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Research Article

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A comparison of the two reliability evaluation methods on CNC lathes

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ABSTRACT

Two Weibull distributions are used to evaluate a certain serial CNC Lathes with position parameter t=0. In fact, the first failure time is not zero according to the data on the spot. Three Weibull distributions are put forward to evaluate the reliability on the basis of two Weibull distributions which can accurately reflect the quality index of CNC Lathes.

Keywords: Weibull distribution, CNC Lathes, reliability evaluation, hypothesis test, parameter estimation

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INTRODUCTION

Weibull distribution is deduced by the weak links model as the model is connected with a series of rings. The link broken is happened in the weakest link. When any part of the CNC machine tools has fault, the whole machine cannot be operated normally. So the CNC machine tools are the typical weakest links model. The paper evaluates the reliability of the CNC machine tools used Weibull distribution according to the spot data.

The Reliability Evaluation on the CNC Machine Tools Based on Two-parameters Weibull Distribution

In the research of the reliability of the CNC machine tools, we need a large amount of observed data to estimate the parameters. We define the point estimation according to the observed sample data to estimate the unknown parameters. We define the interval of the unknown parameters as interval estimation. We apply hypothesis testing to test the total hypothesis. We defer the hypothesis testing correct or not based on the calculations.

The paper extracts twenty-two CNC lathes as the samples (Because the data is large, the detailed data is bypassed here.).

We get the observed values through the data. We get $MTBF$ ($Mean\ \ Time\ \ Between\ \ Failure$), $MTTR$ ($Mean\ \ Time\ \ To\ \ Repair$) as 460.01 hours and 2.99 hours. The inherent availability A_i is 0.9936. We divide the observed data t into nineteen groups. After the primary selection of the distributions, we estimate the parameters and carry out hypothesis testing. According to the point diagrams and the hypothesis testing, we think Weibull distribution as the real distribution and we carry out regression analysis.

Regression analysis is a method used to solve the relationship of the variables. On the analysis of the reliability testing data, it can not only estimate the parameters and calculate the reliability index, but also test the distribution type.

Through the calculation, we know that exponential distribution doesn’t pass the testing. We get the distribution of the fault interval in line with Weibull distribution.

From the point estimation of the parameters, we get:
$A = -7.29$， $B = 0.84$， $k = 1.19$, $b = 460.02$

$$MTBF = \int_0^\infty tf(t)dt = \int_0^\infty t\frac{k}{b}(\frac{t}{b})^{k-1}\exp\left[-(\frac{t}{b})^k\right]dt = b\Gamma(1+\frac{1}{k}) = 460.02\times 0.94263 = 433.63(h)$$

Where: $A = -\ln b$， $B = 1/k$, b is scale parameter, k is shape parameter.

From the interval estimation, the confidence level is 90 percent, we get:
(1) The unilateral confidence interval of MTBF:

$$m > \frac{2T^*}{\chi^2_{0.90}(2r+2)} = 336.98$$

(2) The bilateral confidence interval of MTBF:

$$\frac{2T^*}{\chi^2_{0.95}(2r+2)} < m < \frac{2T^*}{\chi^2_{0.05}(2r)} \quad [1,2]$$

324.95＜m＜468.98

Where: r --the times of the faults; T^* --the total testing time.

The Application of Three-parameters Weibull Distribution on the Life Analysis of the CNC Machine Tools
Weibull Distribution is used widely on the reliability engineering. For the wear and tear failure parts, reference[3,4] refers that we'll get a better accuracy which can reflect the products' reliability really when using three-parameters Weibull distribution.

The fault density formula of three-parameter Weibull distribution is given as below:

$$f(t) = \frac{k}{b-t_0}(\frac{t-t_0}{b-t_0})^{k-1}\exp\left[-(\frac{t-t_0}{b-t_0})^k\right]$$

The cumulative fault distribution function is given as below:

$$F(t) = 1-\exp\left[-(\frac{t-t_0}{b-t_0})^k\right]$$

Where: $t \geq t_0$, $b > 0$, $k > 0$; t_0 is position parameter known as the minimum life which shows that there's no failure occurred before t_0 and is occurred at t_0. It's two-parameter Weibull distribution when t_0 is zero.

We use the estimated $\hat{t}_0$ to replace the minimum life t_0 in three-parameter Weibull distribution, that is:

$$F(t) = 1-\exp\left[-(\frac{t-t_0}{b-t_0})^k\right] \approx 1-\exp\left[-(\frac{t-\hat{t}_0}{b-\hat{t}_0})^k\right]$$

$\hat{y} = \hat{A} + \hat{B}x$ is a line under two-parameters Weibull distribution. Replace t_0 with $t_1(t_1,t)$, that is $x = \ln\ln[1-F(t)]^{-1}$, $y = \ln(t-t_1)$. Now（x , y ）is a plane curve. When $t > t_1 > t_0$, it's under the curve $\hat{y} = \hat{A} + \hat{B}x$ .When $t_1 < t_0 < t$, it's upper the curve $\hat{y} = \hat{A} + \hat{B}x$ [3].

A Comparison of Three-parameter Weibull Distribution to Two-parameter Weibull Distribution

We adopt right approximation method to calculate the estimation t_0 [4~8] .
We define $t_{01} = \min\{t_i\}$ as the initial value t_0 and calculate correlation coefficient ρ_{01}. Select the step $\Delta = 0.05t_{01}$, then $t_{02} = t_{01} - \Delta$, repeat the above calculations, get each correlation coefficient ρ_{0k} . When we get the largest value $|\rho_{0i}|$, this is the situation we want $\hat{t}_0 = t_{0i}$. Two-parameters Weibull distribution is estimated at

$\hat{t}_0 = 0$.

We select $t_0 = 4.66$ as the initial value. The table of correlation coefficients are given as below:

Table 1 Correlation coefficients of three Weibull Distributions

t_i	$\lvert\rho_{0i}\rvert$	t_i	$\lvert\rho_{0i}\rvert$	t_i	$\lvert\rho_{0i}\rvert$	t_i	$\lvert\rho_{0i}\rvert$	t_i	$\lvert\rho_{0i}\rvert$
t_{01}	0.98685	t_{15}	0.99009	t_{29}	0.98659	t_{43}	0.98538	t_{57}	0.98449
t_{02}	0.98687	t_{16}	0.99001	t_{30}	0.98655	t_{44}	0.98529	t_{58}	0.98443
t_{03}	0.98689	t_{17}	0.98998	t_{31}	0.98624	t_{45}	0.98521	t_{59}	0.98440
t_{04}	0.98691	t_{18}	0.98992	t_{32}	0.98601	t_{46}	0.98519	t_{60}	0.98435
t_{05}	0.98695	t_{19}	0.98989	t_{33}	0.98600	t_{47}	0.98511	t_{61}	0.98422
t_{06}	0.98736	t_{20}	0.98985	t_{34}	0.98597	t_{48}	0.98502	t_{62}	0.98420
t_{07}	0.98792	t_{21}	0.98975	t_{35}	0.98593	t_{49}	0.98499	t_{63}	0.98409
t_{08}	0.98979	t_{22}	0.98852	t_{36}	0.98589	t_{50}	0.98492	t_{64}	0.98400
t_{09}	0.99001	t_{23}	0.98695	t_{37}	0.98575	t_{51}	0.98485	t_{65}	0.98399
t_{10}	0.99023	t_{24}	0.98685	t_{38}	0.98563	t_{52}	0.98478	t_{66}	0.98389
t_{11}	0.99033	t_{25}	0.98682	t_{39}	0.98556	t_{53}	0.98468	t_{67}	0.98380
t_{12}	0.99030	t_{26}	0.98672	t_{40}	0.98555	t_{54}	0.98466	t_{68}	0.98372
t_{13}	0.99025	t_{27}	0.98665	t_{41}	0.98546	t_{55}	0.98459	t_{69}	0.98366
t_{14}	0.99012	t_{28}	0.98661	t_{42}	0.98544	t_{56}	0.98455	t_{70}	0.98355

From the table 1, $\lvert\rho_{00}\rvert < \lvert\rho_{011}\rvert < \lvert\rho_{012}\rvert$, $\lvert\rho_{00}\rvert$ is the correlation coefficient corresponding to $t_0 = 0$. From the table, we know that the line defined by t_{011} is the best fitted curve. So t_{011} is the position parameter we want. The estimated value with position parameter t_{011} is more precise than with position parameter t_0.

$$t_{011} = 4.66 - 0.05 \times 10 = 4.16h$$

We calculate the parameters with $\rho_{011} = 0.99203$, $t_{011} = 4.16h$ as given as below: $A = -7.52626$, $B = 0.993615$, $k = 1.006426$, $b = 475.04468$, $t_0 = 4.16h$.

We can see that the shape parameter is decreased from 1.19 to 1.09 to 1.00. Because three-parameter Weibull distribution is close to the reality, the estimated life is more precise.

The Point Estimation of Three-parameter Weibull Distribution

$MTBF$, $E(t)$, $D(t)$ and L_{10} of the CNC machine tools are calculated as below:

$$MTBF = \int_0^\infty tf(t)dt = \int_0^\infty t\frac{k}{b-t_0}(\frac{t-t_0}{b-t_0})^{k-1}\exp\left[-(\frac{t-t_0}{b-t_0})^k\right]dt = (b-t_0)\Gamma(1+\frac{1}{k}) = 448.41(h)$$

$$E(t) = t_0 + (b-t_0)\Gamma(\frac{1}{k}+1) = 453.07(h)$$

$$D(t) = (b-t_0)^2\left[\Gamma(\frac{2}{k}+2) - \Gamma^2(\frac{1}{k}+1)\right]$$

$$= 756500.18(h^2)$$

$$L_{10} = t_0 + (b-t_0)\sqrt[k]{-\ln 0.9} = 53.61$$

We take $t_{011} = 4.16h$ as the situation parameter and calculate under $b = 475.4468$, $k = 1.006426$. We get the below results:

$MTBF = 469.31(h)$, $E(t) = 473.47(h)$, $D(t) = 1079425.7(h^2)$, . $L_{10} = 53.81$.

Interval estimation of Three-parameter Weibull Distribution

(1) The unilateral confidence interval of MTBF:

$$m > \frac{2T^*}{\chi^2_{0.90}(2r+2)} = 358.77$$

(2) The bilateral confidence interval of MTBF:

$$\frac{2T^*}{\chi^2_{0.95}(2r+2)} < m < \frac{2T^*}{\chi^2_{0.05}(2r)}$$

$$347.87 < m < 490.22$$

CONCLUSION

We analyze the data of the CNC machine tools with two-parameter Weibull distribution and exponential distribution. We get the results that the failure time of the CNC machine tools rules to Weibull distribution. We estimate the parameters. When we use three-parameter to estimate the parameters, we know that the results is close to the reality and the estimated life is more precise.

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