Evaluation and Improvement of Unscheduled Removal Component Reliability Calculation Method with No Fault Found (NFF) Shop Finding Results

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Abstract. The test results of the removed aircraft components are classified into No Fault Found (NFF), Real Reason Conform (RRC) and Other Defect Found (ODF). Corrective actions will be taken on findings that are classified as RRC and ODF, while for the NFF category no action will be taken. In the MRO XYZ, for the NFF category, the age of the component during the removal is included into the failure data. Moreover, the reliability calculation in the MRO XYZ uses the 2-parameters Weibull distribution. These will result in unrepresentative reliability calculation. Therefore, it is necessary to evaluate the method. The research compares the results of the reliability calculation between the 2-parameters and the 3-parameters Weibull distributions by applying them to several part numbers data. Furthermore, the reliability calculation using the 3-parameters Weibull is also applied to the data where the NFF category is not included the failure data. The location parameter, γ, is calculated using the Muralidhar method. The research also develops an excel VBA macro-based tool for reliability calculation. The results of the reliability calculation show that there is a significant difference of the failure rate between using the 2-parameters and the 3-parameters Weibull distribution. The failure rate calculated by using the 3-parameters Weibull distribution for the data where NFF category is not included into the failure data show a significant different as compared to the method used by the MRO XYZ, where the difference is affected by the percentage of NFF items in the failure data.

1. Introduction
In carrying out aircraft maintenance, components are usually removed. Component removal are grouped into two, namely scheduled and unscheduled removal. After the component is removed, then they are tested in the store to find the causes (shop finding) and then it can be determined whether the component needs repair or not.

Shop finding are categorized into 3 types namely Real Reason Conform (RRC), Other Defect Found (ODF) and No Fault Found (NFF). RRC is called if the results of shop finding are the same as the reason of removal reported by pilots or technicians on line maintenance. ODF is called if the results of shop finding are different from the reason of removal reported by pilots or technicians on line maintenance. Whereas NFF is called if the testing in the shop turns out that there is no failure on the component.

The NFF will be a problem if it occurs on components with unscheduled removal. If the pilot or technician reports that there has been a failure in a component so that the component needs to be removed while it turns out that shop finding states that the component is fine, then this component needs
further attention. However, what has happened so far is if there is a NFF result on a component with an unscheduled removal, without any improvement, the components are immediately installed again on the aircraft. This causes the component being removed frequently with the same shop finding results, namely the NFF so that the component can be called low reliability. In addition there is also an inappropriate method in calculating component reliability. Therefore, it is necessary to improve the reliability calculation method before making improvements to the NFF component handling method at the shop.

The purpose of this research is to evaluate the reliability calculation method of NFF items used and to design a new method to improve the calculation of reliability of NFF items. The methodology used, first is formulating the research background, then formulating the problem from the results of the background description that has been carried out together with the literature review, then defining the research boundaries. After that, evaluating the methods used in calculating the reliability of components that experienced a lot of unscheduled removal with shop finding NFF results, designing new methods to improve the calculation of component reliability that experienced unscheduled removal with shop finding NFF results, designing data formats and application procedures, testing new methods for some samples of items that have been designed into a data format in such a way, analyze the results of reliability calculations between the methods currently used (existing) and new methods.

2. Literature Review

Maintenance is a combination of various actions taken to safeguard an item or repair it until an acceptable condition. In the maintenance of aircraft components, removal is usually carried out. There are two types of removal namely scheduled removal and unscheduled removal. Scheduled removal is a removal that is done according to a predetermined time interval. Scheduled removal is usually done if there are order documents such as AMI, EO and TO.

In this research, it will be limited to the calculation of Weibull distribution parameters using parametric analysis used to determine failure rate [1].

In this research, Weibull distribution is expressed in 3 parameters. The three parameters are $\beta$ (shape parameter), $\eta$ (scale parameter) and $\gamma$ (location parameter). Shape parameter, $\beta$ can be used to state the failure condition as time goes by. Value of the shape parameter $\beta < 1$ (infant mortality) explains the very high failure rate at the beginning of age (early death) and the action to be taken is system modification. Value of the shape parameter $\beta = 1$ (random failures) describes a failure rate that is constant with age as failure does not depend on time. The action that must be taken is the modification of the component. Whereas the value of the $\beta > 1$ form parameter (wear out failures) explains that the failure rate will increase with age and the action to be taken is inspection or restoration [2]. To prove whether the data really has a Weibull distribution type distribution or not, the Mann test is used. The formula for the statistical test is as follows:

$$M = \frac{k_1 \sum_{i=1}^{r-1} [(\ln t_{i+1} - \ln t_i)/M_i]}{k_2 \sum_{i=1}^{r} [(\ln t_{i+1} - \ln t_i)/M_i]}$$

Where $k_1 = \left\lfloor \frac{r}{2} \right\rfloor$, $k_2 = \left\lfloor \frac{r-1}{2} \right\rfloor$, $M_i = Z_{i+1} - Z_i$ and $Z_i = \ln \left[ -\ln \left( 1 - \frac{i-0.5}{n+2.5} \right) \right]$. As for $r$ is the total number of data, $n$ is the number of failures that occur, $k_1$ is the amount of data before the median, $k_2$ is the amount of data after the median, $2k_1$ is denominator and $2k_2$ is the numerator. If the value of $M > F_{\text{crit}}$ then the failure time is not Weibull. The $F_{\text{crit}}$ value is the value of the function of the numerator and denominator using the statistical function in Excel that is F.INV.RT with a value of $\alpha = 5\%$.

The failure rate of the Weibull $\lambda (T)$ distribution can be stated as follows:

$$\lambda(T) = \frac{\beta}{\eta} \left( \frac{T}{\eta} \right)^{\beta-1}$$
For the shape parameter above 1 the failure rate will increase. If the shape parameter is equal to 1, the failure rate tends to be constant. Whereas for the shape parameter value is less than 1, the failure rate tends to decrease.

In this research the method used to calculate Weibull parameters is least square method along with probability plotting methods. The least square method is a standard approach in regression analysis to approach the solution of overdetermined systems. The least square method is also used in calculating the index of fit of the data. The index of fit value states that the data level follows the Weibull distribution. If it gets closer to 1 then the data gets better and more closely follows the Weibull distribution. Probability plotting in this research uses Excel to reduce the factor of high subjectivity.

The steps to determine the Weibull distribution parameters can be derived from the following reliability equation [1]:

\[ R(T) + Q(T) = 1 \]  

where \( R(T) \) is the Weibull reliability function and \( Q(T) \) is a Weibull unreliability function. So that we will get the following equation:

\[ 1 - Q(T) = e^{-\frac{T-\gamma}{\eta}} \]  

By reversing the terms, the following equation is obtained:

\[ \frac{1}{1 - Q(T)} = e^{\frac{T-\gamma}{\eta}} \]  

By applying a natural logarithm operation, the following equation is obtained:

\[ \ln \left( \frac{1}{1 - Q(T)} \right) = \frac{T-\gamma}{\eta} \beta \]  

Then the natural logarithm operation is applied again, then the following equation is obtained:

\[ \ln \ln \left( \frac{1}{1 - Q(T)} \right) = \beta \ln(T - \gamma) - \beta \ln \eta \]  

The equation above is an equation of a straight line \( Y = mX + C \) with each of them are:

\[ Y = \ln \ln \left( \frac{1}{1 - Q(T)} \right) \]  

\[ m = \beta \]  

\[ X = \ln(T - \gamma) \]  

\[ C = -\beta \ln \eta \]  

The probability plotting method with uncensored data is first done, which is to sort the age to failure (Time to Failure) and give a data index of \( j = 1 \) as the time data to 1 to N where N is the number of data failures. Furthermore, it is calculated the Median Rank value for data to \( j \) and the number of sample N data with the equation [2]:

\[ MR = Q(T_j) \times 100 \approx \frac{j-0.3}{N+0.4} \times 100 \]  

Median Rank is the value of a probability of failure occurring in the data to \( j \) from the sample as much as N. In censored data, the index \( j \) in determining the median rank will not be the same as the value of N. For probability plotting and least-square methods in the data censored value of N in the calculation the median rank is the value of the number of samples. So that a table can be made to simplify calculations by using probability plotting methods with censored data. Calculation of location parameters \( \gamma \) uses Muralidhar method because there is no subjectivity factor involved in the calculation. Assuming that the time to failure (Time to Failure) that has been recorded has been sorted from the smallest to the largest, the equation for calculating location parameters is [1]:

\[ \gamma = \frac{T_{1+1}n-T_{1}^{2}}{T_{1+1}n-2T_{j}} \]  

The index \( j \) becomes \( j_{\text{censored}} \), namely \( j_{\text{censored}} = \lceil np(n/N) \rceil \). While the \( p \) value is as follows:

\[ p = 0.8829n^{-0.3437} \]  

The reliability calculation methods currently used and their improvements are as follows:

(a) using the 2-parameter Weibull distribution (the location parameter \( \eta \) is zero) is fixed to a 3-
parameter Weibull distribution,
(b) removal with shop finding NFF results that are considered as a repaired failure to be not included in the failure data,
(c) TSI values less than 1000 FH are considered as repaired data outliers to remain included in the inserted to analysis category.

To calculate the reliability of a component, failure data is grouped according to part number. Then after that it is classified again based on its failure mode, because the reliability calculation is specific to one failure mode. The TSI value obtained cannot be directly entered into the reliability calculation. TSI values are arranged based on the results of shop finding. If the shop finding results show that the component (in this context part number) has failed, then the component's age is calculated from the start installed on the plane. However, if shop finding of these components shows the results of the NFF, then the age of the component has not stopped when removing, the TSI still continues when installed on the plane (not starting from zero again).

3. Improvement and Application of The New Method
In this research the authors developed Excel-based tools for reliability calculations that are easy to use. The tool used is based on Excel VBA macros. By using VBA macros, the user only needs to enter the failure data and press the run button, then the desired output will be automatically obtained. The script in the VBA macro contains the Weibull functions used in this study. Then, the user needs to enter failure data in the 'i' and 'no' columns. After entering the data, then the user needs to press the run button. After that, the Mann test results will appear whether the data is Weibull distributed or not. If not, the "data does not fit with weibull distribution" dialog box will appear, but if we have a Weibull distribution, a dialog box will appear to enter the number of samples [4].

![Figure 1. Excel based tools for reliability calculations](image)

The next step is to use the 'Data Analysis' tool to get the values of the shape parameter $\beta$ and the scale parameter $\eta$. After selecting the 'Data Analysis' tool, then choose the 'Regression' tool in the 'Analysis Tools' option. In the 'Regression' tool box dialog above for the option 'Input Y Range', enter the ln value ($\ln(1 / (1\text{-Median Rank}))$) from the first row (column name) to the last line containing the failure data. While for the option 'Input X Range', enter the value $\ln(t_i)$ from the first row (column name) until the last line containing the failure data. After that, add a check mark in the 'Labels' box. Next to the option 'Output options', select 'New Worksheet Ply' so that the calculation results appear on a sheet that is different from the data. Finally on the 'Residuals' option, select 'Line Fit Plots' then click OK. Make excel will display the regression results and the results will appear in the new sheet. Scale parameter value $\eta = e^{(-\text{intercept} / \beta)}$. Furthermore, if the value of the shape parameter $\beta$ and the scale parameter $\eta$ is obtained, what needs to be done is to make a plot of the failure rate.

In this research, the comparison of existing methods with new methods was applied in 4 case studies namely part numbers 071-01503-2601, 398908-3, 8055515 and 822-0990-004. From the Mann test results, all three were proven to have Weibull distribution [4-5].
In the 2 parameter Weibull distribution, the existing method produces the shape parameter value $\beta = 1,557$ hr and the scale parameter $\eta = 5972.836$ hr. While the new method produces the shape parameter value $\beta = 0.763$ hr and the scale parameter $\eta = 10748.973$ hr. In the 3-parameter Weibull distribution, the existing method produces the shape parameter value $\beta = 0.993$ hr, the scale parameter $\eta = 4922.18$ hr and the location parameter $\gamma \approx 864$ hr. While the new method produces the shape parameter value $\beta = 0.52$ hr, the scale parameter $\eta = 11824.498$ hr and the location parameter $\gamma \approx 147$ hr.

3.2. PN 398908-3
In the 2 parameter Weibull distribution, the existing method produces shape parameter values $\beta = 1,597$ hr and scale parameters $\eta = 6570.178$ hr. While the new method produces the shape parameter value $\beta = 0.831$ hr and the scale parameter $\eta = 4454.63$ hr. In the 3-parameter Weibull distribution, the existing method produces the shape parameter value $\beta = 0.835$ hr, the scale parameter $\eta = 5375.41$ hr and the location parameter $\gamma \approx 1027$ hr. While the new method produces the shape parameter value $\beta = 0.725$ hr, the scale parameter $\eta = 4542.839$ hr and the location parameter $\gamma \approx 41$ hr.

3.3. PN 8055515
In the 2 parameter Weibull distribution, the existing method produces the shape parameter value $\beta = 2,274$ hr and the scale parameter $\eta = 7934.89$ hr. While the new method produces the shape parameter value $\beta = 0.603$ hr and the scale parameter $\eta = 6005.25$ hr. In the 3 parameter Weibull distribution, the existing method produces the shape parameter value $\beta = 0.998$ hr, the scale parameter $\eta = 6221.620$ hr and the location parameter $\gamma \approx 1191$ hr. While the new method produces the shape parameter value $\beta = 0.383$ hr, the scale parameter $\eta = 7373.904$ hr and the location parameter $\gamma \approx 25$ hr.

3.4. PN 822-0990-004
In the 2-parameter Weibull distribution, the existing method produces the shape parameter value $\beta = 1,799$ hr and the scale parameter $\eta = 9354.004$ hr. While the new method produces the shape parameter value $\beta = 0.522$ hr and the scale parameter $\eta = 8254.707$ hr. In the 3-parameter Weibull distribution, the existing method produces the shape parameter value $\beta = 1.414$ hr, the scale parameter $\eta = 1.414$ hr and the location parameter $\gamma \approx 786$ hr. While the new method produces the shape parameter value $\beta = 0.573$ hr, the scale parameter $\eta = 8212.335$ hr and the location parameter $\gamma \approx -23$ hr.

4. Analysis of Calculation Results

4.1. PN 071-01503-2601
Comparison of failure rate graphs for PN 071-01503-2601 between the existing method and the new method for 2-parameter Weibull distribution and for the 3-parameter Weibull distribution, as follow:

![Figure 2. Failure rate curve for PN 071-01503-2601](image)
Comparison of failure rate graphs for PN 398908-3 between the existing method and the new method for 2-parameter Weibull distribution and for the 3-parameter Weibull distribution, as follow:

![Failure Rate Curve for PN 398908-3](image)

**Figure 3.** Failure rate curve for PN 398908-3

### 4.3. PN 8055515

Comparison of failure rate graphs for PN 8055515 between the existing method and the new method for 2-parameter Weibull distribution and for the 3-parameter Weibull distribution [6], as follow:

![Failure Rate Curve for PN 8055515](image)

**Figure 4.** Failure rate curve for PN 8055515

### 4.4. PN 822-0990-004

Comparison of failure rate graphs for PN 822-0990-004 between the existing method and the new method for 2-parameter Weibull distribution and for the 3-parameter Weibull distribution, as follow:

![Failure Rate Curve for PN 822-0990-004](image)

**Figure 5.** Failure rate curve PN 822-0990-004

The percentage of NFF for each part number is shown in the graph below.
5. Conclusions

The method used which considers the NFF as a failure cannot be justified should the NFF not be considered a failure. The new method has a more consistent form of failure rate curve between the 2 and the 3 parameter Weibull. The results of the reliability calculation show the difference in the parameter value of the form $\beta$ which depends on the percentage number of NFF in the data sample. The use of 2-parameter Weibull in reliability calculations cannot be justified, it should use a 3-parameter Weibull calculation. The reliability calculations should use a 3-parameter Weibull distribution so that component failures before operation can also be detected. Making user-friendly Excel calculations using VBA macros can be implemented and searching for the life of an item needs to be done in more detail from the beginning of the item being put into operation.

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