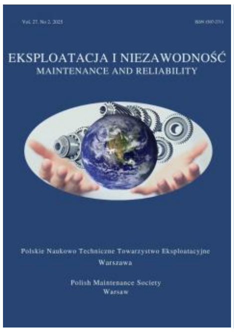

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Reliability analysis of the vehicle door system EDCU based on Weibull distribution

Indexed by:

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Highlights

- A two-parameter Weibull function model was proposed to research the failure law of EDCU.
- A two-parameter Weibull function model fitted by the least squares method.
- Logarithmic approach based on the least squares method.
- The failure law of components provides a basis for optimizing their maintenance methods.

Abstract

The paper established a two-parameter Weibull distribution model to analyze the failure law of key components of metro vehicles and employed the least squares method to fit the parameters of the Weibull function. The paper provided a detailed introduction of the model's parameter fitting method based on actual historical failure data. Taking the EDCU (Electrical Door Control Unit) as an example, the failure rate, cumulative failure rate, and reliability of EDCU for 3 different vehicle models were calculated, and the calculation results were verified to conform to the Weibull distribution through Q-Q diagrams. The results show that although the designed service life of EDCU of vehicle door system is 15 years, the reliability of the EDCU decreases significantly around 10 years. The EDCU reliability of the three vehicle models declines by 22%, 4.2%, 10.6% and the failure rates are 2.7%, 0.57%, 1.13%. Based on the reliability of EDCU mentioned above, while ensuring the reliability of components, the maintenance methods of components can be optimized to reduce maintenance costs.

Keywords

reliability, failure rate, Weibull function, the least squares method, Q-Q plots, EDCU

1. Introduction

Metro vehicles contain many key systems and components. In order to ensure the traveling safety of passengers, the reliability research of key systems and key components of metro vehicles is extremely important. Currently, the methods used in the reliability research of metro vehicle systems and key components [1] mainly include failure mode, impact and hazard analysis (FMECA), fault tree analysis (FTA), the GO method, the reliability block diagram (RBD) method, and experimental research and testing methods.

The FMECA method analyzes all possible faults and failure modes of the product, determines the effect of each failure mode on the product's operation, identifies the single point of failure, and determines the harmfulness based on the severity and probability of occurrence. X Cheng et al. [2]used the FMECA

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method to analyze the reliability of the metro door system. They identified the main failure modes, grouped them by their effects, and conducted a detailed analysis. Wang W et al. [3]used three methods to analyze the reliability of a metro door system: the FMECA method with linear interpolation, the uncertain ordered weighted average (DUOWA) algorithm combined with the hierarchical analysis process (AHP), and the Weibull distribution to determine the system's failure rate. However, the FMECA method is a single-factor analysis that focuses on a specific failure mode's impact on system reliability,but it has limitations in studying the reliability of multiple factors combined with each other; thus, Shi. Feng et al. proposed the construction of a fault tree analysis (FTA) for the door system, combining the fault tree model with Monte Carlo simulation [4] to identify system weaknesses and provide technical support for reliability design and fault diagnosis. However, Traditional fault tree analysis has limitations, including data shortages and difficulty calculating failure rates, leading to a time-consuming and resource-intensive construction process.

The GO method (GO methodology) [5] is a kind of safety analysis applicable to gas flow, liquid flow, and electric current production processes. In recent years [6], the reliability technology research of the GO methodology for complex systems has received extensive attention from scholars due to its apparent advantages in modeling and analysis capabilities. The GO methodology is used for reliability and safety analysis in transportation and power systems. However, it has multiple operators, is complex to use, and requires a thorough system understanding. This makes the method's workload and calculation larger, making it less suitable for complex systems.

Reliability block diagram (RBD) is a graphical representation of the reliability logic relationships between system components, uesd to analyze the impact of component failures on the system. It is a well-developed and widely used method [7]. RBD is usually converted to Bayesian networks [8] for quantitative analysis of systems. However, this technique is only suitable for non-repairable systems.

Experimental research and testing methods mainly apply to the reliability study of key components. Wang B et al. proposed a [9] structural fatigue reliability assessment method combining dynamic stress in-service measurements and probabilistic life prediction methods for the reliability analysis of rail train bogies and obtained a reliability of 99% of the welded joints with a failed mileage of 340,000 kilometers; another method [10] based on the bogie's static strength and fatigue strength experiments, through simulation to identify the fatigue strength of the bogie, to provide data support for reliability studies of bogies; Hansheng Zhang et al. conducted a study on the thermal reliability of the crown spring connector in a power supply system using fault tree, current-carrying test evaluation, and experimental and thermal theory research [11]. In addition, Long Liu et al. studied the reliability of drippers for contact network components [12], proposed the use of stereo microscopy and scanning electron microscopy for observation, and combined with the EDS technology to study the failure rule of drippers, thus providing data support to improve the reliability and life of drippers.

The Mean Time Between Failures (MTBF)[13] is commonly used to evaluate electrical components but has limitations. The MTBF is only valid when the failure rate is constant, unlike the "bathtub curve," where the failure rate is only constant during occasional failures. The distribution of the failure rate of many electrical components in the actual engineering does not conform to the "bathtub curve," so it is not suitable to interpolate the mean time between failures to predict the electrical component's life cycle of electrical components.

Regarding the above methods and problems in the reliability study of vehicle systems and key components, it can be found that the main problems in the process of reliability research are complex calculations, large calculations, and difficulty in calculating the failure rate of key components and systems, etc. However, the failure rate [14] is an important indicator in the reliability assessment and should not be ignored. The Weibull[15] distribution is a flexible function used to analyze the failure rate of characteristic cycles, making it an essential tool in electromechanical product failure analysis. Compared with the above methods, the Weibull function offers accurate failure analysis and prediction for small data samples, providing simple, easy-to-understand graphs for individual failure modes; the shape of the distribution state can be well selected by adjusting the parameters to the corresponding distribution, making it an excellent choice for calculating reliability and constructing failure models.

At present, research on the reliability of metro vehicles mainly focuses on the reliability of key systems, and rarely on the reliability of key electrical components. However, in the actual maintenance process of metro vehicles, the reliability of key components is very important, directly affecting the system reliability and maintenance strategies of metro vehicles. Therefore, this paper proposes a method for reliability analysis of vehicle systems and key components based on the Weibull function. Taking the EDCU, a key component of the Vehicle door system, as an example, the reliability study was carried out through a two-parameter Weibull distribution to calculate the failure rate and reliability of the EDCU. The least-squares method was used for parameter fitting, and a logarithmic approach is proposed in the process of parameter fitting using the least squares method, the study provided support for strategy optimization of the EDCU.

2. Basic theory

This paper calculates the failure rate of the vehicle door EDCU based on the Weibull function. Due to the possibility of failure of the EDCU in the early stages, the two-parameter Weibull function is used for the calculation, and the least squares method is used to fit the Weibull parameter. Finally, the calculation results are verified by the Q-Q plots. Theoretical framework for the approach is shown in Fig.1.

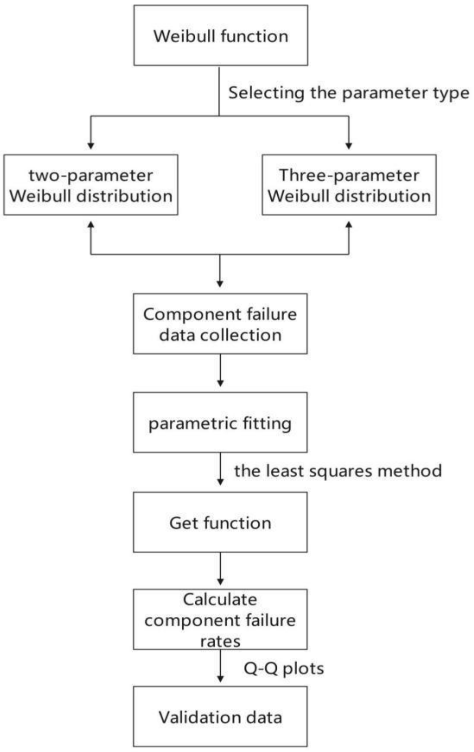


Fig. 1. Theoretical framework for the approach.

2.1. The Weibull function

2.1.1. Weibull functions

The Weibull distribution is the theoretical basis for reliability analyses and the theoretical basis for life testing. In reliability engineering, it is widely used, especially for the distribution of cumulative failures of electromechanical products, and it is the most popular model in the life cycle. The two common Weibull functions are the three-parameter Weibull distribution and the two-parameter Weibull distribution.

The three-parameter Weibull function is a continuous probability distribution with a probability density function:

$$f(t,m,\gamma,\eta) = (\eta/m)(\frac{t-\gamma}{\eta})^{m-1} e^{-(\frac{t-\gamma}{\eta})^{m}} \tag{1}$$

where t is a free variable that generally indicates the working time of the evaluated component,m is a shape parameter,η is a scale parameter, andγ is a displacement parameter.

When using the Weibull function to calculate the failure rate, critical components may fail at an early stage. If there is a possibility of failure in the early stages of using components, it can be assumed that the displacement parameter is 0. This time, the three-parameter Weibull function will be transformed into a two-parameter Weibull distribution, and the probability density function is:

$$f(t,m,\eta) = (m/\eta)(\frac{t}{\eta})^{m-1} e^{-(\frac{t}{\eta})^{m}} \tag{2}$$

The cumulative distribution function is:

$$F(t) = 1 - e^{-(\frac{t}{\eta})^{m}} \ (t>0, m>0) \tag{3}$$

The reliability function is:

$$R(t) = 1 - F(t) \tag{4}$$

The failure rate can be expressed as:

$$\lambda(t) = \frac{f(t)}{R(t)} \tag{5}$$

2.1.2. Least squares fitting of parameters of the Weibull distribution

The Weibull function is a nonlinear model, and the common methods for fitting the parameters of the Weibull function are the maximum likelihood estimation method and the least squares method. The maximum likelihood estimation method requires a significant amount of computation during the fitting process, while the least squares method is simple to implement, requires relatively less computation. Simultaneously, it boasts a higher accuracy,and is suitable for practical engineering applications. When using the least squares method for nonlinear model computation, the commonly method is to use Taylor expansion for the objective function, convert it to a linear model, solve the linear incremental equation or find the optimal value by direct iteration. In the process of transforming to a linear model, the Taylor expansion method has good positioning performance. However, the method requires a recursive solution, and the amount of calculation of the algorithm is huge, making it unsuitable for practical engineering projects. To solve this problem, this paper proposes a logarithmic method for linear model transformation, which can simplify the linear process and effectively reduce the amount of calculation.

Before the least squares method is used to fit the parameters, the function needs to be transformed into a linear model, essentially into the form Y = AX+B.At this point, a logarithmic method can be used to linearly transform the function. The specific process is as follows:

Introducing the cumulative distribution function for the Weibull distribution:

$$F(t) = 1 - e^{-(\frac{t}{\eta})^{m}} \text{ (t>0, m>0)} \tag{6}$$

The value of the cumulative distribution function can be approximated by the median rank:

$$F(t_i) = \frac{i - 0.3}{n + 0.4} \tag{7}$$

Where n is the sample data , i is the i-th sample

Then, the cumulative distribution function needs to be transformed into a linear model. Using the logarithm method to take the logarithm of both sides of the function, the following equation is obtained:

$$ln(\, ln\frac{1}{1 - F(t)}) = m\, ln(\, t) - m\, ln(\, \eta) \tag{8}$$

Let y=$ln(\, ln\frac{1}{1-F(t)})$, x=$ln(\, t)$, a=m , b=$m\, ln(\, \eta)$, and the original equation is transformed into y=ax+b

Introducing variance and

$$L = \sum_{i=1}^{n} (y_i' - y_i)^{2} \tag{9}$$

where y_i' is the value of $F(t_i)$ substituted for $ln(\, ln\frac{1}{1-F(t)})$ obtained by the median rank algorithm

The extreme points of L are obtained by the extreme value method, which can be calculated by applying the matrix expression for ease of operation:

$$A = \begin{pmatrix} a \\ b \end{pmatrix} \tag{10}$$

$$X = \begin{pmatrix} x_1 & 1 \\ \vdots & \vdots \\ x_i & 1 \end{pmatrix} \tag{11}$$

$$Y = \begin{pmatrix} y_1 \\ \vdots \\ y_i \end{pmatrix} \tag{12}$$

Derivation of A yields:

$$A = (X^T X)^{-1} X^T Y \tag{13}$$

With the above equation, the parameters of the two-parameter Weibull model$m$ andη can be calculated:

$$\begin{gathered} m = a \\ \eta = e^{\frac{b}{m}} \end{gathered} \tag{14}$$

2.2. Testing the data for compliance with the Weibull function

After calculating the required data, it is necessary to test the data to see if it conforms to the distribution model applied； introducing the concept of Q-Q plots and using Q-Q plots for testing, it can be visualized whether the data conforms to the Weibull distribution or not.

2.2.1.Q-Q Plot Test Distribution Principle

A Q-Q plot is a probability plot that compares the quantile plots of one data set with another data set [16]. It reveals outliers, differences in location and size, and other differences between distributions. It is useful for comparing the residuals of an estimated linear model with those of a normal model and can be used to visualize whether a set of data conforms to a certain distribution.

If the two distributions are similar, then this Q-Q plot tends to fall on the y=x line but not necessarily on the y=x line. Q-Q plots can be used to assess parameters that can be visualized in the context of the positional scales of the distributions.

2.2.2. Q-Q plotting process

(1) Raw data processing

Sort the raw data from smallest to largest x_1, x_2,...x_n and calculate the cumulative probability values corresponding to them.

(2) Calculate the quantile q_1, q_2, q_3...q_n

The quantile is the point at which a batch of data is separated using probability as a basis.

Let the distribution function of a continuous random variable x be F(X) and the density function be f(x), satisfying the conditions for any P ∈ (0, 1):

$$F(x_p) = \int_{-\infty}^{x_p} p(x)\,dx = p \qquad (15)$$

Then x_p is said to be the p-quantile of this distribution and x_p is found as follows:

$$x_p = \begin{cases} x_{(np+1)}, \text{np is not an integer} \\ \left[\dfrac{x_{(np)} + x_{(np+1)}}{2}\right], \text{np is an integer} \end{cases} \qquad (16)$$

(3) Plotting the Q-Q plot

Plot pairs of numbers (q_n , x_n) into the coordinate plane to see if they form a straight line. The more closely it converges to a straight line, the more the data fits the distribution being tested.

3. Failure model of EDCU

3.1. EDCU

The door system is a key subsystem of vehicle vehicles, and door failures can seriously affect vehicle operation safety and service quality. The historical fault records of vehicle vehicles in a certain city show that EDCU faults account for about 65% of door system faults. EDCU is the core component of the metro vehicle door system[17], responsible for driving the door motor switching, status detection, safety and security, and controlling the light display of the door. Each vehicle door is equipped with an EDCU installed in the top box of the door body. Therefore, the reliability research of EDCU is critical. The working principle of the EDCU is shown in Figure 2.

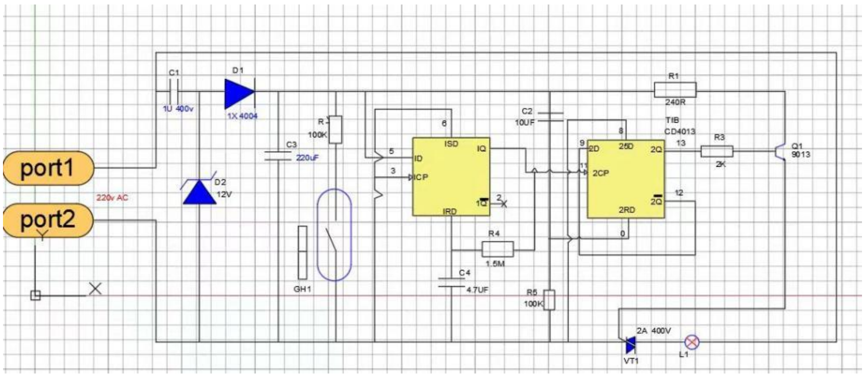


Fig. 2. EDCU working principle diagram.

3.2. Data collection

Three vehicle models, A, B, and C, are selected to study the reliability of EDCU. Three vehicle models have different service lives; the basic information is shown in Table 1. The A vehicle model is put into use in 2003, with 60 EDCUs per train and 1680 EDCUs for the entire model. The B Model is put into service in 2009, with 60 EDCUs per train. The total number of EDCUs for the whole vehicle model is 2520. 2007 Model C entered service, with 48 EDCUs per train and 1344 EDCUs for the entire model. The vehicles of the 3 models adopt a planned maintenance mode. The frame overhaul of the vehicle is carried out every 5 or 10 years, and the frame overhaul time of A, B, and C models is shown in Table 1.

Table 1. Basic information of A,B,C models.

Model	A	B	C
Service (year)	2003	2009	2007
Number of EDCUs per train	60	60	48
Number of EDCUs for the module	1680	2520	1344
Overhaul Time (year)	2013-2015	2017-2020	2016-2019

The annual and the monthly failure numbers of EDCU for each vehicle model are shown in Table 2 and Table 3 below.

Table 2. Annual failure numbers of A,B,C vehicle model.

Year	A	B	C
2005	0	/	/
2006	0	/	/
2007	115	/	/
2008	137	/	/
2009	149	/	/
2010	196	/	/
2011	197	32	21
2012	228	22	43
2013	182	52	53
2014	10	53	46
2015	16	62	96
2016	54	106	102
2017	47	107	146
2018	61	52	164
2019	56	55	128
2020	61	35	126
2021	104	102	108
2022	66	91	43
2023	122	47	101

Table 3 Monthly failure numbers of A,B,C model.

Year	Jan			Feb			Mar			Apr			May			Jun		
	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
2007	1	/	/	6	/	/	1	/	/	14	/	/	14	/	/	17	/	/
2008	2	/	/	2	/	/	8	/	/	12	/	/	9	/	/	11	/	/
2009	25	/	/	14	/	/	20	/	/	5	/	/	11	/	/	12	/	/
2010	17	/	/	3	/	/	5	/	/	6	/	/	1	/	/	10	/	/
2011	23	1	3	12	2	0	28	2	0	20	2	0	10	3	0	6	5	1
2012	26	0	1	35	0	5	53	0	5	37	0	2	28	0	6	5	0	4
2013	42	7	3	14	6	1	25	4	2	18	2	4	5	0	10	11	5	6
2014	2	2	3	0	3	4	1	2	3	1	2	4	0	1	1	3	3	1
2015	3	5	10	0	5	3	2	2	4	5	2	6	0	2	8	0	2	8
2016	3	4	7	3	5	2	1	5	2	2	7	5	5	8	7	7	9	8
2017	6	8	10	6	13	14	2	8	9	4	3	8	2	6	8	4	11	6
2018	8	9	16	2	7	9	5	5	13	6	5	12	8	7	8	2	3	9
2019	2	5	10	5	3	10	2	5	11	4	2	11	15	4	6	2	7	3
2020	4	2	20	3	3	6	4	7	6	4	2	3	1	3	4	4	0	12
2021	15	4	14	15	0	7	4	1	8	7	1	8	7	4	6	8	4	6
2022	9	6	0	5	9	1	3	12	2	0	0	0	3	2	0	4	2	0
2023	12	4	14	10	10	6	7	2	3	4	4	3	15	3	13	13	3	11

Year	Jul			Aug			Sept			Oct			Nov			Dec		
	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
2007	5	/	/	3	/	/	13	/	/	12	/	/	11	/	/	18	/	/
2008	14	/	/	28	/	/	8	/	/	14	/	/	14	/	/	15	/	/
2009	8	/	/	7	/	/	12	/	/	4	/	/	18	/	/	13	/	/
2010	7	/	/	6	/	/	9	/	/	13	/	/	47	/	/	72	/	/
2011	6	2	0	7	4	2	11	4	1	17	3	5	18	1	2	39	3	7
2012	5	3	0	9	2	6	4	6	3	6	1	3	9	3	6	11	7	2
2013	13	6	5	10	5	5	10	9	3	12	4	2	10	2	6	12	2	6
2014	2	11	3	0	8	9	0	8	6	0	2	2	1	3	5	0	8	5
2015	0	9	19	1	9	8	2	7	5	2	2	3	1	11	15	0	6	7
2016	10	15	10	7	11	8	6	7	14	0	13	5	6	13	20	4	9	14
2017	3	3	1	5	16	12	4	12	12	4	9	20	7	8	21	0	10	25
2018	3	4	10	12	3	10	1	2	13	5	5	13	6	1	22	3	1	29
2019	3	8	5	3	3	16	8	4	12	6	2	17	3	6	11	3	6	16
2020	0	4	23	3	4	6	11	3	12	7	4	15	12	1	6	8	2	13
2021	9	16	4	6	20	13	5	10	7	8	13	10	14	16	8	6	13	17
2022	5	3	3	3	12	9	6	1	4	8	5	7	7	6	10	13	3	7
2023	25	7	7	7	3	6	9	4	7	7	1	14	8	4	7	5	2	10

3.3. Constructing Weibull Function Model for EDCU

EDCU is a key component in the door system of rail vehicles, which affects the safety of vehicle operation and service quality. It needs to be maintained, inspected, and replaced in time to ensure its reliability. When applying the Weibull function for failure rate calculation, the default number of failures has been growing during the calculation cycle. However, in the actual operation process of rail transport, the vehicle will be regularly maintained and components replaced. Based on the above, this paper adopts segmented fitting in the process of fitting parameters, with one cycle per year and data collection in months in each cycle, so that the results are more in line with the actual situation. According to the data in Table 2 , the number of EDCU failures is labeled and arranged by month; then based on the data in Table 3, the total number of EDCU failures per year is determined. Build the data model with a yearly cycle, and then fit the parameters of the Weibull function through the least squares method. Use Eq. (9-13) to build the calculation matrix. Finally, through Eq. (14), the parameters of the Weibull function are obtained for each year for the 3 vehicle models each year, as shown in Table 4-6:

Table 4. Weibull parameters for the vehicle model A .

Year	m	η
2007	1.835954359	49.86724305
2008	2.004576821	39.75912073
2009	1.039323198	113.3349412
2010	1.246806027	94.57924682
2011	1.119767584	82.55013981
2012	1.294522444	34.61895245
2013	0.979397013	96.32127497
2014	0.961746974	2132.558635
2015	0.973037753	1265.737243
2016	1.489161022	118.2163945
2017	1.0891121	307.1925036
2018	1.167058725	195.5788977
2019	1.517365073	100.5813179
2020	1.290480182	184.8805414
2021	1.057970792	158.3402606
2022	1.032376115	337.4380544
2023	1.304089356	79.76096375

Table 5. Weibull parameters for the vehicle model B.

Year	m	η
2011	1.55026082	189.0043574
2012	4.258719859	36.96194766
2013	1.081855535	420.2432437
2014	1.547494001	153.3201748
2015	1.241099005	266.423371
2016	1.608211862	85.58908787
2017	1.246349212	150.4171757
2018	1.084791924	327.2288484
2019	1.249555129	255.0444544
2020	1.287878062	293.6944225
2021	1.81195145	79.84793123
2022	1.11900865	299.9285548
2023	1.157952211	320.4709019

Table 6. Weibull parameters for the vehicle model C.

Year	m	η
2011	1.340705049	362.1603297
2012	1.419264284	123.9203549
2013	1.50025969	100.1116465
2014	1.271476724	178.9938507
2015	1.27418901	96.27404258
2016	1.430803283	82.30154303
2017	1.248631826	79.04030449
2018	1.210052181	73.48102889
2019	1.258981056	80.0121296
2020	1.080755791	113.2685018
2021	1.109896433	122.2052545
2022	2.320328226	58.94322161
2023	1.125694901	123.4971971

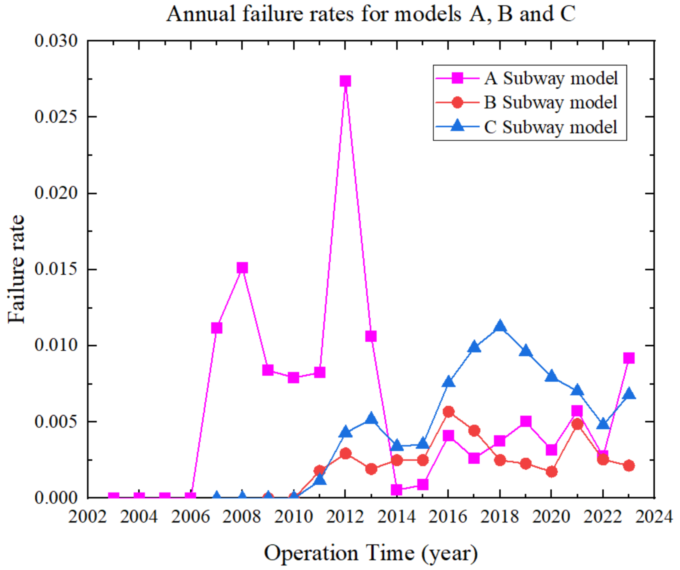
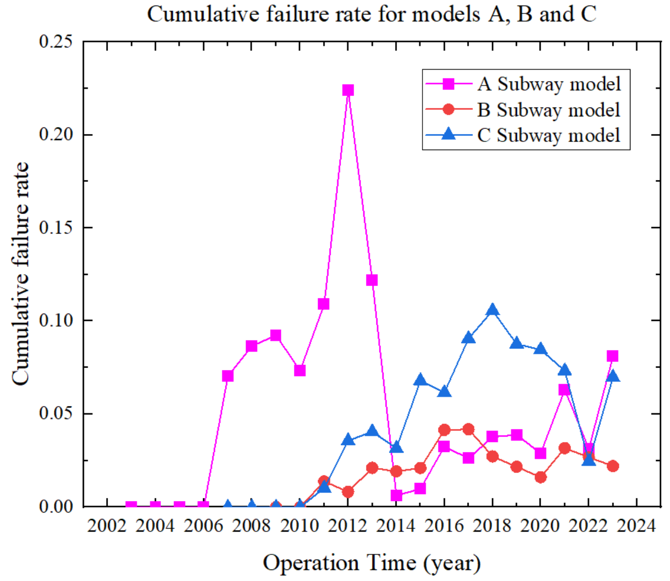
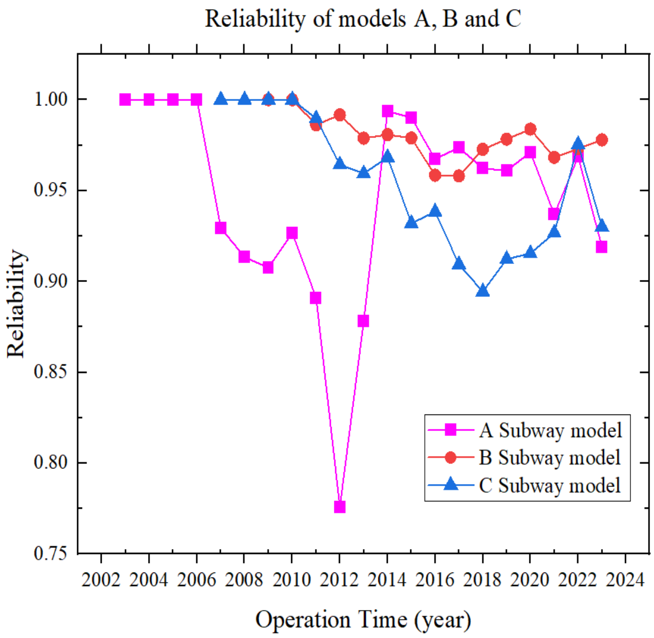


Fig. 3. Annual failure rates for models A, B and C.



（a）Cumulative failure rate for models A, B and C.



(b) Reliability of models A, B and C.

Fig. 4. Cumulative failure rate and reliability for models A, B and C.

Combining Eq. (5), Eq. (3), and Eq. (4), the obtained Weibull parameters are input to calculate the failure rate, cumulative failure rate, and reliability of EDCU. Figure 3 shows the annual failure rate curves of EDCUs, and the Cumulative failure rate and reliability are shown in Fig. 4 for vehicle models A, B and C. The following can be seen from Fig. 3 and 4.

(1) The failure rate of model A reached a maximum of 2.7% in 2012 and then showed a decreasing trend from 2013 onwards and then gradually increased. Meanwhile, The cumulative failure rate increased from 2005 to 2012, reaching a maximum of 22% in 2012. The door system maintenance records of model A show that the model underwent an overhaul from 2013 to 2015, which significantly reduced the EDCU failure rate and improved its reliability.

(2) The overall reliability of the EDCU for model B is high, with the failure rate being the highest in 2016 at nearly 0.57%. The cumulative failure rate reached its maximum in 2017, close to 4.2%. According to the planned maintenance requirements, the 2017-2020 major overhaul of Model B resulted in a slight increase in reliability and a slight decrease in the cumulative failure rate and failure rate from 2017.

(3) Model C had a large failure rate in 2018, which reached nearly 1.13%, and a large increase in cumulative failure rate in 2018, which reached nearly 10.6%, with reliability decreasing to 89.4%. According to the requirements of the planned maintenance, the C model was overhauled in 2016-2019, and after the overhaul, the reliability was significantly improved, and the cumulative failure rate was reduced.

(4) In the actual operation of rail vehicles, to ensure operational safety and service quality, EDCU needs to be repaired or replaced in time to ensure equipment reliability. As an electronic component, the reliability of EDCU generally decreases with the increase in service life. From the reliability trend of EDCUs of vehicle models A, B, and C, there are significant differences in the degree of reliability decline among different models, manufacturers, and usage environments. The design service life of the EDCU is 15 years, but in about 10 years the reliability of the EDCU decreases more, and the reliability of the three models decreases by 22%, 4.2%, and 10.6% respectfully. However, significant improvements in component reliability can be achieved through major overhaul to the component.

(5) For models A, B, and C, the planned maintenance mode is used regardless of the actual status of the EDCU. As can be seen from Fig.4, the reliability of the EDCU of model A reached the lowest level of 77.59% in 2012, and after the major overhaul, the reliability significantly improved, indicating that the maintenance measures for the EDCU are effective. Model C was put into service in 2007, and the reliability decreased significantly to 89.4% in 2018. After the major overhaul, the reliability was correspondingly improved. The overall failure rate of model B is low and the reliability is high, and the reliability slightly improves after the planned overhaul in 2017-2020，from the economic perspective, for the B vehicle model, under the premise the reliability meets the operational requirements, the cycle of planned maintenance can be extended, or according to the actual state of the EDCU, the condition maintenance mode can be considered.

4. Data validation

Q-Q plot can visually observe whether the data conforms to the Weibull distribution. The cumulative failure rate data in this paper were verified by Q-Q plot，using SPSS software，and the results are shown below.

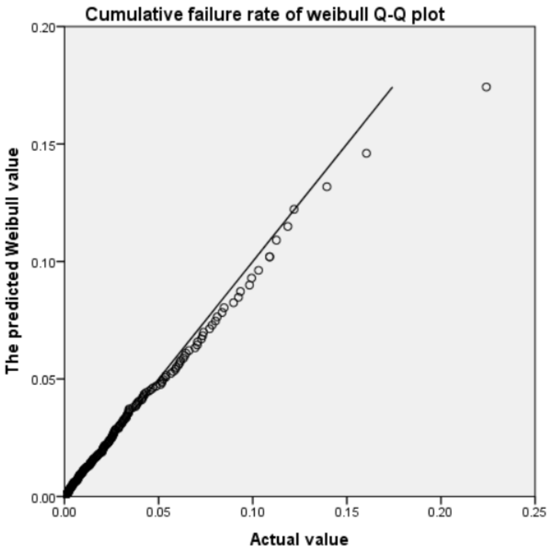


Fig. 5. Q-Q plot of cumulative failure rate for model A.

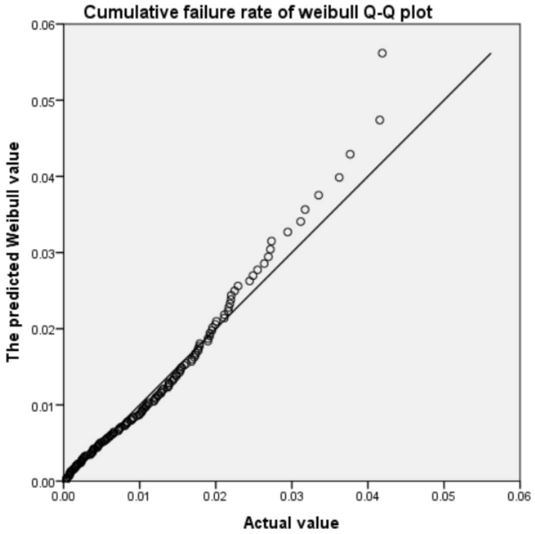


Fig. 6. Q-Q plot of cumulative failure rate for model B.

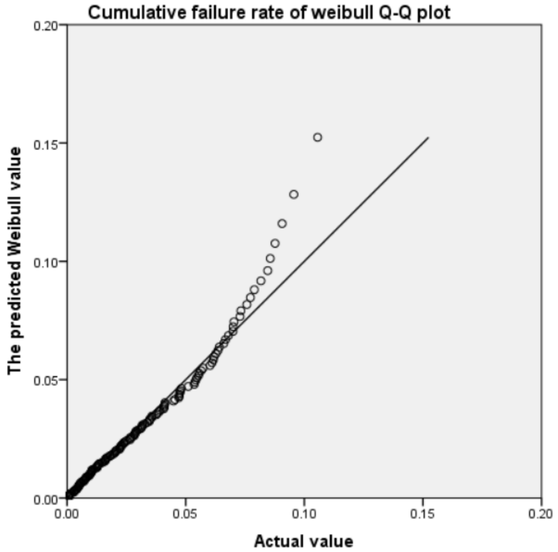


Fig. 7. Q-Q plot of cumulative failure rate for model C.

From Fig. 5-7, it can be seen that: the cumulative failure rate data of the 3 vehicle models A, B, and C were 189, 149, and 146, respectively. The three models of calculation results and the estimated Weibull function essentially converge to a straight line, with only a few results not around the line, indicating that the overall results conform to the Weibull distribution.

In conclusion, the cumulative failure rate data of the three models basically and largely conform to the Weibull distribution, and the reliability study of the EDCU can be carried out by this model.

5. Conclusion

This paper proposed a reliability analysis model based on Weibull distribution, fitted the distribution parameters through the least squares method, and analyzed the reliability law of EDCU of the door system during service. This reliability analysis model provides a method for analyzing the reliability of electrical components, and the following conclusions are obtained.

(1) In this paper, a two-parameter Weibull model was built to study the failure law of key electrical components of metro vehicles by fitting the function parameters through the least-squares method. The failure rate, cumulative failure rate, and reliability of the EDCU were analyzed, and the results were verified by using Q-Q plots. The final result show that the logarithmic method based on the least squares method can fit the parameters well. In addition, the failure distribution law of many electrical components is similar to that of the door controller. Therefore, this method can also be used to study the failure law of key electrical components of the vehicle system, such as the traction control unit-control unit, auxiliary power supply inverter and chopper module, which is of great significance for the preventive maintenance of key electrical components of metro vehicle systems.

(2) Through the analysis of the failure rate of the 3 vehicle models, the failure rate of the EDCU reached the peak around 10 years, at 2.7%, 0.57%, and 1.13% respectively, and the trend of the cumulative failure rate is to increase first and then decrease. Although the service life of the EDCU is 15 years, the cumulative failure rate will reach its maximum value around 10 years, respectively 22%, 4.2%, and 10.6%.

(3) To ensure the safety of metro vehicle operation and

service quality, the planned maintenance mode is frequently used for key components, regardless of their actual status. It is found that there were significant differences in the reliability of EDCU components among the 3 different vehicle models. Under the premise of meeting reliability requirements, in order to achieve the goal of reducing maintenance costs, the planned repair cycle can be extended, or a condition maintenance mode can be implemented according to the actual reliability of the components.

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