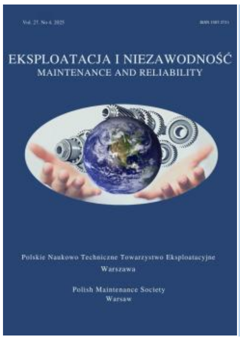

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Predictive maintenance of belt conveyor idlers based on measurements, analytical calculations and decision-making algorithms

Indexed by:

Przemysław Rumin[a,*], **Janusz Kotowicz**[a], **Anna Zastawna-Rumin**[b]

[a] Silesian University of Technology, Poland
[b] Cracow University of Technology, Poland

Highlights

- An innovative algorithm is proposed to improve belt conveyors maintenance decisions.
- An novel solution as part of the idea of industry 4.0 and the concept of a digital twin.
- Conveyor geometry and measurements were used to optimize models.
- Based on measurements and simulations the accuracy of the method was demonstrated.

Abstract

Due to the size and complicated geometry of modern belt conveyor installations and, consequently, the number of idlers installed, preventing failures is one of the biggest challenges. The research is based on the study of a unique belt conveyor of considerable length which is located in mountainous terrain. The study proposes an innovative algorithm that supports decision-making during inspections of conveyor idlers and an innovative use of existing measurement to estimate its remaining lifetime. The biggest challenge solved in the article is the further development of existing proposals with the possibility of adapting the theoretical models while also considering the variable measurement palette and the influence of the conveyor's operating parameters. Additionally, by utilizing the adapted models, the article provides tools for determining optimal intervals between inspections. The article presents measurements and calculations of the tested conveyor as well as simulations confirming the validity of the proposed algorithm.

Keywords
belt conveyor, machine learning, predictive maintenance, reliability

1. Introduction

Belt conveyors are fundamental devices for transporting bulk materials. They are used in situations where material needs to be moved along a designated route at a constant speed. The main advantage of this type of installation is high efficiency and low environmental impact compared to road transport. Belt conveyor structures vary in length, ranging from several meters to several kilometres. Modern installations can transport very large amounts of material, reaching up to a thousand tons per hour [1]. Idlers are critical components of belt conveyors, and monitoring their condition is vital, as failures can cause system stoppages or even fires. However, their distribution along the conveyor makes monitoring challenging, requiring a system that spans the entire length and ensures continuity. Environmental exposure adds complexity, necessitating weather-resistant monitoring solutions. Vasic [2] found that over 80% of idler failures in exposed environments are due to

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(*) Corresponding author.

E-mail addresses: P. Rumin (ORCID: 0000-0001-7620-3646) przemyslaw.rumin@gmail.com, J. Kotowicz (ORCID: 0000-0002-1348-3537) janusz.kotowicz@polsl.pl, A. Zastawna-Rumin (ORCID: 0000-0003-4442-6559) anna.zastawna@pk.edu.pl

plastic deformation and corrosion, with more than 70% occurring in side idlers. These idlers endure forces parallel and perpendicular to their axis, making their arrangement and load forces key considerations in failure analyses.

Scientific research on idler diagnostics focuses on methods like vibrations, sound emissions, and temperature. Bortnowski [3] proposed a method for detecting idler vibration anomalies with the support of deep learning. Morales [4] and Liu [5] grouped these techniques by applicability, noting their benefits and limitations. Y. Liu [6] compared temperature and sound measurement methods for detecting failures caused by fatigue, wear, or contamination, concluding that single-measurement approaches risk missing issues, while temperature increases often indicate serious failures. X. Liu [5] confirmed temperature monitoring as an affordable yet limited method for detecting severe faults.

Alternative methods, such as idler rotational speed monitoring [7], were tested on unloaded flat conveyors, unlike real bulk material systems. Monitoring large conveyor systems has spurred research into robots and fiber optics. Faria [7] developed a robot for thermal imaging and sound analysis. Dąbek [8] and Skoczylas [9] explored computer vision and acoustic signal measurement on operational conveyors.

Fiber optic cables are another focus for monitoring long conveyors, offering broad coverage but being prone to interference. Wijaya [10] [11] and Pan [12] demonstrated the efficacy of fiber optics for belt conveyors.

Industry 4.0 advancements enhance failure detection, enabling predictive maintenance through tools like regression, machine learning, and pattern recognition [13]. In belt conveyors, monitoring systems were proposed by Skoczylas [9] and Stefaniak [14], while Huanzhong Wang [15] developed reliability simulations for underground conveyors. Convolutional neural networks [16]and ARM-based systems [17] have been explored for motor maintenance, with expert systems suggested by Kiangala [18], Yang [19], and Yuan [20]. Expert systems were also proposed for pipe conveyors [21][22]. Jurdziak [23] also improves systems for belt damage diagnostics. Liu [24] proposes the Polar k-Nearest Neighbour algorithm for fault diagnostics of belt conveyor idlers.

Economic research highlights optimization algorithms [25][26] for component usage. Machine learning, such as Support Vector Regression, has been applied to estimate roller lifespan [27], with decision support algorithms developed by Liu [28].

When trying to implement the aforementioned research on a real conveyor, particularly the algorithm proposed by Liu [28], several unresolved issues arose. For example, Liu's proposal to measure only temperature is insufficient based on 16 years of operational experience and other scientific research (e.g., [5][4]). Moreover, relying solely on an arbitrary temperature limit is impractical due to changes in ambient temperature affecting bearing temperature. Additionally, the proposed method does not accommodate adjusting the theoretical model to real-world parameters and operational insights. Instead, it uses an arbitrary error function that generates incorrect results. Another issue is the inability to account for idlers with different characteristics and installation times. The operation duration of rolling bearings in conveyor idlers is influenced by external environmental conditions (temperature, humidity, air dust) and intrinsic parameters related to conveyor operation, such as rotational speed, which is a linear function of transport speed, and the forces acting on the idler and bearings.

The assumptions for calculating forces acting on the conveyor and idlers were developed by Hettler [29], Grimmer [30], and Gładysiewicz [31]. Limberg [32] and Greune [33] defined methods for determining belt tension, enabling the estimation of belt displacement on conveyor curves. Determining the forces acting on individual conveyor elements is a complex topic, thus being a subject of extensive research. The influence of belt tension on idler pressure was examined [34], and the distribution of contact forces between the belt and idlers was analyzed [35].

This article addresses the aforementioned gaps. The authors propose an innovative procedure adaptable to any belt conveyor, extending the methods to determine belt shifts on curved conveyor regions. For this research, measurements were conducted on a unique conveyor belt located in a mountainous area in China, with a total length of 12,461 meters. It should be emphasized that the research and methods presented in this article will complement the concept of a “digital twin” in the area of belt conveyors [36].

2. Material and methods

All measurements, studies, and simulations conducted in the article were performed on an existing belt conveyor. The examined conveyor is located in a forested and mountainous region in southeastern China. The conveyor was commissioned in 2009, with its construction completed a year earlier. The total length of the conveyor is nearly 12.5 km. Due to the complex terrain geometry, this complexity is also reflected in the conveyor's design, resulting in numerous curves and inclines. For the purpose of load analysis, the conveyor was divided into 61 sections characterized by common geometric features. Table 1 presents the initial and final sections of the conveyor. The conveyor was selected for the simulation due to the varying loads on the idlers resulting from the operating geometry. Figure 1 shows one of the curves of the tested object.

Table 1. Selected sections of the tested conveyor.

Index of Section	Horizontal length of sections	Height at end of section	Radius of horizontal curve	Radius of vertical curve
-	**m**	**m**	**m**	**m**
1	495,5	862,50	0,00	0,00
2	9,1	862,50	0,00	1000,00
3	341,5	860,00	0,00	0,00
4	1000,00	850,00	3000,00	0,00
5	219,70	848,00	1000,00	0,00
6	51,50	850,00	1000,00	-1000,00
7	163,80	856,00	1000,00	0,00
8	21,20	857,00	1000,00	500,00
9	56,80	857,00	1000,00	0,00
...	...	...	...	...
57	37,70	740,00	2000,00	-1250,00
58	194,00	740,00	2000,00	0,00
59	787,00	740,00	0,00	0,00
60	217,80	750,00	0,00	-1500,00
61	84,70	760,00	0,00	0,00

Figure 1. The curve on the tested conveyor.

Material transport is carried out using a conveyor belt driven by motor sets located in the loading and unloading zones. In the loading zone, there are four identical motors with a total power of 1.8 MW, while in the unloading zone, there are three motors with a total power of 1.68 MW. The critical value, i.e., the mass of the material, is measured using a belt scale, while the belt tension is measured using a load cell sensor. All measurement data is transmitted via an IoT-class system to a data analysis center. A schematic view of the tested system is shown in Figure 2.

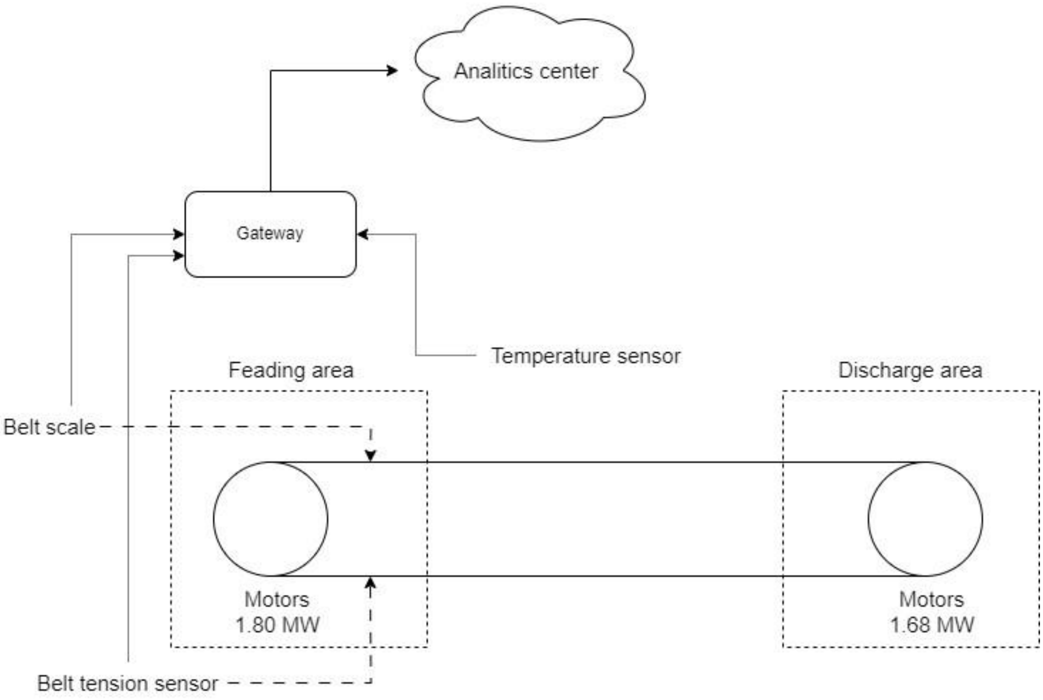

Figure 2. Schematic description of the tested conveyor.

3. Theory/calculation

The primary goal of the proposed method is to ensure the longest possible failure-free operation of the idlers in the belt conveyors, which requires estimating the theoretical life of the bearings inside them and then estimating the theoretical number of failures in time intervals. In the next step of the procedure, it is proposed to compare the collected theoretical results with the measurement results of the idlers in order to select the elements to be replaced.

3.1. Determination of the forces acting on bearings

In modern belt conveyor installations, there are frequent curves and hills. Due to changes in the geometry of the route, there are displacements of the belt and the transported material relative to the conveyor idlers. This constantly changing geometry also requires the use of different stands for the idler skates and their rotation relative to the route level. The complex geometry, therefore, results in different forces acting on the idlers in different sections of the route. The forces required to determine the service life of idlers are shown in Figure 3. The expression representing the forces ($F_{N,k}$) acting on the idlers is presented in Formula 1.

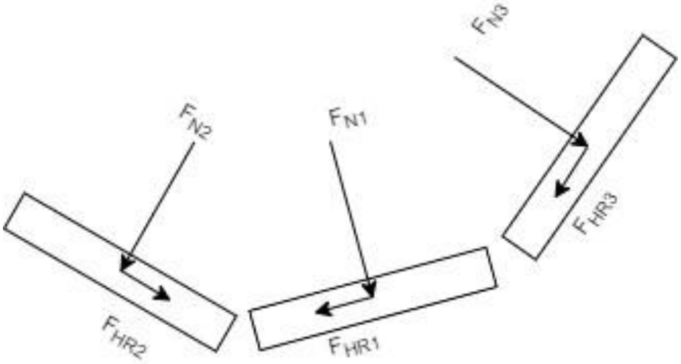

Figure 3. Distribution of the most important forces acting on the idlers placed on the stand.

$$F_{N,k} = F_{NB,k} + F_{NG,k} + F_{NH,k} + F_{NMB,k} + F_{NMG,k} + F_{N} \qquad (1)$$

k idler position on the idler stand

F_{NB} normal force component from the belt weight and troughability

F_{NG} normal force component from the conveyed material

F_{NH} normal force component from the belt tension in the horizontal curve

F_{NMB} normal force component from the centrifugal force of the belt weight in the horizontal curves.

F_{NMG} normal force component from the centrifugal force of the material weight in the horizontal curves

F_{NV} normal force component from the belt tension in the vertical curves

To determine the forces acting parallel to the idler axis, it is necessary to determine the FHR force using Formula 2.

$$F_{HR,k} = sign(\varphi_k) * F_{N,k} * \mu_k * \cos\varphi_k \tag{2}$$

φ effective camber angle calculated as a result of the rotation of the idler stand in all three dimensions

μ friction coefficient between the belt and the idler

In order to correctly determine the forces acting on the conveyor idlers, it is also necessary to determine the position of the belt in relation to all the idlers of the tested conveyor. To determine the position of the belt, the following forces must be balanced iteratively: the force acting perpendicular to the direction of belt movement (friction force), the horizontal component of the force due to the material being moved, the horizontal component of the force resulting from the weight of the belt, the horizontal component of the force due to the centrifugal force of the belt's weight on the horizontal curve, the horizontal component of the force from the centrifugal force of the weight of the material on the horizontal curves, and the horizontal component of the force resulting from the belt tension on the vertical curves. The independent variable in the above equations is the displacement of the belt relative to the idlers. The procedure for determining these forces is shown in Figure 4.

Due to the uneven distribution of the pressure on the conveyor idlers, which results from the inclination and the distribution of material on the conveyor, in order to estimate the distribution of forces, it is also necessary to determine the forces acting on individual bearings. The specificity of the conveyor idlers, which are placed at different angles, means that in addition to the forces acting perpendicularly F_r to the bearing axis, the forces acting parallel F_a should also be considered. The expression for determining the equivalent dynamic bearing load P takes the form of Formula 3, where X_1 is the radial load factor, and X_2 is the axial load factor.

$$P = X_1F_r + X_2F_a \tag{3}$$

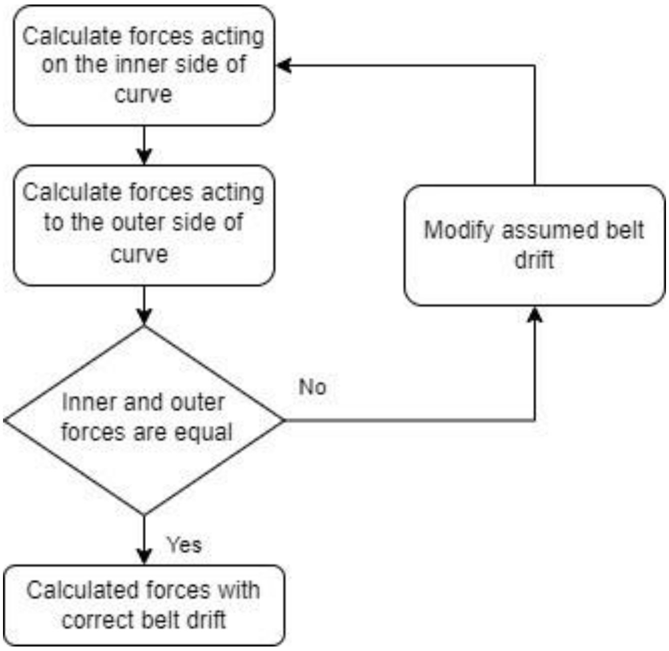

Figure 4. Procedure for determining forces, including belt slippage.

3.2. Determination of the service life of idlers

The service life of the idlers is closely correlated with the life of the bearings since the bearings are the only moving element. The life of the bearings in accordance with ISO 281 is determined by the formula (4), where L_{10} denotes the durability understood as the number of revolutions for which at least 90% of bearings in a given group will be functional, and C denotes the nominal dynamic load capacity, which is the catalog value of a given bearing. P denotes the bearing equivalent dynamic load determined according to Formula 3. The p-value depends on the type of bearing, which in the case of ball bearings is 3.

$$L_{10} = \left(\frac{C}{P}\right)^p \tag{4}$$

Because the values resulting from Formula 4 vary depending on the manufacturer and the certainty to be achieved, the above formula is supplemented with modifiers to account for the level of certainty (e.g., 90%, 95% or 99%) and the dependence of operating conditions. The modified expression is indicated by Formula 5, where a_1 is the coefficient related to the level of confidence and a_2 is the coefficient related to the conditions in which a given bearing operates.

$$L_{nm} = a_1a_2\left(\frac{C}{P}\right)^p \tag{5}$$

Since the bearings in the belt conveyors experience different loads due to changing external conditions, it is necessary to determine the average value of the L_{10} coefficient by Formula 6, where L_{10n} is the value of the coefficient under given operating conditions, and U_n is the share of the given conditions in the overall operating time of the bearing.

$$L_{10m} = \sum_n^1 \left(\frac{1}{\frac{U_n}{L_{10n}}} \right) \tag{6}$$

Based on the research [28], it was proposed that the time distribution of the failures is characterized by the distribution F(x) resulting from the Weibull distribution (7)

$$F(x) = 1 - e^{-\left(\frac{x}{\propto}\right)^{\beta}} \tag{7}$$

The β coefficient is a parameter responsible for the ball bearing shape and is defined as 10/9. The α coefficient is a scale parameter and is closely correlated with the parameters a_1 and a_2. The parameter x represents the ratio of the actual working hours to the parameter L_{10}. In the works [31], the following coefficients were proposed as the distribution function.

$$F(x) = 1 - e^{-\left(\frac{x}{7.58}\right)^{10/9}} \tag{8}$$

3.3. Model fitting

Since the initial adoption of parameters β and α may cause discrepancies between the actual number of failures and the predicted number, it is necessary to designate a procedure to adjust the model to the actual measurements and observations. The Weibull distribution can be derived using mathematical transformations in a form in which the sought coefficients can be estimated using linear regression. The distribution transformation takes the form of Formula 9.

$$y = \beta x' + a \tag{9}$$

Where $y = \ln\left(-\ln(1 - F(x))\right)$, $x' = \ln(x)$ and $a = -\beta \ln(\alpha)$

To fit the model, an appropriate pool of failed idlers, along with information about the actual hours worked, must be collected.

3.4. Procedure for designating groups

Following the considerations presented in Section 3.1, different forces act on the conveyor idlers depending on the location of the idlers on the stand as well as on specific sections of the conveyor belt. The curvature of the route and the idler stand have a particularly large impact on the experienced forces. The close correlation of the occurring forces (Section 3.2) with the expected life of the idlers makes it necessary to create groups that will then be analyzed in terms of the risk of failure. To determine the appropriate groups, it is proposed to take into account the location of the idler on the stand and the location along the conveyor route, with particular emphasis on the curved sections. In the next step, it is proposed to group the idlers according to the forces acting perpendicular and parallel to the idler axis. The proposed grouping procedure is presented in Figure 5.

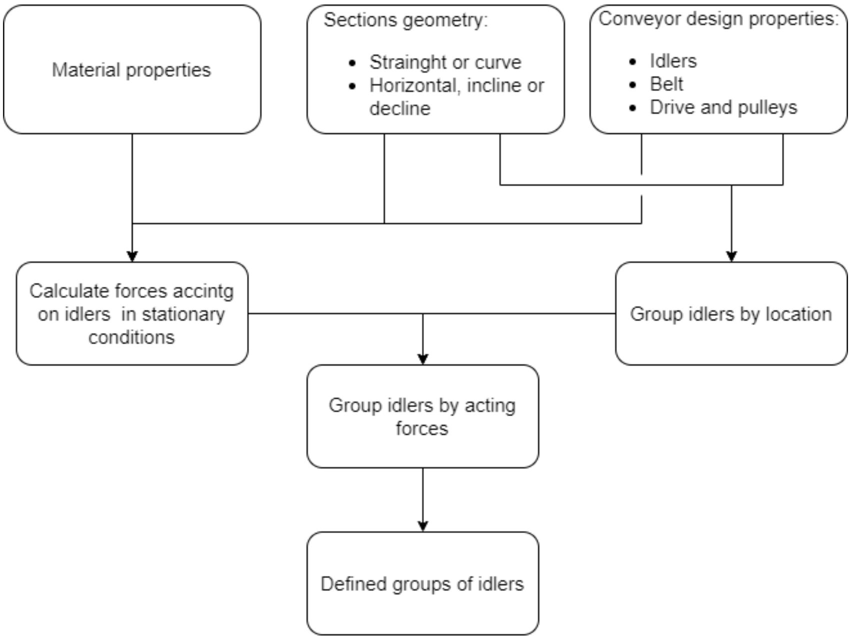

Figure 5. Procedure for determining idler groups.

3.5. Decision-making algorithm

The key problem when performing inspections is identifying the idlers that need to be replaced. While detecting the failure itself does not cause significant difficulties, selecting idlers at an early stage of degradation can be troublesome. For this reason, creating an algorithm supporting the decision-making process during service significantly increases the reliability of the device and reduces the number of redundantly replaced components. The operation of the algorithm is based on several pillars: measuring the conveyor parameters, determining the forces acting on the conveyor idlers, determining the theoretical idler lifetime, adjusting the acceptable deviations of the idler parameters, and adjusting the theoretical model of the idler lifetime. The measurement data is divided into two categories: continuously collected and collected during inspection. The data collected continuously includes the conveyor operating parameters such as material quantity, transport speed, external temperature, preload and the pulley torque. The data collected during inspections include the temperature values, vibration levels, sound intensity and the background impact levels. Since a full range of measurements may not be available in all installations, the algorithm has been designed so that it can also operate on a reduced set of input data. This means that if it is not possible to measure the vibration level, the algorithm will still function when limited to sound intensity and temperature data.

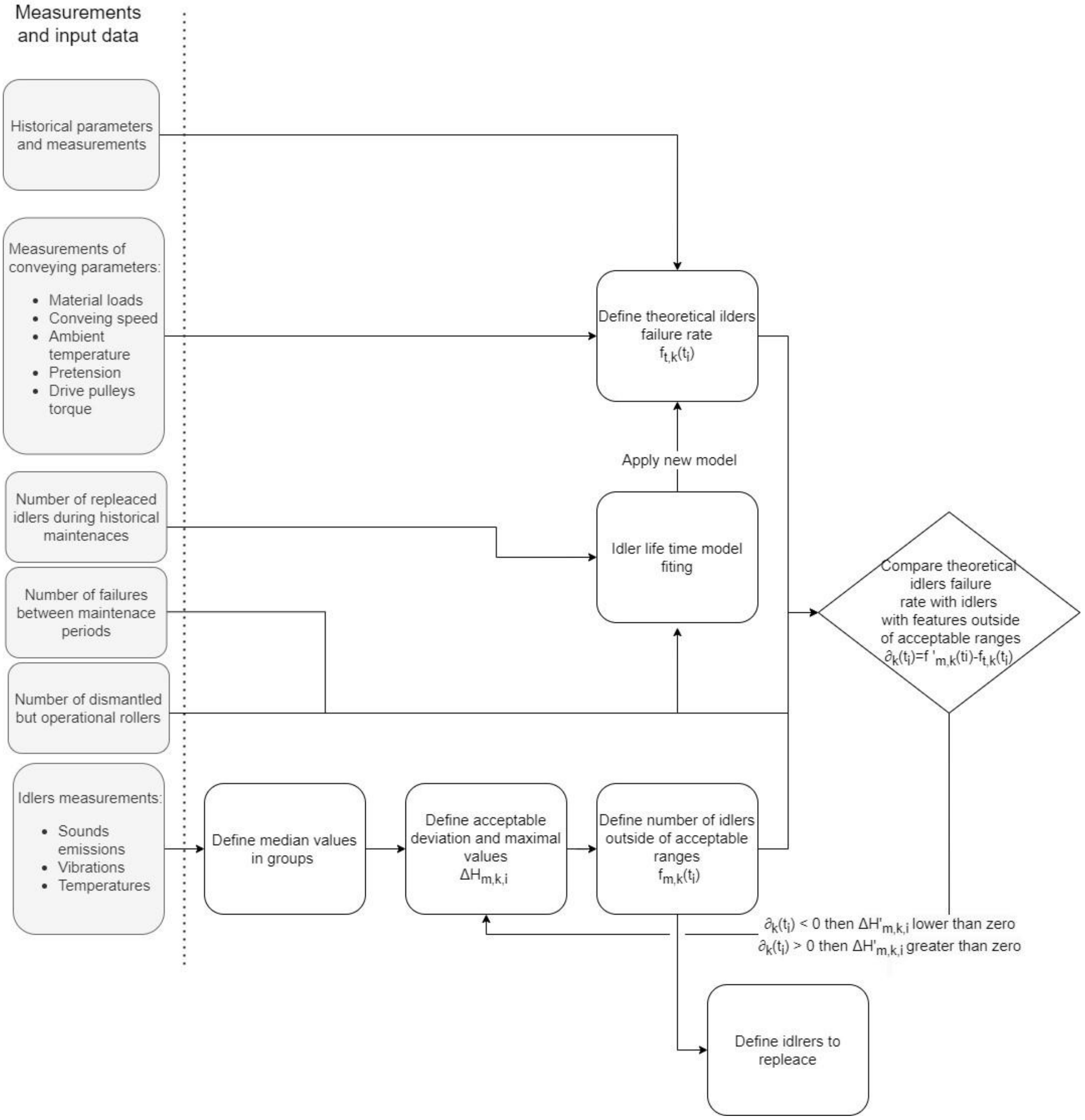

Figure 6. Decision-making algorithm during conveyor belt inspection.

In order to distinguish between idlers operating with different loads and in different external conditions, it was proposed to divide the idler population into groups in accordance with Section 3.4. Then, when performing the review, the algorithm will determine the median value of the examined phenomena and determine the permissible deviation. The level of the allowable deviation should be adjusted based on the accuracy of the previous estimates. The deviation from the median of the parameter values in a given group is proposed as an indicator, marked as $\Delta H_{m,k,i}$, and $\Delta H'_{m,k,i}$, the correction value. Where *k* stands for the group number, *m* for the type of measurement, and *i* the index of the period of a given review. After each inspection, the value of the permissible deviation should be adjusted to match the actual number of idlers requiring replacement, this is to both avoid unnecessary replacement of functional idlers and to prevent failures and interruptions in the operation of the conveyor belt.

$$\Delta H_{m,k,i} = \Delta H_{m,k,i-1} + \Delta H'_{m,k,i} \tag{10}$$

In order to determine the correction value $\Delta H'_{m,k,i}$, it is proposed to determine the difference between all the replaced idlers in a given group since the previous inspection $\mathrm{f}'_{m,k}(\mathrm{t}_i)$, and the number of idlers to be replaced. The procedure should be performed in accordance with the theoretical model $\mathrm{f}_{t,m,k}(\mathrm{t}_i)$. Where $\mathrm{f}'_{m,k}(\mathrm{t}_i)$ is the number of idlers with parameters exceeding the current permissible deviation $\mathrm{f}_{m,k}(\mathrm{t}_i)$, which is corrected for the number of failures occurring in the periods between inspections and the redundantly replaced idlers.

$$\partial_k(\mathrm{t}_i) = \mathrm{f}'_{m,k}(\mathrm{t}_i) - \mathrm{f}_{t,m,,k}(\mathrm{t}_i) \tag{11}$$

The model determining the theoretical number of idlers requiring replacement is described in Sections 3.1 to 3.4. The advantage of the proposed algorithm is the ability to adjust the model during the operation of the monitored installation. The authors recommend using the Weibull distribution. However, due to the modular structure of the proposed solution, it is also possible to use other models, e.g., the Poisson distribution, other analytical models, or machine learning algorithms. The entire algorithm is adjusted to real conditions based on: - the number of idlers that had been physically replaced, including any excess idlers replaced, - the operating time of the physically replaced idlers compared to the forecast ones, - the modification of the relative values of deviations of the measured parameters. The complete decision-making algorithm is shown in Figure 6.

4. Results and discussion

The research results include two components. The first component is the measurement of the actual parameters of the belt conveyor located in China, as described in Section 2. The second component is the analytical calculations of the forces acting on the conveyor idlers and simulations of the algorithm operation, along with simulations of the idler failures and conveyor inspections. Due to the advanced algorithm, the simulation was created as a separate application written in the .Net environment. The operating parameters of the conveyor are described in Table 2.

Table 2. Conveyor operating parameters.

Conveying speed	5 m/s
Throughput	2400 t/h
Idlerstand spacing	1.5 m
Conveyor length	12461 m
Total motor power	3480 kW
Belt width	1.2m

Based on the presented operational and geometric parameters of the conveyor, calculations were made of the forces acting on the conveyor idlers in the section containing an arc with a radius of 1000 m in the straight section. Table 3 summarizes the calculation results.

Table 3. Forces acting on the bearings in the idler and L_{10h} in the nominal operating parameters of the conveyor.

Idler position on Idler stand	Bering position	Acting forces [N]		L_{10h}	
		Straight	Curve	Straight	Curve
Left (c)	1	364.79	211.06	184000	250000
	2	422.74	329.42	119000	200000
Right (b)	1	422.74	491.86	119000	75600
	2	364.79	561.95	184000	50700
Middle (a)	1	837.13	823.11	20700	20700
	2	837.13	823.11	20700	20700

After accounting for material shift, it is evident that the idlers placed on the outer side of the arc (idler position right) are loaded more than the idlers placed on the inner side (idler position left), as a result, the forecasted idler operating time is significantly shorter. In both scenarios, the center idlers are under the greatest load. This distribution of forces proves that when considering the operating time of individual idlers, the position of the stands and the geometry of the conveyor belt should be accounted for.

Because conveyors are very durable installations and considering that idler failure, depending on the location, may have disastrous consequences, the simulation covers 7,100 days of operation. Such a long simulation period results from the characteristics of the tested conveyor, which was built in 2008. Therefore by the time of publication, it has been operating for 16 years. The simulation also includes changing the characteristics of the idlers mounted on the conveyor. Accounting for the installation of another type of idler results from installation experience, namely in the examined case, it was necessary to install idlers from another manufacturer due to the need to reduce the noise generated during operation.

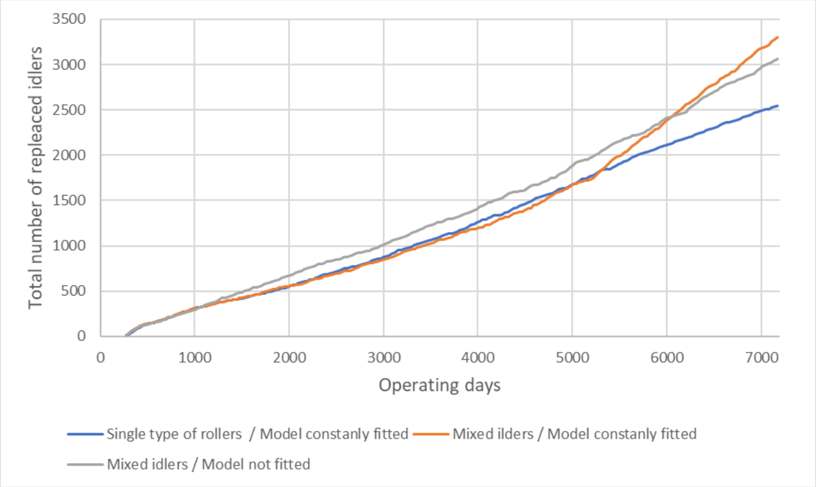

Figure 7. Total number of replaced idlers without knowledge of the failure distribution.

Figure 7 shows the results of the total number of replaced idlers within three defined groups, namely: iteratively fitted single-type (Identical) idlers, constantly fitted mixed-type idlers, and mixed-type idlers (not fitted). The installation of idlers with different characteristics was initiated halfway through the period under study. Figure 6 shows the case where the failure distribution is initially unknown, forcing the model to be fitted based on a statistically significant sample. The sample was obtained after 1,200 days of operation and from that moment on, the graphs diverge between the fitted and unfit models. Figure 7 shows a similar simulation, however, in this scenario, the distribution of idler failures is known. All studies whose results are presented in Figures 7 and 8 refer to the middle roll (position a)

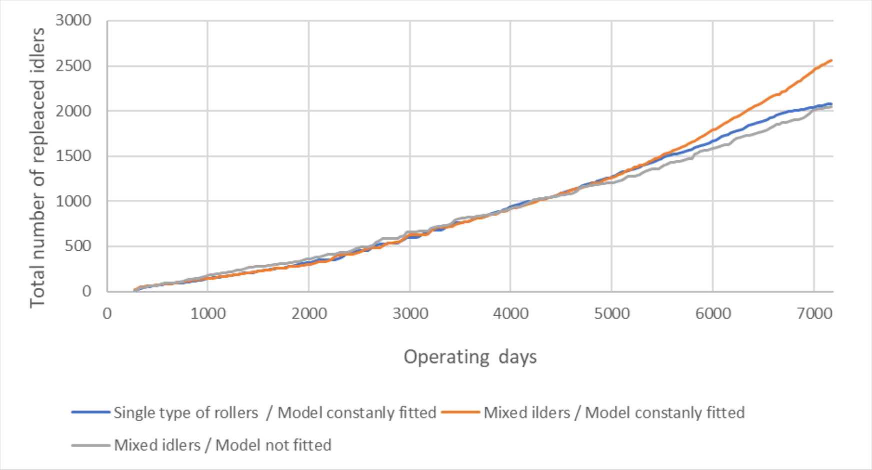

Figure 8. Total number of replaced idlers when failure distribution is known.

Figure 9 shows the result of the simulation of idler failure while considering the differentiation of the position of the idlers on the stand. The analyses show that the location of the idler is very important in the context of failure risk analysis. The total number of failures of the middle idlers (position a) for the same number of idlers in a given population is over 2,500 pieces, while for the idlers placed on the side of the stand (position c), the total number of replaced idlers is less than 250 pieces.This situation occurs because the middle idlers (a), in the analyzed case, are subjected to greater loads than the idlers located on the left side of the idler set (b).

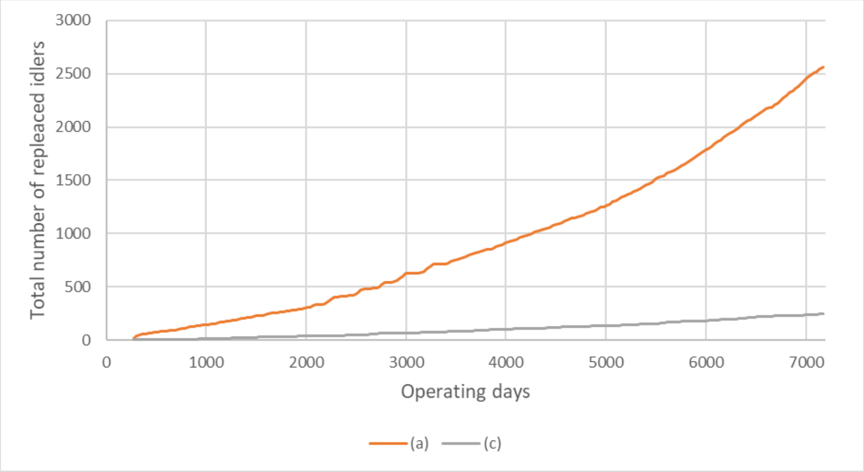

Figure 9. Total number of replaced idlers for various positions of the tested idlers.

Figure 10 shows the development of the relative permissible maximum deviations for the three scenarios considered. The conclusions drawn from the values are not universal because they strongly depend on the simulation parameters, as well as on specific operating conditions, which may be both external and related to the conveyor parameters. However, the intrinsic value is that the use of relative values allows for the reduction of excessively replaced idlers and the number of failures causing the conveyor to break down. This is because assuming a low permissible deviation results in the removal of functional elements while assuming a too-high permissible deviation results in a significant number of failures requiring emergency downtime. During the entire period of study, in the scenario of the constantly fitted model, 79 incidents of such failures were obtained in the simulation, while in the case of the not fitted model, as many as 129 incidents.

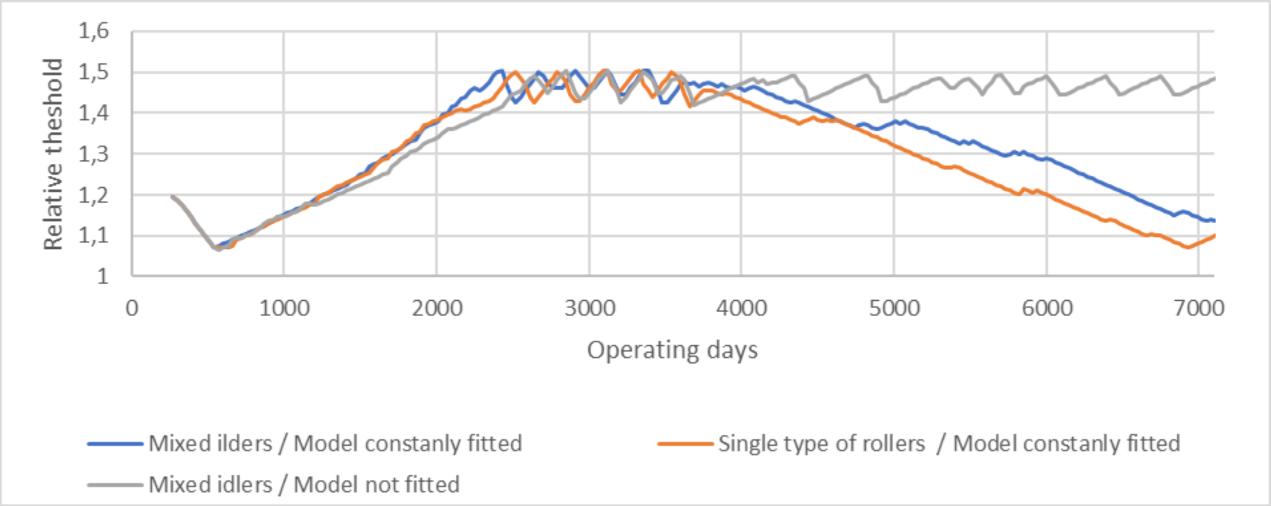

Figure 10. Relative acceptable difference from normal operation conditions.

Figure 11 shows a graph of the expected time needed for 3% of the idlers to fail. The graph in the first half shows large intervals needed for idler damage to occur. The results fully match the measurement data from the conveyor. For instance, in the previous work conducted across 16 years, the number of idlers requiring replacement was a maximum of 1% per year.

The noticeable increase in required intervals is due to the installation of new idlers. However, in the second part of the simulation period, the interval between replacements decreases because the idlers are reaching the end of their service life and need to be replaced. This is also evident in Figure 9, where the algorithm becomes much more sensitive to anomalies.

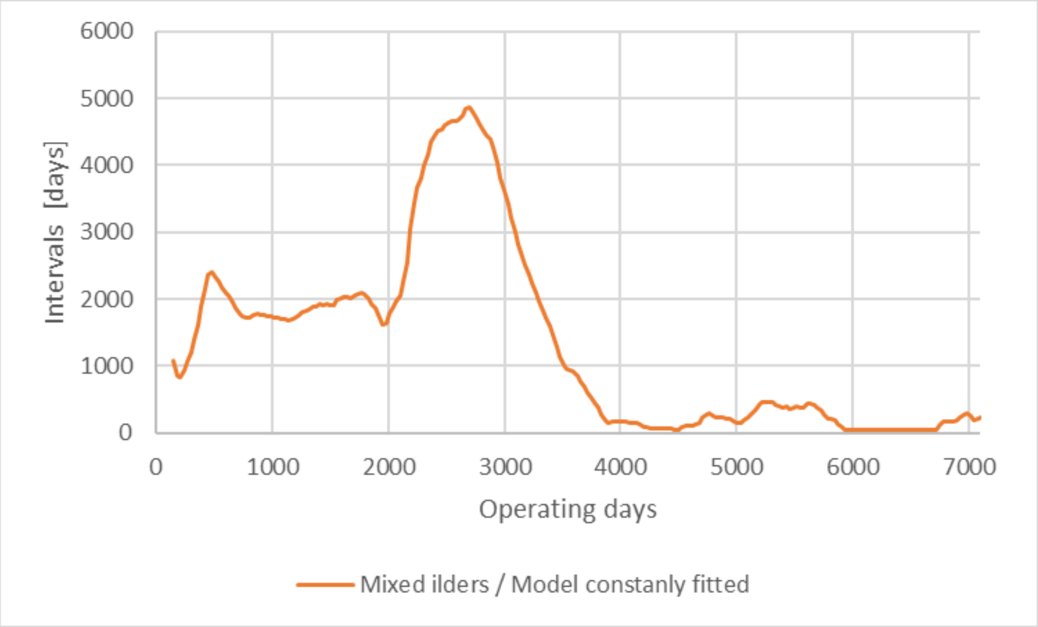

Figure 11. Expected period for 3% of idlers to fail.

Since the tested algorithm is based on fitting models using data collected from the physically replaced idlers, the parameters of the Weibull distribution changed throughout the simulation period. Figures 12 and 13 show changes in the alpha and beta coefficients. Changes are shown from day 3000 onwards because the model fitting begins only after a statistically significant number of sample measurement data has been collected. During the second half of the simulation graphs presented, a change in the parameters between the group containing one type of idler and the group containing mixed idlers is clearly visible, this is because, according to the simulation, the second type of idler began to be installed during this part of the simulation. The simulation proved that the model adapts to changing operating conditions and the characteristics of the analyzed idlers.

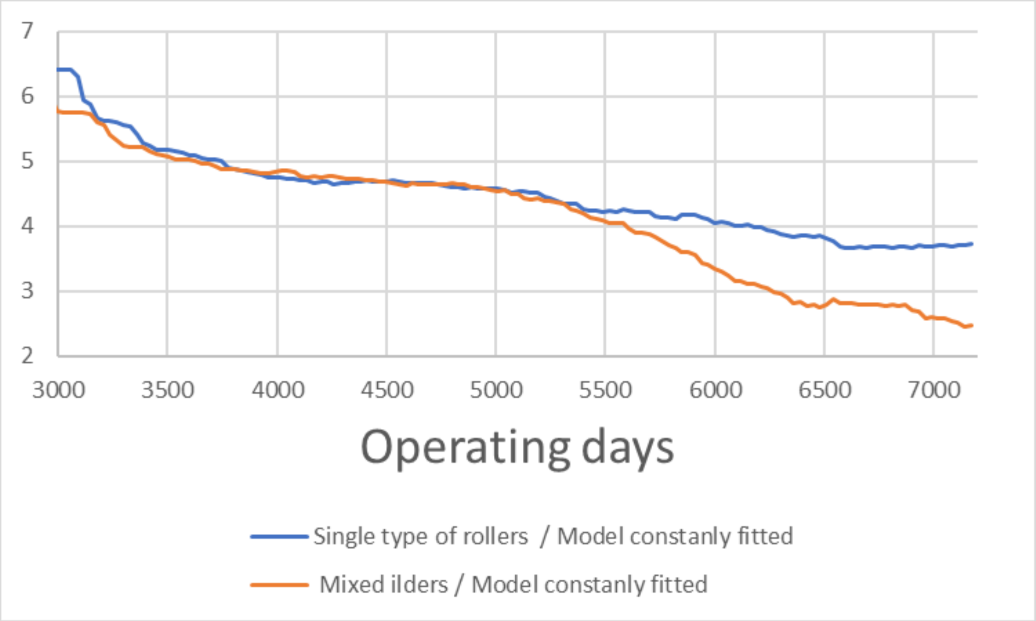

Figure 12. Changes in the alpha coefficient of the Weibull distribution.

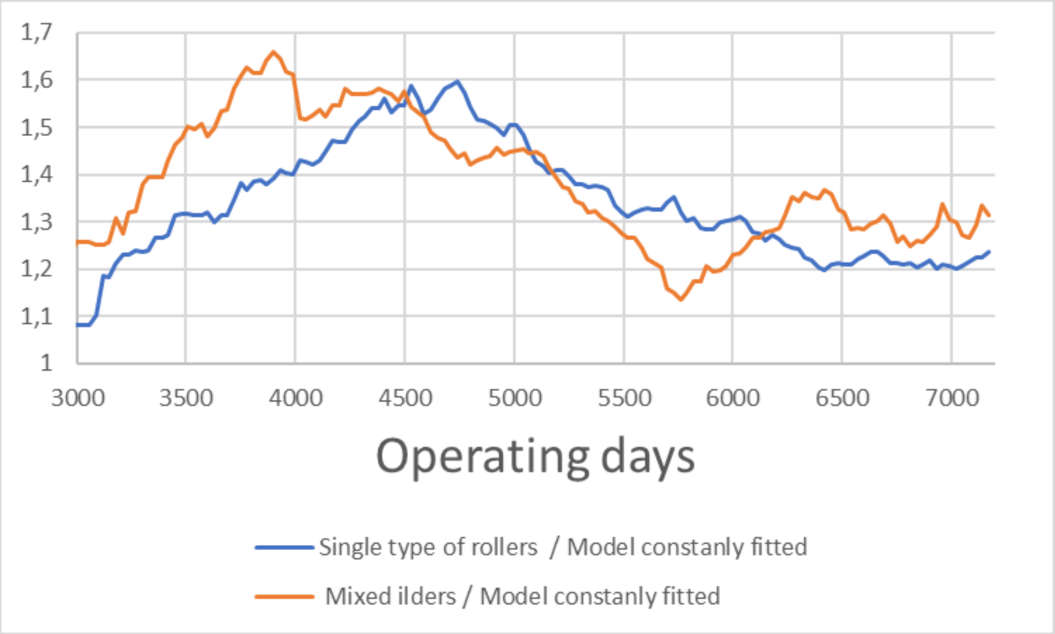

Figure 13. Changes in the beta coefficient of the Weibull distribution.

5. Conclusions

The article presents an innovative decision-making algorithm related to the inspection of belt conveyor idlers. The proposed idea significantly expands the existing concepts, in particular in terms of considering variable operating conditions of the device and the load distribution characteristics, which enable the adaptation of the measured values to the technical capabilities of a given installation, and most importantly, introduces methods of automatic adjustment of the algorithm. The simulations confirmed the possibility of creating an algorithm supporting decisions regarding the inspection of conveyor idlers in such a way as to ensure high reliability and continuity of operation of the device. By considering a different set of measurement data for conveyor idlers, a limited number of sensors can be used. However, this reduces the certainty with regard to the reliability of the conveyor, due to the risk of detecting a failure at too late a stage [4]. The proposed approach can significantly reduce the risk of critical failures and the ability to plan inspections at appropriate time intervals. As part of subsequent research, it is proposed to investigate how limiting the amount of measurement data affects the certainty of selecting idlers for replacement and the reliability of the devices. In addition, it is proposed to explore other types of models simulating the distribution of conveyor idler failures. In the future, further monitoring of the tested conveyor is also planned in order to assess the correctness of the model fit and the number of idler failures.

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