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# Reliability Evaluation of Transplanter Based on Weibull Model

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# Reliability Evaluation of Transplanter Based on Weibull Model

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**Abstract.** Some fault time data of a certain type of transplanter are collected and counted, and regression analysis is used as the judgement basis for establishing reliability model. A two-parameter Weibull model is established by using the fault time data. The model parameters are estimated by the least squares method, and the regression analysis is used to verify the model. After the linearization of the Weibull model distribution function, the least squares method is used and the regression equation is derived by means of Matlab programming. The correlation coefficient is calculated, and the linear correlation test is performed by t-test. The fitting precision is obtained. Plotting the fault probability distribution function graph, failure probability density function graph, Reliability function graph and Failure rate function graph of the transplanter. Based on the Weibull model, the cumulative failure probability and reliability of the transplanter are evaluated under a certain service life. It provides a reference for the repair of the transplanter.

## 1. Introduction
Rice is China's largest food crop. By 2020, China's rice planting area will be stable at 450 million mu. Such a large area will require mechanized planting, and transplanter is used in most rice mechanized planting. At present, compared with the imported rice transplanter, the domestic rice transplanter basically meets the demand, but the number of faults is large, the repair time is long, the reliability is obviously low, and the work efficiency is greatly reduced. Wang Nenghuan proposed an analysis method for passenger car repair data with two and three parameter Weibull distribution [1]. Chen Jianneng improved the reliability evaluation index of transplanter and proposed the maintenance factor as an indicator to measure its reliability [2]. Emad E. Elmahdy proposed a method for modeling the life data of system components with failure modes [3]. In this paper, a certain amount of transplanter fault data is selected as a sample, and the Weibull model is selected to describe its life distribution. The model parameters are estimated by the least squares method, and the regression analysis method is used to verify the model. Finally, the reliability level of this type of transplanter is obtained by the Weibull model. It provides suggestions for users.

## 2. Establishment of a reliability model of transplanter

### 2.1. Identification method of mechanical reliability distribution model

In the analysis and design of mechanical reliability, it is important to determine the type of failure distribution of a product, and it is difficult to identify the type of failure distribution of a product. Commonly methods for identifying life distribution models are graph method, hypothesis test method, regression analysis method and failure mechanism analysis method. Compared with the other three methods, the regression analysis method is simple and easy, and the recognition model is excellent. Therefore, the regression analysis method is used to select the reliability model of the transplanter.

### 2.2. Transplanter reliability model determination

When assessing the reliability level of a machine, the commonly used life distributions have a normal distribution, an exponential distribution, a logarithmic distribution, and a Weibull distribution. Weibull distribution is the most commonly used. Firstly, assuming that the life distribution of a transplanter is Weibull distribution. Regression analysis is used to analyze the model, and the reliability model of the transplanter is determined according to the regression analysis results.

The Weibull distribution has two expressions which are two parameters and three parameters. The three-parameter Weibull distribution function expression is as follow:

$$F(x) = 1 - \exp\left(-\left(\frac{x-\gamma}{\eta}\right)^m\right), \quad (x > \gamma) \tag{1}$$

Where $m$ is a shape parameter, $\eta$ is a scale parameter, and $\gamma$ is a position parameter.

When the position parameter $\gamma \neq 0$, the above model is a three-parameter Weibull model. When the position parameter $\gamma = 0$, the above model is a two-parameter Weibull distribution.

According to the maintenance record of a certain type of transplanter in a working season, the following 72 fault time data of the transplanter are collected.{63.2, 63.5, 81, ..., 382.3, 382.5 (unit: hour)}.

The life distribution of the transplanter is fitted by the Weibull model. The random variable $x$ of the Weibull model is the life $t$ of the rice transplanter. The $F(x)$ of the Eq.(1) is the cumulative failure probability value of the transplanter, which is the transplanter's cumulative failure probability value. It can be known from the above sample fault data and the actual situation that the transplanter works from zero time, and the fault generation is random. There may be a fault condition from the beginning of use, so the position parameter of the Weibull model is zero, namely $\gamma$ equals zero. The life distribution model of the transplanter is a two-parameter Weibull distribution, and the corresponding distribution function is:

$$F(t) = 1 - \exp\left(-\left(\frac{t}{\eta}\right)^m\right) \tag{2}$$

In Eq. (2), $m$ is the shape parameter that reflecting the failure rate curve of the transplanter in different periods, $\eta$ is the scale parameter for measuring the average fault interval time of the transplanter, $t$ is the fault time of the transplanter.

### 2.3. Parameter estimation of the transplanter reliability model

The reliability model of the transplanter is a two-parameter Weibull distribution. The parameters of the Weibull distribution are commonly used in the least squares estimation, method of moments estimator, maximum likelihood estimation method, and artificial neural network. The least squares method is used for estimation.

In the distribution function of the Weibull model, the shape parameter which $m$ don't equal 1 is nonlinear. After the linear transformation is needed and converted into a linear function, the parameters of the linear function can be estimated by the least squares method.

Assuming that a certain type of transplanter has a total of $n$ faults during the observation time period, and its fault occurrence time that is $t_1 < t_2 < ... < t_n$. The life expectancy of the model transplanter obeys the two-parameter Weibull distribution. $T \sim W(m, \eta)$.

Substituting the data which are $\{(t_i, F(t_i))\}(i=1,2,...,n)$ into Eq.(2), and linearizing it. Performing an equivalent transformation on Eq. (2). The natural logarithm is taken twice on both sides of the equation. Then the result is:

$$\ln \ln \left[ \frac{1}{1-F(t_i)} \right] = m \ln t_i - m \ln \eta \tag{3}$$

Making $Y_i = \ln \ln \left[ 1/(1-F(t_i)) \right]$, $X_i = \ln t_i$, $A = -m \ln \eta$, and $B=m$. the two-parameter Weibull distribution model can be transformed into:

$$Y_i = BX_i + A \tag{4}$$

According to the regression analysis method, it can be deduced that the expressions of the estimated values of parameters $B$ and $A$ are:

$$\hat{B} = \frac{\sum_{i=1}^{n}(X_i - \overline{X})(Y_i - \overline{Y})}{\sum_{i=1}^{n}(X_i - \overline{X})^2} \tag{5}$$

$$\hat{A} = \overline{Y} - \hat{B}\,\overline{X} \tag{6}$$

By substituting the sample data that are $t_1$, $t_2$,...,$t_n$ and the corresponding $F(t_i)$ into Eq.(6). The values of $A$ and $B$ can be calculated, thereby calculating estimated values of the shape parameter $m$ and the scale parameter $\eta$.

$$\hat{m} = \hat{B} \tag{7}$$

$$\hat{\eta} = \exp\left( -\frac{\hat{A}}{\hat{B}} \right) \tag{8}$$

The median rank is used as an estimate of $F(t_i)$. $MR(t_i)$ is the median rank at time $t_i$. The general median rank is:

$$F(t_i) = MR(t_i) = \frac{n(t_i) - 0.3}{n + 0.4} \tag{9}$$

According to the transplanter failure occurrence time data which are $t_i$ ($i=1, 2, ..., 72$). $F(t_i)$, $X_i$ and $Y_i$ are calculated, as shown in Table 1.

Table 1. Error data of transplanter and median rank formula to calculate empirical distribution function.

| Serial number $i$ | transplanter life $t_i$ | Median rank $F(t_i)$ | $X_i$ | $Y_i$ |
|---|---|---|---|---|
| 1 | 63.2 | 0.009669 | 4.146304 | -4.634027 |
| 2 | 63.5 | 0.023481 | 4.151040 | -3.739721 |
| ⋮ | ⋮ | ⋮ | ⋮ | ⋮ |
| 71 | 382.3 | 0.976519 | 5.946206 | 1.322177 |
| 72 | 382.5 | 0.990331 | 5.946729 | 1.534473 |

Substituting the data of Table 1 into Eq. (5), (6), (7), and (8) can be calculated.

$\hat{B} = 3.0415$, $\hat{A} = -16.1721$, $\hat{m} = 3.0415$, $\hat{\eta} = 203.7905$

## 2.4. Inspection and evaluation of the transplanter reliability model

The regression analysis method is used to test and evaluate the above-mentioned transplanter reliability model. The two-parameter Weibull distribution function is linearly transformed. Then the least squares method is used to perform regression analysis on the sample values and probability estimates. The regression linear coefficient is estimated. The correlation coefficient is calculated. Then the examine sample value and the probability estimate whether have a linear relationship. The specific steps are as follows.

1) Regression analysis by least squares method

As described in Section 2.3, after linearizing the Weibull distribution function, the least squares method is used to perform linear regression analysis on the sample values and probability estimates.

The values of the regression equation coefficients *A* and *B* are obtained, and the regression equation is $Y_i$=3.0415$X_i$-16.1721.

According to the regression linear equation, the correlation coefficient is calculated. It is expressed as follows:

$$R = \frac{\sum_{i=1}^{n}(X_i - \bar{X})(Y_i - \bar{Y})}{\sqrt{\sum_{i=1}^{n}(X_i - \bar{X})^2 \cdot \sum_{i=1}^{n}(Y_i - \bar{Y})^2}} = 0.9674 \tag{10}$$

The relationship between correlation coefficient *R* and correlation degree is shown in table 2.

Table 2. Correlation coefficient table.

| \|R\| | (0,0.4] | (0.4,0.7] | (0.7,0.9] | (0.9,1] |
|---|---|---|---|---|
| degree of correlation | low | middle | high | very high |

According to Eq. (10), the correlation coefficient is 0.9674. It can be seen from the correlation coefficient table that the correlation between *X* and *Y* is extremely high, and the fitting effect is good.

2) Linear correlation test

It is tested whether there is a linear correlation between X and *Y*, *T* test method is used. The specific inspection steps are as follows:

(1) Establishing null hypotheses. $H_0$: B=0 (Regression is not significant);

(2) Calculating the statistic *t* value;

$$t = \frac{\hat{B}}{\hat{\sigma}}\sqrt{S_{xx}} \sim t(n-2) \tag{11}$$

$$\sqrt{S_{xx}} = \sqrt{\sum_{i=1}^{n}(X_i - \bar{X})^2} \tag{12}$$

$$\hat{\sigma} = \sqrt{\frac{\sum_{i=1}^{n}(Y_i - \hat{a} - \hat{b}X_i)^2}{n-2}} \tag{13}$$

(3) For a given level of significance $\alpha$, checking the *t* distribution table, and getting the critical value $t_{\alpha/2}(n-2)$;

(4) From the *t* value and the critical value $t_{\alpha/2}(n-2)$, making statistical judgment is made on the significance of the regression equation. If $|t|>t_{\alpha/2}(n-2)$, $H_0$ is rejected, and the regression equation is considered significant. If $|t|<t_{\alpha/2}(n-2)$, $H_0$ is accepted, and the regression equation is not significant.

Substituting the sample data into Eq. (5), (11), (12) and (13) and combined with Matlab programming to solve that $|t|$=31.9614. A significant level that $\alpha$=0.05 is gave. According to the t distribution table, the critical value $t_{0.025}(72-2)$=1.9908 is got. Becaues $T>t_{0.025}(70)$, $H_0$ is rejected. It shows that the regression effect is significant, and there is a linear relationship between *X* and *Y*.

In a word, the reliability model of transplanter is a two-parameter Weibull distribution. The shape parameter *m* is 3.0415, and the scale parameter $\eta$ is 203.7905.

## 3. Transplanter reliability analysis

### 3.1. Reliability evaluation index of transplanter

Product reliability indicators typically include reliability, failure rate, average life and reliable life.

The transplanter reliability is a probability value, which is the probability that the transplanter will complete the specified function within the specified time and the specified conditions.

The failure rate of the rice transplanter refers to the frequency at which the product has failed within a unit time after the operation has not failed.

The average life of a product is one of the commonly used reliability indicators. If the probability density function of the transplanter life is $f(t)$. The average life expectancy is its expectation. Since the rice transplanter is a repairable product, the average life of the rice transplanter is the average working time between two adjacent faults, which is recorded as MTBF (Mean Time Between Failure).

The reliable life of transplanter refers to the time that the machine can work when the probability of normal operation is higher than a certain level $R$, Which is called the reliable life. The median lifetime is a reliable lifetime at the reliability of $R=50\%$, namely $t_{0.5}$. The characteristic lifetime is a reliable lifetime when the reliability is 0.368, namely $t_{0.368}$.

### 3.2. Transplanter reliability level

Through the statistical analysis of the fault time data of a certain type of transplanter. The life distribution model of the transplanter is established as a two-parameter Weibull distribution. The reliability function of the transplanter can be obtained as follows:

$$R(t) = \exp\left(-\left(\frac{t}{\eta}\right)^m\right) = \exp\left(-\left(\frac{t}{203.7905}\right)^{3.0415}\right) \tag{14}$$

The unreliability function of the transplanter is:

$$F(t) = 1 - \exp\left(-\left(\frac{t}{\eta}\right)^m\right) = 1 - \exp\left(-\left(\frac{t}{203.7905}\right)^{3.0415}\right) \tag{15}$$

The fault probability density function of the transplanter can be represented as:

$$f(x) = \frac{m}{\eta}\left(\frac{t}{\eta}\right)^{m-1}\exp\left(-\left(\frac{t}{\eta}\right)^m\right) = \frac{3.0415}{203.7905}\times\left(\frac{t}{203.7905}\right)^{2.0415}\times\exp\left(-\left(\frac{t}{203.7905}\right)^{3.0415}\right) \tag{16}$$

The failure rate function of the transplanter is defined by:

$$\lambda(t) = \frac{m}{\eta}\left(\frac{t}{\eta}\right)^{m-1} = \frac{3.0415}{203.7905}\times\left(\frac{t}{203.7905}\right)^{2.0415} \tag{17}$$

The average life of the transplanter is:

$$E(t) = \eta\Gamma\left(1+\frac{1}{m}\right) = 203.7905\times\Gamma\left(1+\frac{1}{3.0415}\right) = 182.092（h）$$

According to Eq. (14), (15), (16) and (17), drawing the reliability function graph, fault probability function graph, fault probability density function graph and fault rate function graph of the transplanter. as shown in Fig.1-Fig.4.
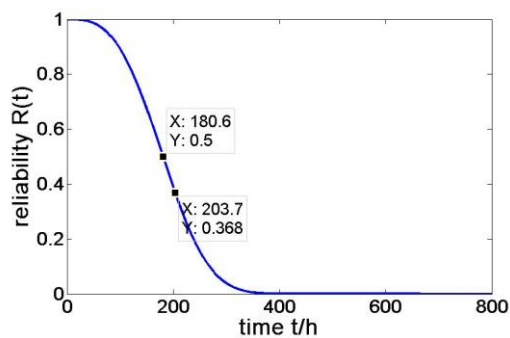


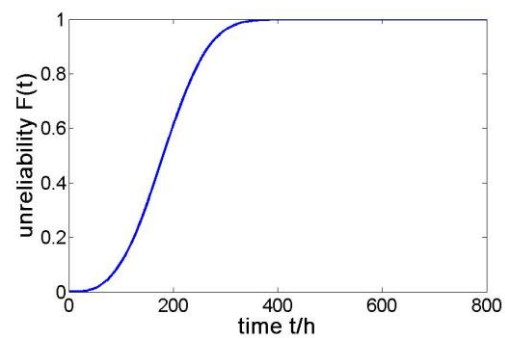Figure 1. Reliability function curve.



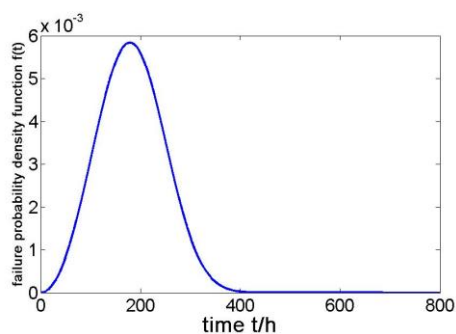Figure2. Unreliability function curve.



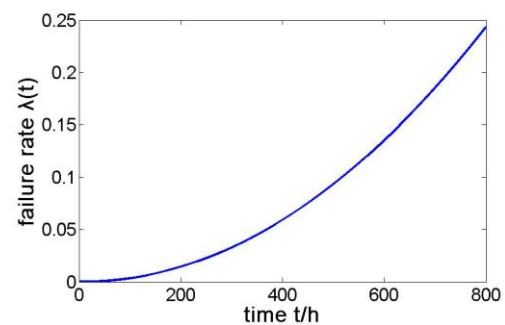Figure 3. Failure probability density function curve.



Figure 4. Failure rate curve.

It can be seen from Fig.1 to Fig.4 that the median life of the transplanter is 180.6 hours and the characteristic lifetime is 203.7 hours. The average life expectancy is 182.02 hours, namely $t_{0.5}$=180.6, $t_{0.368}$=203.7 and MTBF=182.02. According to the failure rate curve, the early failure probability of transplanter is low and high in the late stage.

## 4. Conclusion

In this paper, a two-parameter Weibull model is established based on the field fault data of the transplanter. The model parameters are estimated by the least squares method and the Weibull model is verified by regression analysis. T-test was used to test the linear correlation of regression line. The degree of correlation is described by the correlation coefficient which is calculated. The reliability curve, unreliability curve, cumulative failure probability density curve, and failure rate curve of the transplanter are obtained by the two-parameter Weibull model. The average life, reliable life and characteristic life of the transplanter are calculated. The reliability level of transplanter is measured quantitatively with the above indexes. Based on the analysis results, the manufacturer can improve the reliability of the transplanter. Users can speculate the reliability of transplanter and organize maintenance in time.

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