RELIABILITY FUNCTION FIT REGARDING ONE JAW CRUSHER LINERS

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ABSTRACT: The paper deals with some formulations in resource assessment function for lining parts in one jaw crusher operating in a Bulgarian gold ore mine. This crusher is operating as a sizing crusher for full ore productivity flow in preventing oversize material fragments to fall on the belt conveyor. In critical view the reliability of that particular crusher influences on the overall mine productivity. Reliability calculations of that machine are based on mathematical assumptions and interpolations using Weibull models. The presented case reviews the modelling with two major interpolation techniques and compares them with estimated data from on-site exploitation. Fitting of the resource function is used in calculation of the reliability, survival and hazard functions for two main lining plates – the lining plate of a moving jaw and the lining plate of a stationary jaw. The research envelopment is the median regression estimation (MRE) method and the maximum likelihood estimation (MLE) method used for density function fitting procedures. The compared fitting procedures are implemented in OpenOffice Calc spreadsheet for MRE and R Studio for MLE algorithm. The fitted functions are compared in a graphical way, and there are some tables presenting the calculated parameter values. Weibull model functions are used to present some diagrams in which it is easy to investigate valuable survival and hazard over time.

Keywords: lining plates, wear, resource, jaw crusher, Weibull reliability function, Weibull model fit

ИЗВЕЖДАНЕ НА ФУНКЦИЯ НА НАДЕЖДНОСТТА ЗА ОБЛИЦОВКИТЕ НА ЧЕЛЮСТНА ТРОШАЧКА

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РЕЗЮМЕ: В работата се разглеждат постановки при определяне ресурса и надеждностната функция на облицовките на челюстна трошачка при експлоатационни условия на мина за добив на златна руда в България. Ресурсните изчисления засягащи надеждността обичайно използват математически допускания относно предполагаемият характер на математическата функцията на надеждността, от което се определя и интерполационният метод за извличане на самата функция. В настоящата разработка са използвани два метода за интерполация на функциите на надеждността чрез разпределението на Вейбул. Получени са и са изследвани са функциите на отказите, кумулативната функция на отказите, функцията на надеждността и функция на опасността. На базата на събраните данни са проведени няколко интерполации съгласно статистическото разпределение на Вейбул. Използвано е двупарметрично разпределение на Вейбул като са сравнени два интерполационни метода - с използване на неитеративна интерполация в OpenOffice Calc и итеративна интерполация в RStudio. Представени са резултати в графичен и функционален вид за формения и мащабния параметър на разпределението на Вейбул. Оценката на разпределението е проведена в графичен вид спрямо кумулативните функции на разпределението и плътността на вероятностите на разпределението.

Ключови думи: облицовъчни плочи, износване, ресурс, челюстна трошачка, Вейбул надеждностна функция, Интерполиране на функцията на Вейбул
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Introduction

Resource calculations, reliability models and their calculations in complex mechanical ore processing machines are multifactor functions. The revealing of adequate mathematical models is a complex job which is usually done by graphical representation. Current research deals with some formulations in resource assessment function for lining parts in one jaw crusher operating in a Bulgarian gold ore mine. The presented method uses mathematical interpolation procedures in comparison with graphical presentation in reveal process.

The jaw crusher (Minin, 2017; Minin, 2012) is a basic machine in first stage ore and rock breakage placed in ore processing and construction material disintegration. That crusher is operating as a sizing crusher for full ore productivity flow in preventing oversize material fragments to fall on the belt conveyor. In critical view the reliability of that particular crusher is influenced by the full mine productivity flow. In case of estimating the product performance regarding the jaw crusher, reliability and recourse calculations are part of its lifecycle and it has to be subjected to its (PLM) product lifecycle management system and maintenance system.

The reliability of the machine is based on some mathematical idealisation and interpolations using some exponential, Gaussian (normal), lognormal, Weibull models and etc. Previous research (Minin, 2017) is focused on the exponential model with its own advantages and disadvantages, and some other researchers (Savov, 2017; Murthy, 2004; Dimitrov, 1994) tend to be using an improved model containing composite exponential function. Widely used are the Weibull models (Weibull 1951, Murthy 2004) in density function fitting, so the presented paper is focused on their application with regard to the reliability of jaw crusher's lining plates.

The presented particular case reviews the case with two major interpolation techniques (Delignette-Muller, 2014; Ricci, 2005) and compares them in estimated data from on-site exploitation. Fitting of the resource function is used in calculation of the reliability, survival and hazard functions for two main lining plates - the lining plate of a moving jaw and the lining plate of a stationary jaw.

THEORY

The reliability theory widely uses the statistical Weibull distribution function (Weibull, 1951) despite the fact that it uses heavy mathematical and software application.

The Weibull probability distribution (density) function /pdf/ is defined as a three parameter function:

$$f(\tau)=\frac{\beta}{\eta}\cdot\left(\frac{\tau-\gamma}{\eta}\right)^{(\beta-1)}\cdot\exp\left[-\left(\frac{\tau-\gamma}{\eta}\right)^{\beta}\right] \quad (1)$$

, where:

- $\beta>0$ - shape (slope) parameter;
- $\eta>0$ - scale parameter;
- $\gamma\in(-\infty,\infty)$ - location parameter;

, and integral (cumulative/CDF/) distribution function is:

$$F(t)=\int_{-\infty}^{t}f(\tau)\,d\tau=1-\exp\left[-\left(\frac{t-\gamma}{\eta}\right)^{\beta}\right], \quad (2)$$

Often the two parameter Weibull function is derived from a zeroing location parameter γ = 0 so the function looks like:

$$f(\tau|\gamma=0)=\frac{\beta}{\eta}\cdot\left(\frac{\tau}{\eta}\right)^{(\beta-1)}\cdot\exp\left[-\left(\frac{\tau}{\eta}\right)^{\beta}\right] \quad (3)$$

$$F(t|\gamma=0)=\int_{-\infty}^{t}f(\tau)\,d\tau=1-\exp\left[-\left(\frac{t}{\eta}\right)^{\beta}\right], \quad (4)$$

The survival function *S(t)* or reliability function is defined as an admission life period to exceed some time interval *P(T>t)* so the function is:

$$S(t)=1-P(T\le t)=1-F(t)=exp\left\{-\left(\frac{t-\gamma}{\eta}\right)^{\beta}\right\} \quad (5)$$

, and the hazard function is defined by:

$$h(t)=\frac{f(t)}{S(t)}=\frac{f(t)}{1-F(t)}, \quad (6)$$

$$h(t|\gamma=0)=\frac{\beta}{\eta^{\beta}}\cdot t^{(\beta-1)} \quad (7)$$

The cumulative hazard function is:

$$H(t)=\int_{0}^{t}h(t)\,dt=\int_{0}^{t}\frac{\beta}{\eta^{\beta}}\cdot t^{(\beta-1)}\,dt=\left(\frac{t}{\eta}\right)^{\beta}, \quad (8)$$

or

$$H(t)=-\ln\left[S(t)\right], \quad (9)$$

The reliability functions are defined in upward way, but the computational problems appear at the parameter estimation method about the Weibull statistics (Delignette-Muller, 2014; Ricci, 2005; Murphy, 2004).

One of the easiest method is achieved by median rank regression estimator /**MRE**/ using the equation:

$$\sum_{k=i}^{N}\binom{N}{k}\cdot Z_i^{k}\cdot(1-Z_i)^{(N-k)} \quad (9)$$

, approximated with Bernard algorithm to:

$$F_T(t_i)\cong Z_i\cong\frac{i-0.3}{N+0.4} \quad (10)$$

, where:

N, $number$ - total number of data;

i - data point ascending rank;

After some transformations shown below:

$$1-F_T(t)=exp\left\{-\left(\frac{t}{\eta}\right)^{\beta}\right\} \quad (11)$$

$$\ln\left\{\ln\left[\frac{1}{S_T(t)}\right]\right\}=\beta\cdot\ln\left(\frac{t}{\eta}\right)=\beta\cdot\left[\ln(t)-\ln(\eta)\right] \quad (12)$$

, the following equation can be obtained:

$$y=\beta\cdot x-\beta\cdot\ln(\eta)=A_1\cdot x+A_0$$

or:

$$\left|\begin{array}{l}\beta=A_1\\ \beta\cdot\ln(\eta)=-A_0\end{array}\right.\Rightarrow\left|\begin{array}{l}\beta=A_1\\ \eta=exp\left(-\dfrac{A_0}{A_1}\right)\end{array}\right. \quad (13)$$

According to these formulas a non-iterative algorithm in spreadsheet can be easily created as shown in the next section. Usually MRE algorithm is represented as values in Table 1 and as a graphical representation of equation (16) in Fig. 1. The advantage of that method is the ability of revealing a small amount of data, despite the fact that it is fast and has a simple algorithm.

Another algorithm is the maximum likelihood estimation /**MLE**/ (Delignette-Muller, 2014) which uses a product of iterative logarithmic and power functions for independent and identical parametrical distributions /iid/ $f(x_i|\theta)$, in which the parameters $\theta_1, ..., \theta_j$ are extracted in function maximisation for:

$$L(\theta)=\prod_{i=1}^{n}f(x_i|\theta) \quad (14)$$

, where:

θ_j - function parameters;

x_i - value for variable x;

n - total count of data x_i and

$f(x_i|\theta)$ - probability density function.

Parameter θ_j extraction uses:

$$\max\left[L(\theta)\right]\Rightarrow\frac{dL(\theta)}{\theta}=0 \quad (15)$$

or

$$\max\left\{\ln\left[L(\theta)\right]\right\}\Rightarrow\frac{d\ln\left[L(\theta)\right]}{\theta}=0 \quad (16)$$

, and about particular Weibull distribution:

$$L(t|\beta,\eta)=\prod_{i=1}^{n}f(t_i|\beta,\eta)=$$

$$=\prod_{i=1}^{n}\left[\frac{\beta}{\eta^{\beta}}\cdot t_i^{(\beta-1)}\cdot exp\left\{-\left(\frac{t_i}{\eta}\right)^{\beta}\right\}\right]=$$

$$=\left(\frac{\beta}{\eta^{\beta}}\right)^{n}\cdot\prod_{i=1}^{n}t_i^{(\beta-1)}\cdot exp\left\{-\left(\frac{\sum t_i}{\eta}\right)^{\beta}\right\} \quad (17)$$

The upper function can be simplified by using a logarithm, so:

$$ln\left\{L\left(t\middle|\beta,\eta\right)\right\} =$$

$$= ln\left[\left(\frac{\beta}{\eta^{\beta}}\right)^{n}\cdot\prod_{i=1}^{n} t_i^{(\beta-1)}\cdot exp\left\{-\left(\frac{\sum t_i}{\eta}\right)^{\beta}\right\}\right] =$$

$$= n\cdot ln(\beta) - n\cdot ln\left(\eta^{\beta}\right) + (\beta-1)\cdot\sum_{i=1}^{n} ln(t_i) - \sum_{i=1}^{n}\left(\frac{t_i}{\eta}\right)^{\beta} \qquad (18)$$

The theoretical way is given by those formulas (14 - 18) and the computation way is quite complicated, with implementation of computational iterative algorithm (Delignette-Muller, 2014).

Data and results

The particular estimation about parameters of failure data for jaw crusher's lining plates is described. The data is represented as the point on a lining plate changing according to the cumulative productivity Q_{int}, which is easy to recalculate in relative productivity:

$$Q_i = Q_{Ci} - Q_{Ci-1},\, t \qquad (14)$$

, respectfully in average hour productivity $Q_h, t/h$ working hours are:

$$t = \frac{Q_i}{Q_h},\, h \qquad (15)$$

The median rank is calculated by equation (12), and the regression parameters according to equation (13); Fig.1 and 4 represent the regression:

$$\left| \begin{array}{l} ln(t) \\ ln\left\{ln\left[\dfrac{1}{S(t)}\right]\right\} \end{array} \right. \qquad (16)$$

The survival function *S(t)* and the hazard function *h(t)* are calculated in Table 1 at particular points.

Data extractions represent a real lining plate changing for different plates (Minin, 2017), the first extract (D1) shown in Table 1 is for the lining of a moving jaw, and the second extract (D2) shown in Table 2 is for the lining of a stationary jaw in one and same jaw crusher.

The calculations shown for D1 and D2 and conducted in the same way with the upper formulations give different statistical results. Clearly, the large data (Table 2) quotation gave better MRE regression parameters shown on Fig.4 but there are still issues about the distribution fit.

As shown on Fig. 3 and Fig. 6, the data histogram compared to the fitted distribution shows a difference in the peak height, however, some small shift differences can easily be neglected.

Table 1. *First data extract (**D1**) and MRE calculations*

time	R	time	MR	1/(1-MR)	ln(t)	ln(ln(1/S))	results		
156					5.049	-3.996	***A0***	-19.389	
1235					7.119	1.387	***A1***	2.9702	
608					6.337	-0.557	**R²**	0.8595	
	38	***sorted***	**MR**	1/(1-MR)	ln(t)	ln(ln(1/S))			
h	*№*	*h*							
C	*D*	*E*	*F*	*G*	*H*	*G*	*K*	*L*	*M*
928.6	*1*	155.9	0.0182	1.019	5.049	-4.0	β	2.9702	
607.1	*2*	378.8	0.0443	1.046	5.937	-3.1	η	683.92	
1110.7	*3*	387.6	0.0703	1.076	5.960	-2.6	γ	*0*	
732.1	*4*	391.7	0.0964	1.107	5.970	-2.3	T	1	y
746.4	*5*	391.9	0.1224	1.139	5.971	-2.0	t =	7300	h
475.8	*6*	397.7	0.1484	1.174	5.986	-1.8	S(t)	0.000	
1234.9	*7*	406.1	0.1745	1.211	6.007	-1.7	S(t), %	0	%
522.9	*8*	411.5	0.2005	1.251	6.020	-1.5	h(t)	0.461	
451.0	*9*	451.0	0.2266	1.293	6.111	-1.4	h(t), %	46.1	%
391.9	*10*	456.7	0.2526	1.338	6.124	-1.2	H(t)	4E+08	
482.3	*11*	464.0	0.2786	1.386	6.140	-1.1	T	1/2	y
502.1	*12*	468.7	0.3047	1.438	6.150	-1.0	t =	3650	h
378.8	*13*	474.5	0.3307	1.494	6.162	-0.9	S(t)	0.000	
679.3	*14*	475.8	0.3568	1.555	6.165	-0.8	S(t), %	1.6E-61	%
456.7	*15*	481.5	0.3828	1.620	6.177	-0.7	h(t)	0.118	
489.9	*16*	482.3	0.4089	1.692	6.179	-0.6	h(t), %	11.8	%
527.2	*17*	489.9	0.4349	1.770	6.194	-0.6	H(t)	5.6E+07	
995.2	*18*	502.1	0.4609	1.855	6.219	-0.5	T	1/12	y
406.1	*19*	522.9	0.4870	1.949	6.259	-0.4	t =	608	h
411.5	*20*	527.2	0.5130	2.053	6.268	-0.3	S(t)	0.494	
587.0	*21*	556.8	0.5391	2.169	6.322	-0.3	S(t), %	49.4	%
739.9	*22*	560.3	0.5651	2.299	6.328	-0.2	h(t)	0.003	
397.7	*23*	587.0	0.5911	2.446	6.375	-0.1	h(t), %	0.3	%
468.7	*24*	595.6	0.6172	2.612	6.390	0.0	H(t)	2.719E+05	
938.1	*25*	607.1	0.6432	2.803	6.409	0.0	T	1/24	y
560.3	*26*	658.4	0.6693	3.024	6.490	0.1	t =	304	h
749.2	*27*	679.3	0.6953	3.282	6.521	0.2	S(t)	0.914	
474.5	*28*	732.1	0.7214	3.589	6.596	0.2	S(t), %	91.4	%
556.8	*29*	739.9	0.7474	3.959	6.606	0.3	h(t)	0.001	
387.6	*30*	746.4	0.7734	4.414	6.615	0.4	h(t), %	0.1	%
840.3	*31*	749.2	0.7995	4.987	6.619	0.5	H(t)	3.470E+04	
155.9	*32*	840.3	0.8255	5.731	6.734	0.6	T	3/32	y
658.4	*33*	928.6	0.8516	6.737	6.834	0.6	t =	684	h
481.5	*34*	938.1	0.8776	8.170	6.844	0.7	S(t)	0.368	
464.0	*35*	995.2	0.9036	10.378	6.903	0.9	S(t), %	36.8	%
391.7	*36*	1110.7	0.9297	14.222	7.013	1.0	h(t)	0.004	
595.6	*37*	1136.4	0.9557	22.588	7.036	1.1	h(t), %	0.4	%
1136.4	*38*	1234.9	0.9818	54.857	7.119	1.4	H(t)	3.851E+05	

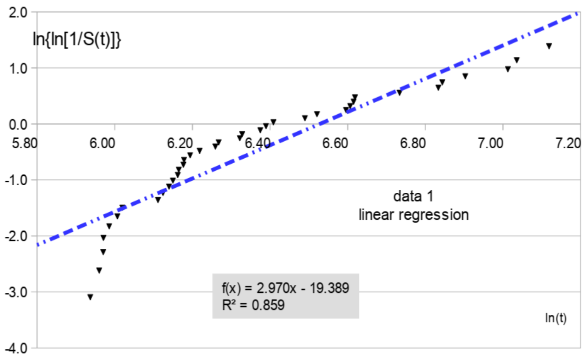

Fig. 1. MRE regression for the second data extract with linear interpolation as shown on the diagram

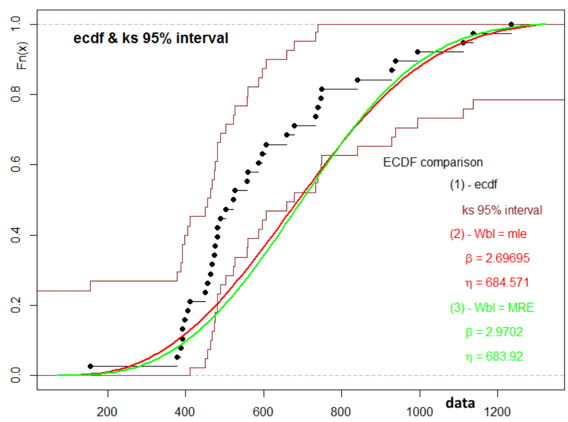

Fig. 2. MRE and MLE fit in comparison with empirical cumulative distribution function

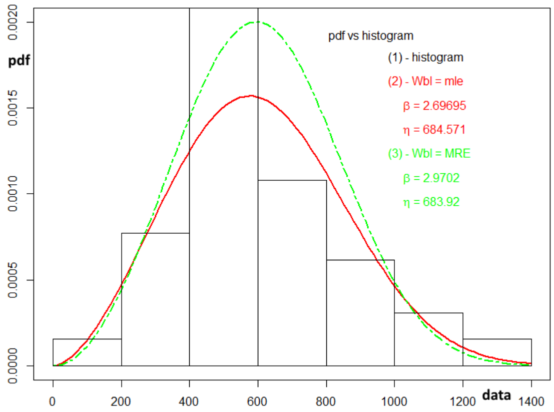

Fig. 3. MRE and MLE fit with histogram for D1

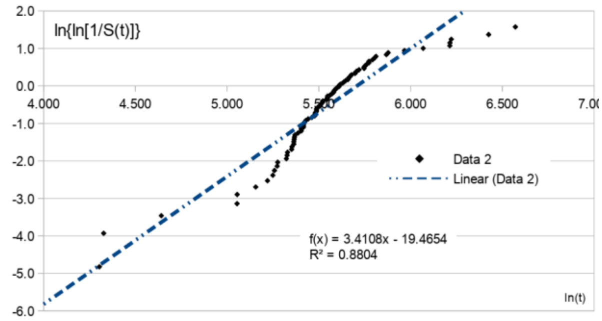

Fig. 4. MRE regression for D2 with linear interpolation

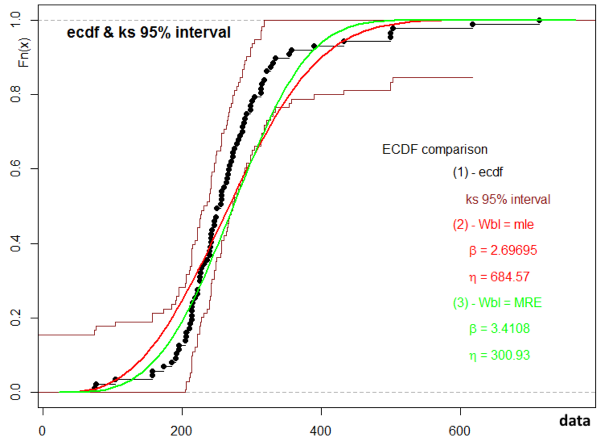

Fig. 5. MRE and MLE fit in comparison with empirical cumulative distribution function for D2

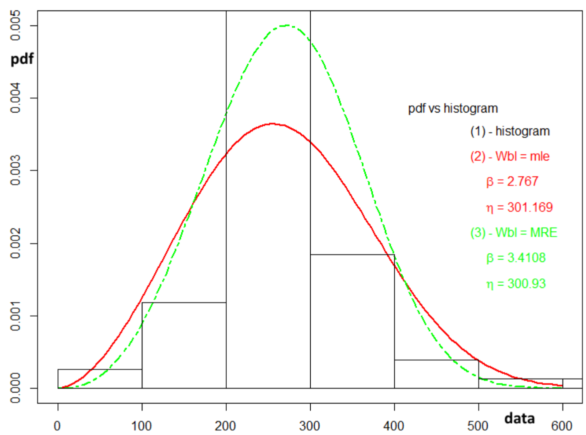

Fig. 6. MRE and MLE fit with histogram for D2

The comparison between the empirical cumulative distribution function /ECDF/ and the estimated cumulative distribution function /CDF/ of fitted distributions is shown on Fig. 2 and 5. The particular plots represented are with 95% Kolmogorov - Smirnov (Ricci, 2005) distance placed in the plot.

Table 2. *Second data extract (**D2**) and MRE calculations*

time	R	time	MR	1/(1-MR)	ln(t)	ln(ln(1/S))	results		
73.99					4.30	-4.82	A0	-19.465	
714.26					6.57	1.57	A1	3.4108	
269.61					5.54	-0.57	R²	0.8804	
	87	sorted	MR	1/(1-MR)	ln(t)	ln(ln(1/S))			
h	№	h							
C	D	E	F	G	H	G	K	L	M
357.1	1	74.0	0.0080	1.008	4.304	-4.8	β	3.4108	
250.0	2	75.7	0.0195	1.020	4.327	-3.9	η	300.93	
432.1	3	103.7	0.0309	1.032	4.641	-3.5	γ	0	
353.6	4	156.7	0.0423	1.044	5.054	-3.1	T	1	y
250.0	5	156.8	0.0538	1.057	5.055	-2.9	t =	7300	h
500.0	6	173.5	0.0652	1.070	5.156	-2.7	S(t)	0.000	
503.6	7	184.9	0.0767	1.083	5.220	-2.5	S(t), %	0	%
321.4	8	190.4	0.0881	1.097	5.249	-2.4	h(t)	0.461	
317.9	9	192.1	0.0995	1.111	5.258	-2.3	h(t), %	46.1	%
278.6	10	195.0	0.1110	1.125	5.273	-2.1	H(t)	4E+08	
321.4	11	195.5	0.1224	1.140	5.276	-2.0	T	1/2	y
239.3	12	205.0	0.1339	1.155	5.323	-1.9	t =	3650	h
240.0	13	205.8	0.1453	1.170	5.327	-1.9	S(t)	0.000	
235.8	14	206.3	0.1568	1.186	5.329	-1.8	S(t), %	0.0E+00	%
327.8	15	210.9	0.1682	1.202	5.352	-1.7	h(t)	0.118	
260.7	16	211.4	0.1796	1.219	5.354	-1.6	h(t), %	11.8	%
239.6	17	213.4	0.1911	1.236	5.363	-1.6	H(t)	5.6E+07	
246.9	18	213.5	0.2025	1.254	5.363	-1.5	T	1/12	y
227.9	19	213.9	0.2140	1.272	5.366	-1.4	t =	608	h
292.4	20	214.2	0.2254	1.291	5.367	-1.4	S(t)	0.000	
314.9	21	214.8	0.2368	1.310	5.370	-1.3	S(t), %	0.0	%
280.7	22	218.5	0.2483	1.330	5.387	-1.3	h(t)	0.003	
75.7	23	222.2	0.2597	1.351	5.404	-1.2	h(t), %	0.3	%
334.0	24	222.3	0.2712	1.372	5.404	-1.2	H(t)	2.72E+05	
195.5	25	225.0	0.2826	1.394	5.416	-1.1	T	1/24	y
225.0	26	225.0	0.2941	1.417	5.416	-1.1	t =	304	h
213.5	27	225.2	0.3055	1.440	5.417	-1.0	S(t)	0.354	
246.4	28	226.4	0.3169	1.464	5.422	-1.0	S(t), %	35.4	%
210.9	29	227.9	0.3284	1.489	5.429	-0.9	h(t)	0.001	
173.5	30	230.8	0.3398	1.515	5.441	-0.9	h(t), %	0.1	%
218.5	31	235.8	0.3513	1.541	5.463	-0.8	H(t)	3.47E+04	
270.4	32	239.3	0.3627	1.569	5.478	-0.8	T	4/97	y
273.2	33	239.6	0.3741	1.598	5.479	-0.8	t =	301	h
248.1	34	240.0	0.3856	1.628	5.481	-0.7	S(t)	0.368	
714.3	35	241.5	0.3970	1.658	5.487	-0.7	S(t), %	36.8	%
304.7	36	241.6	0.4085	1.691	5.487	-0.6	h(t)	0.001	
256.2	37	241.7	0.4199	1.724	5.488	-0.6	h(t), %	0.1	%
617.5	38	243.2	0.4314	1.759	5.494	-0.6	H(t)	3.36E+04	
213.9	39	246.4	0.4428	1.795	5.507	-0.5			
230.8	40	246.9	0.4542	1.832	5.509	-0.5			
211.4	41	248.1	0.4657	1.872	5.514	-0.5			
206.3	42	250.0	0.4771	1.912	5.521	-0.4			
256.7	43	250.0	0.4886	1.955	5.521	-0.4			
195.0	44	255.5	0.5000	2.000	5.543	-0.4			
290.8	45	256.2	0.5114	2.047	5.546	-0.3			
255.5	46	256.7	0.5229	2.096	5.548	-0.3			
298.1	47	256.7	0.5343	2.147	5.548	-0.3			
313.2	48	260.7	0.5458	2.202	5.563	-0.2			
299.0	49	263.1	0.5572	2.258	5.573	-0.2			
283.1	50	265.0	0.5686	2.318	5.580	-0.2			
301.1	51	265.5	0.5801	2.381	5.582	-0.1			
287.2	52	266.8	0.5915	2.448	5.586	-0.1			
273.1	53	268.2	0.6030	2.519	5.592	-0.1			
241.6	54	270.4	0.6144	2.593	5.600	0.0			
331.2	55	273.1	0.6259	2.673	5.610	0.0			
225.0	56	273.2	0.6373	2.757	5.610	0.0			
268.2	57	275.3	0.6487	2.847	5.618	0.0			
289.2	58	278.6	0.6602	2.943	5.630	0.1			
313.2	59	280.7	0.6716	3.045	5.637	0.1			
286.7	60	283.1	0.6831	3.155	5.646	0.1			
263.1	61	286.7	0.6945	3.273	5.659	0.2			
390.3	62	287.2	0.7059	3.401	5.660	0.2			
156.8	63	289.2	0.7174	3.538	5.667	0.2			
74.0	64	290.8	0.7288	3.688	5.673	0.3			
266.8	65	292.4	0.7403	3.850	5.678	0.3			
265.5	66	298.1	0.7517	4.028	5.697	0.3			
214.2	67	299.0	0.7632	4.222	5.700	0.4			
275.3	68	301.1	0.7746	4.437	5.708	0.4			
205.8	69	304.7	0.7860	4.674	5.719	0.4			
243.2	70	313.2	0.7975	4.938	5.747	0.5			
205.0	71	313.2	0.8089	5.234	5.747	0.5			
214.8	72	314.9	0.8204	5.567	5.752	0.5			
241.5	73	317.9	0.8318	5.946	5.762	0.6			
184.9	74	321.4	0.8432	6.380	5.773	0.6			
265.0	75	321.4	0.8547	6.882	5.773	0.7			
222.2	76	327.8	0.8661	7.470	5.792	0.7			
156.7	77	331.2	0.8776	8.168	5.803	0.7			
190.4	78	334.0	0.8890	9.010	5.811	0.8			
226.4	79	353.6	0.9005	10.046	5.868	0.8			
192.1	80	357.1	0.9119	11.351	5.878	0.9			
256.7	81	390.3	0.9233	13.045	5.967	0.9			
222.3	82	432.1	0.9348	15.333	6.069	1.0			
499.7	83	499.7	0.9462	18.596	6.214	1.1			
103.7	84	500.0	0.9577	23.622	6.215	1.2			
225.2	85	503.6	0.9691	32.370	6.222	1.2			
213.4	86	617.5	0.9805	51.412	6.426	1.4			
241.7	87	714.3	0.9920	124.857	6.571	1.6			

Conclusions

A product life cycle usually is described as "the time from the initial concept of a product to its withdrawal from the market". In the case of mechanical damage or wearing the withdrawal point is subordinated to a particular law of quality/quantity decreasing. So far, many researchers (Murthy, 2004; Lazov, 2010) have found that these dependences follow the Weibull models. In comparison with the exponential model (Minin, 2017) the Weibull fit uses some advantages focused on the reliability over the life cycle of a product. The formula describing the hazard function follows the time dependent formula (7) in distinction to the time independent exponential hazard function (Minin, 2017).

Table 3. *Parameters results*

	Data 1		Data 2		
	mle	MRE	mle	MRE	*unit*
β	2.69695	2.9702	2.767	3.4108	
η	684.571	683.92	301.169	300.93	
γ	*0*	*0*	*0*	*0*	
t = η	685	684	301	301	h
F(t)	63.2	63.2	63.2	63.2	%
S(t)	36.8	36.8	36.8	36.8	%
h(t)	0.4	0.4	0.0	0.0	%
t = 2η	1369	1368	602	602	h
S(t)	0.2	0.0	0.1	0.0	%
h(t)	1.3	1.7	3.1	6.0	%

As a particular conclusion from the research the valuated survival for the lining plates can be followed, as shown on Fig. 7. Hence, the repair period has to be multiple to that value. The results in Table 3 give the comparison between the coefficients achieved through the different fit technique and the different data extracts.

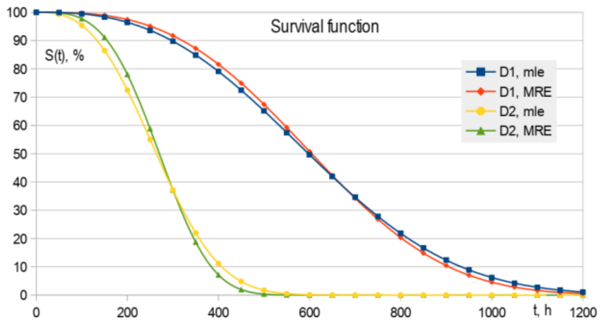

Fig. 7. Survival functions based on fitted Weibull models

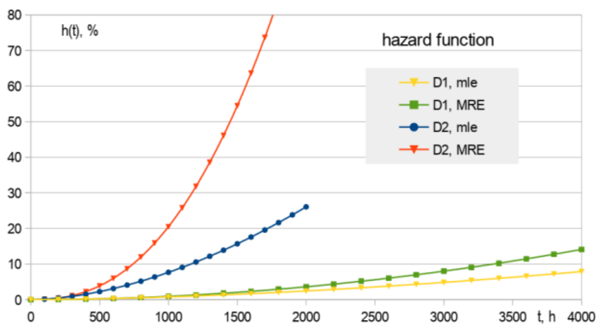

Fig. 8. Hazard functions based on fitted Weibull models

The fitting procedures and the software instruments about distribution functions are in constant development. Many commercial software packages are widely used, and also, many free or under CC and GNU license are applied by the scientific research community. In this research, for the programme calculation and the graph presenting plots the iterative package for R Studio under GNU license is used in comparison with non-iterative calculation made in spreadsheet OpenOffice Calc.

The acceptance of these models is considerable with the graphical instruments shown above. Further implementations should be used with numerical goodness-of-fit test. In the reliability research field the Kolmogorov-Smirnov test, Anderson-Darling test and Chi squared test are preferred.

Some improvement in model fitting can be observed by increasing the data sampling in Fig. 5 in comparison to Fig. 2.

Logically, these conclusions show that the presented Weibull model fit gives an account of the wearing process of jaw crusher's liners with shown values in parameters interpolation. The results and methods should be placed in a modern project design methodology (Lazov, 2010; 2015) with periods' account of the maintenance cycle. It is advisable to expand the research in other interpolation procedures and with different data sampling volume.

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