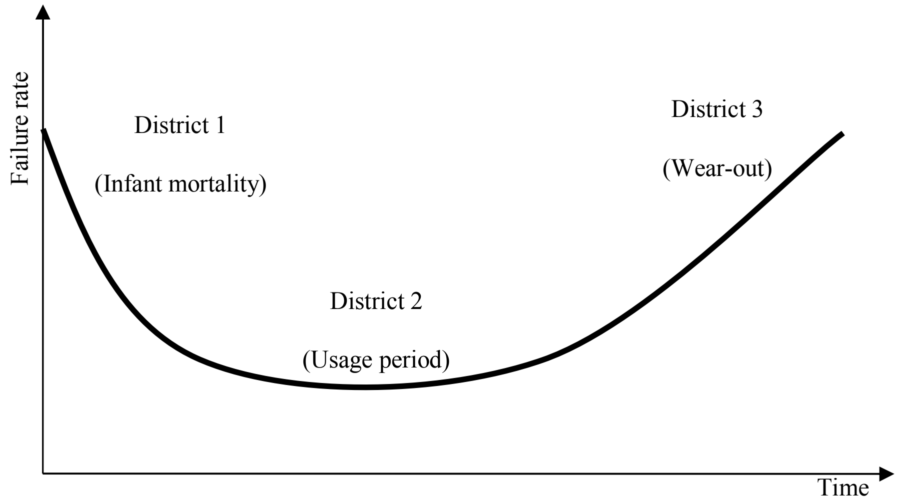

Fig 2. The bathtub curve **[12]**

• District (1): represents the high rate of failure of the initial part of each life cycle of the system (equipment) which is known as "the period of infant mortality or burn-in phase". At this stage, prevention operation, including replacement (repair) of the parts of the system is not only helpful, but also increases the probability of failure occurrence rate. In this situation the only suitable policy for the system would be "Corrective maintenance" [8], [13].
• District 2: When the possibility of a failure is constant, the system is in the second stage of life or "the normal stage of life or useful life phase", and policy related to this stage is " fix time maintenance" [8], [13].
• District (3): If the system status is declining, the system is in the third stage "wear out phase" and the comparison should be done between the expected costs of preventive maintenance (P.M.) and corrective maintenance (C.M.). If the cost of P.M. is higher than C.M. cost, C.M. policy is used. Otherwise, the possibility of conducting condition monitoring and inspection is checked and if possible, then maintenance based on condition is selected and if impossible maintenance based on time is chosen as the appropriate policy that both are a kind of preventive maintenance. In both cases, the time span between the inspections is determined based on desired reliability level.

3. Case Study

In this paper, the conveyor belt system of the transfer of material from the output of the crusher to the mixing bed hall of Azarabadegan Khoy cement factory located in West Azarbaijan province, 17 kilometers from the city of Khoy toward Maku after Malahzan village has been investigated. This system is located in the crusher department of the factory and is used to transport output minerals (limestone and clay) of the crusher with the capacity of 1000 to 1200 tons per day in the mixing bed hall with the capacity of two piles (each with a capacity of 30,000 tons).

Each system consists of parts or subsystems, which are in the form of series or parallel with each other. The reliability of the whole system is based on the reliability and individual performance of all subsystems. Therefore, before any kind of analysis, the system and its subsystems should be identified. The subsystems of the conveyor system are:

I. Conveyor belt subsystem 1 with code: CBS1
II. Conveyor belt subsystem 2 with code: CBS2
III. Conveyor belt subsystem 3 with code: CBS3

A schematic diagram of crushing department is illustrated in Fig 3.

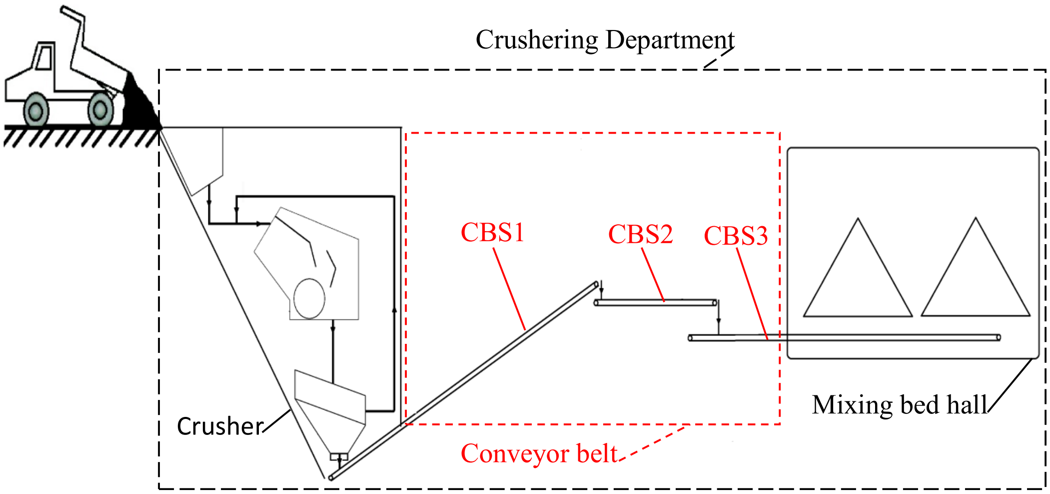

Fig 3. Schematic diagram of crushing process in Khoy cement factory

3.1. Data collection and the frequency analysis

To analyse the data, the relevant data regarding the performance of the equipment should be collected. The data in this study (TBF) were gathered from two sources: daily reports and reports of mechanical components of the factory for 18 months. Then Pareto methods were applied to analyse the frequency of the data. In addition, the Minitab 16 and Weibull++8 software were used to analyse the data.

According to the collected reports, six types of failure in the system have been occurred:

- Conveyor belt came out from the axis (CO)
- Conveyor belt was damaged (CD)
- Roller was damaged (RD)
- Material chute Failures (Sh)
- Belt cleaner was damaged (BC)
- Splice bar was damaged (SB)

Frequency analysis was performed after coding these failures (Fig 4). The result of the analysis showed that in CBS1 and CBS2, RD failure with 40.6 and 27.3 percent respectively, and in CBS3, CO failure with the 39.3 percent had the highest frequency.

In this section, because of the limitations, only the result of frequency analysis (Pareto) of the whole system is shown in Fig 4. In this chart, the height of the column shows the percentage and the number of failures in each subsystem, and the broken line above the columns represents the percentage of cumulative frequency of failures. As can be seen, RD failure with 35.4 percent has the highest frequency of failures, and CO and BC failures with 24.6 and 14.3 percent, followed by.

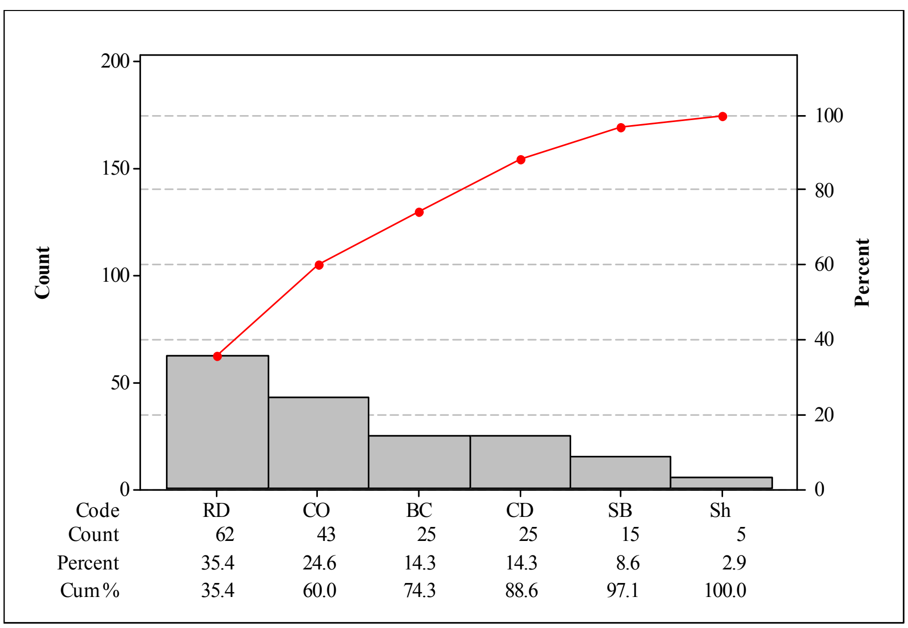

Fig 4. Pareto chart of conveyor belt system failures

3.2. Independence and identical distribution (iid) test

To analyse the hypothesis of iid of the data, trend and correlation tests are applied. To conduct the trend test, the analytical method, which is offered in the book of American Army (MIL-Hdbk-189), and Laplace test (LA) were used. In addition to the correlation test, graphical method is employed [9], [14].

Analytical results of the trend test of the system at a significance level of α = 0.05 are presented in Table 1. As can be seen, the values of P-value in the system are larger than α. Therefore, the null hypothesis that there is no trend for CBS1 and CBS3 is rejected while for CBS2 the hypothesis is retained. In addition, for the two subsystems having trends, LA statistics with a confidence level (α) with percentiles of the standard normal distribution (high values for improvement and low values for decrease) are compared as follows and the kind of the trend of the data is determined according to the LA column of Table 1 [15]:

- $LA < -Z_{\frac{\alpha}{2}}$, The failure trend is to improve and therefore TBFs are increasing.
- $LA > Z_{\frac{\alpha}{2}}$, The failure trend is declining and therefore the TBFs are decreasing.

Table 1. Results of the Analysis of conveyor belt systems trend

Conveyor system	CBS1		CBS2		CBS3	
Test	**MIL-Hdbk-189**	**LA**	**MIL-Hdbk-189**	**LA**	**MIL-Hdbk-189**	**LA**
Test Statistic	80.64	3.39	119.74	-1.3	70.05	2.82
p-value	0.001	0.001	0.979	0.193	0.001	0.005
Result	Trend	Deteriorating Trend	No trend	No trend	Trend	Deteriorating Trend

To decide whether to accept or reject the null hypothesis of no correlation, the ith TBF (TTR) is compared to the (i-1) the TBF (TTR) should be plotted, the result for three subsystems is shown in Fig 5. In this approach, if the data are correlated and dependent, the data points will be located along a straight line.

An important point that should be considered in conjunction with the test is that the data should be plotted chronologically because sorting the data will lead to convergence [9], [11]. As can be seen from Fig 5, there is no correlation in the TBFs of the various subsystems.

Based on the results of the trend and serial correlation tests, the iid hypothesis for the two CBS1 and CBS3 is rejected and suitable Non-homogenous Poisson process (NHPP) for describing the behavior of variables is a failure over time. As noted above, in this study, a special kind of NHPP, that is, the PLP method for analyzing the reliability of the system are used. For the subsystem CBS2 that the iid hypothesis about it is true, according to the algorithm of Fig 1, classical method is used.

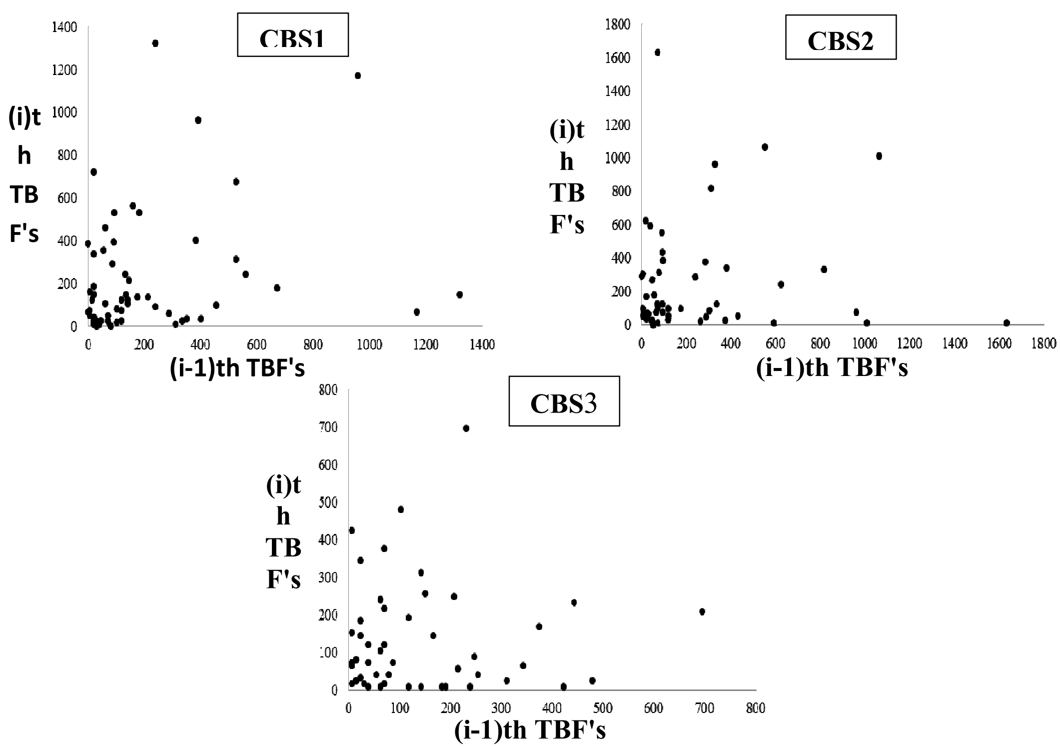

Fig 5. Serial correlation test for conveyor belt system

3.3. Analysis of subsystems with trends

After determining the PLP method for describing the behavior of the subsystems with trends, the parameters of scale (θ) and shape (β) with the confidence level of 95% are computed and the result is shown in table 2:

Table 2. Parameter estimation of the subsystems CBS1 and CBS3

				95% Normal Confidence Interval (CI)	
		Estimation	Standard Error(SE)	Lower	Upper
CBS1	θ	1.563	0.197	1.221	2
	β	914.032	314.101	466.070	1792.550
CBS3	θ	1.599	0.214	1.230	2.077
	β	553.814	191.997	280.716	1092.600

After determining the parameters of the model, the graphical method based on the mean cumulative function (MCF), with 95% confidence level was used to test the goodness-of-fit test as shown in Fig 6. As can be seen, the PLP model and the estimated parameters are able to describe the behavior of failure of CBS1 and CBS3 respectively.

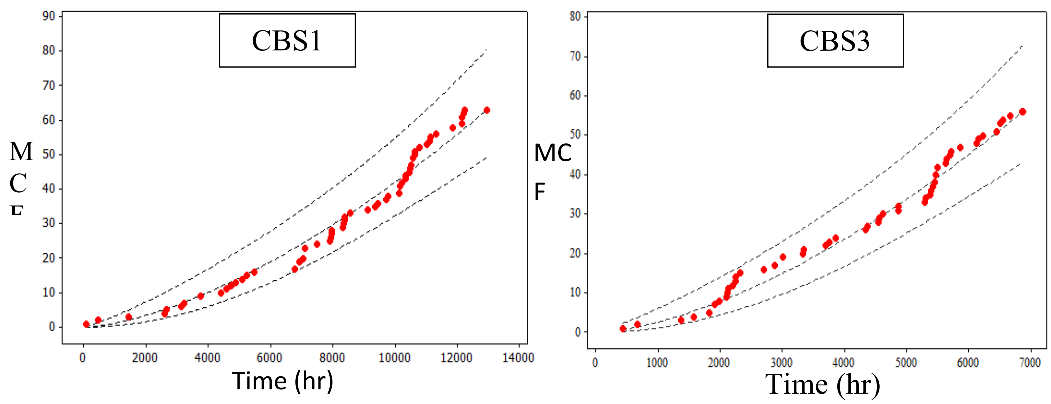

Fig 6. Goodness -of-fit based on mean cumulative function for CBS1 and CBS3

3.4. Analysis of trend free subsystems

Given the iid hypothesis for CBS2, at this stage the proper distribution of the data is fitted to the subsystem. The goodness of fit analysis of this subsystem is based on the analytical approach of Kolmogorov and Smirnov statistics (Average Goodness of fit test (AVGOF)), Anderson Darling (AD), correlation coefficient (CC), and the probability plot techniques [16]. In addition, the least squares estimation method (LSE) is used to estimate the parameters of the fitted distribution [5], [7]. According to the AVGOF and AD statistic values in Table 3, the normal-log distribution with parameters Log-Mean (hour) = 5.146 and Log-Std = 1.638 is considered the best fit to the distributed data. Moreover, in Fig 7 the graphical goodness-of-fit approach for CBS2 with 95% confidence level is depicted which confirms the suitability of the fitted distribution on TBFs.

Table 3. Results of tests of goodness-of-fit analysis for CBS2

	Distribution	AVGOF	AD	CC
1	Lognormal	0.142	11.160	0.988
2	3P-Weibull	2.919	11.551	0.976
3	2P-Weibull	23.511	12.779	0.963
4	2P-Exponential	86.418	12.361	N/A
5	Exponential	94.87	13.379	N/A
6	Normal	88.407	17.213	0.818

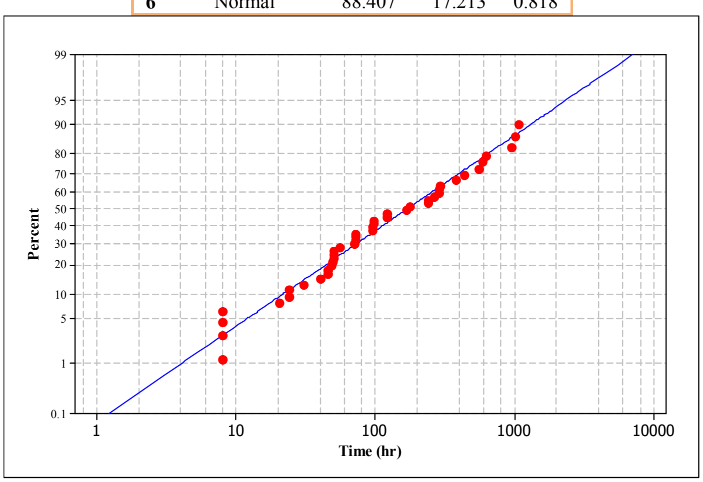

Fig 7. Probability plot of CBS2

3.5. Reliability of the conveyor belt systems

Reliability values are calculated at the end of time intervals of 100-hour performance based on estimated parameters for the subsystems and the result is shown in Table 4.

All subsystems of the conveyor belt are connected in series. This means that the system is able to perform the requested function appropriately only when all its subsystems are working well. Therefore, the whole system reliability (last row in Table 4) is calculated from the product of the individual subsystems. In addition, in Fig 8, the diagram of reliability for 2000 hours working time interval is shown.

Table 4. The reliability of conveyor systems and subsystems

Subsystem	Process or distribution	Reliability of subsystems at the end of different time intervals (hr)				
		100	200	300	400	500
CBS1	Power low	96.90%	91.11%	83.91%	75.96%	67.73%
CBS2	Lagnormal	62.94%	46.30%	36.67%	30.28%	25.70%
CBS3	Power low	93.73%	82.18%	68.71%	55.19%	42.77%
Total		57.16%	34.67%	21.14%	12.70%	7.45%

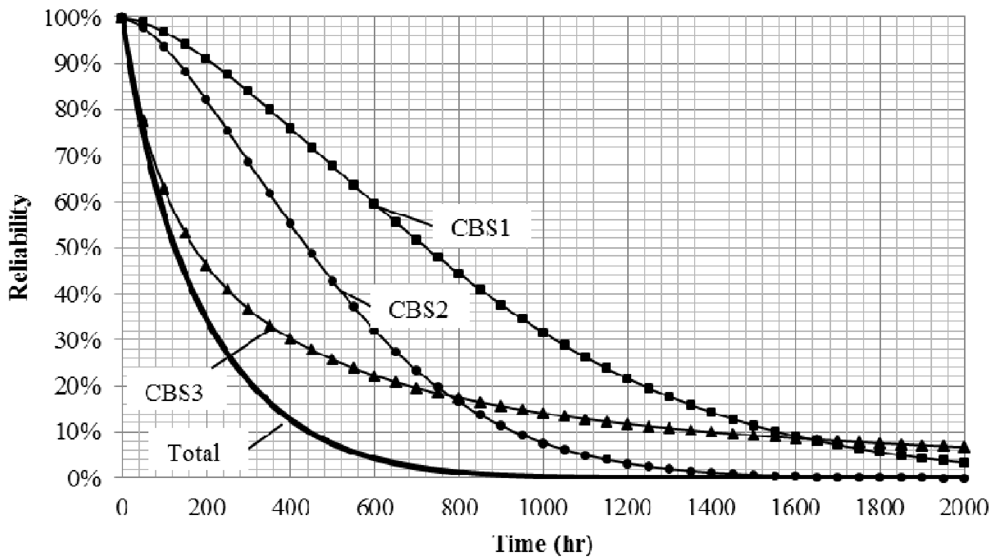

Fig 8. Reliability of conveyor belt systems and subsystems

As can be seen, CBS3 has the highest reliability. Without maintenance, the reliability of the whole system after almost 950 hours will be zero. The total reliability reduction rate at the beginning of the period is very intense and after 120 hours of operation, the reliability of the system will be reduced to 50%. In this situation, after 450 hours of operation, the probability of failure occurrence without performing maintenance will be 90 percent.

3.6. Appropriate maintenance strategy

In order to determine the life cycle of the system based on the Fig 1 and 2, for suggesting the proper maintenance policy for the subsystems with trends, the shape parameter, which is symbolized by (β) can be used. Different values of β is to determine the state of the system (Fig 2) as follows [8], [17]:

- $0<\beta<1$ The system is located in the district (1).
- $\beta = 1$ The system is located in the district (2).
- $\beta> 1$ The system is located in the district (3).

Therefore, for CBS1 and CBS3 with trends, based on the shape parameter, which is more than 1, the system is to be found in district 3 of the life cycle. In this region, in order to prevent fatigue failures as well as the diagnosis and repair of potential failures (damages that are not detectable during normal operations), conducting preventive maintenance or PM is required. In this paper, reliability based preventive maintenance is suggested. Therefore, operating times of subsystems with trends are calculated for different levels of reliability and the result is shown in Table 5.

Table 5. Reliability-based preventive maintenance time intervals for subsystems with trend

Subsystem	Reliability-based maintenance intervals for different reliability levels (hr)				
	50%	60%	70%	80%	90%
CBS1	722.9	594.7	472.5	350	216.5
CBS3	440.4	363.8	290.6	216.7	135.5

In most engineering operations, reliability of 80% is used as the best operating value for evaluating the performance and efficacy of the system. However, in this case (the cement factory) with regard to the importance of the continuity and complexity of the operation, reliability of 90% for scheduling of the maintenance is considered, and the time spans of 216.5 and 135.5 hours for the CBS1 and CBS3 as the time for performing maintenance operations were offered.

For system without trend, the "total time on test plot (TTT)" can be used [18]. In this plot, the convexity of the curve shows the improvement of the system or being system in district 1 (Fig 2). The concavity of the curve or being in district 3 shows the decline of the system. The conformity of the curve to the diametrical line shows that the system is in district 2.

Total time on test plot for CBS2 is shown in Fig 9. As can be seen, the convexity of the curve indicates the status of the subsystem in district (1) and after nearly 840 hours, the subsystem enters in its useful life cycle. Therefore, the suitable strategy is the C.M. and there is no need for any special scheduled maintenance in the event of a failure.

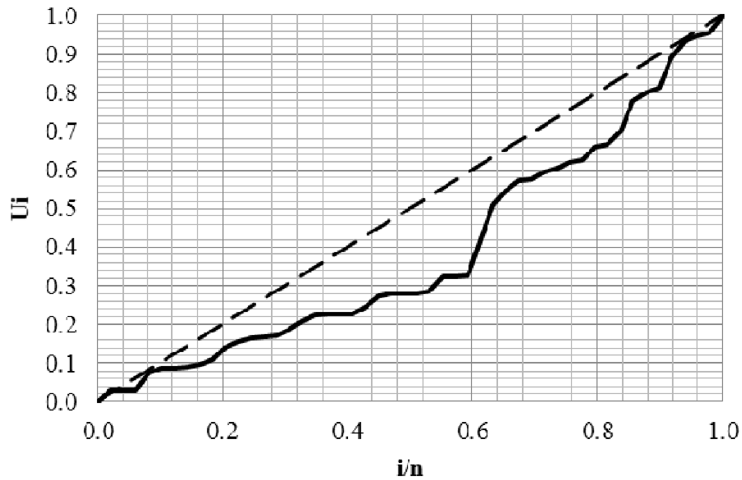

Fig 9. TTT diagram for CBS2

4. Conclusions

In this paper, the reliability of conveyor belt system between crusher and the mixing bed hall in the Azarabadegan cement factory was analysed. Frequency analysis performed on TBFs of different subsystems showed that in CBS1 and CBS2, RD failure and in CBS3 CO failure had the highest frequency and in case of prioritizing implementing operations, these kinds of failure should be considered. The result of statistical analysis indicated the deteriorating of the CBS1 and CBS3 and the improvement of the CBS2. Therefore, preventive maintenance policy for 90 percent level of reliability performance with 216.5 and 135.5 hours intervals for CBS1 and CBS3 has been suggested in order to prevent failure occurrence and improve the system performance. For the CBS2, corrective maintenance policy is suggested as the appropriate strategy in order to prevent the extra costs expenditure associated with preventive maintenance and useless replacement of different parts which are actually due to design problems or random failures.

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