International Conference on Computer Information Systems and Industrial Applications (CISIA 2015)

Reliability Analysis of The Subway Door System Based on Monte Carlo

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***Abstract*—The subway door is one of the most important part of the metro vehicle system .The operation reliability of this door affects the quality of safety, economy and convenience of metro transportation. In this paper, failure modes of the door system were analyzed based on maintenance history of Guangzhou metro line 2. Firstly, the fault tree analysis (FTA) of the door system was then built. The qualitative and quantitative fault tree analysis methods were used to obtain failure modes, following by developing Monte Carlo simulation model. Finally, Combining Fault tree model and Monte Carlo simulation the importance degree of each component was solved. The results identify the weaknesses in the system and could provide technical support for the reliability design and fault diagnosis.**

Keywords: reliability; door system; monte carlo; FTA.

I. INTRODUCTION

With the rapid development of urban rail transport, The safety of rail train have attracted the door design unit and metro operating company great attention. Door system is a key component of the urban rail vehicle, which consists of complex mechanical and electrical parts. When metro train is operating, the door is opened and closed frequently, Comparing with other components, it is more likely to cause door system components damage, leading door frequent failure and affecting the safety of passengers travelling as well as the urban rail trains running. So it is necessary to analysis the reliability of door system, to identify its weaknesses part and improve the system reliability.

In recent years, different methods are used by scholars to study the ways of improving the reliability of the system. Zhu[1] established a traditional way of fault tree analysis of computer-based systems. Fault tree qualitative and quantitative analytical methods are used to analyze reliability of computer-based system；Dong [2] established reliability model based on GO methodology, getting all the factors that caused the doors failure and identify weaknesses in the system. FTA has a disadvantage of calculation amount, which is exponential growth with the scale of the problem. Above literatures are mainly identifying the weakness in system through fault tree analysis, which cost large calculation for complex system. Monte Carlo method have been widely used in engineering practice[3,4]. It is a kind of random simulation method, which overcomes the shortcoming of FTA in large calculation. Zhu [3] established a Monte Carlo simulation model on the basis of FTA to identify the weaknesses and improve the system reliability. Zhou [4] combined the Monte Carlo with the FTA to analyze the reliability of the hydraulic system of special vehicles, obtaining the degree of importance and system reliability index of the end event.

So far, relevant literatures about applying the Monte Carlo method to reliability analysis of door system have not been retrieved. Therefore, the Monte Carlo simulation method was introduced into fault tree analysis in this paper. Simulation results obtain the weak links that affects the door system reliability, which provide the support for the reliability design and fault diagnosis.

II. DOOR SYSTEM FAULT TREE ANALYSIS

A. Fault tree Door Systems Established

The door system failure is set into the top event. All levels of the end event which caused the door system failure were found out through analysis of a subway line 2 historical failure data. Top event failure mainly caused by the five intermediate events including gated signal error M1, motor no action M2, door removal failure M3, unlock failure M4 and closed large resistance M5. Apart from five intermediate events, the others are gated hold circuit failure M6, no open /close signal M7, EDCU functional failure M8, safety circuit failure M9, unlock signal error M10, insufficient lubrication M11, bodies catching M12. The FTA model of the door system is built as shown in Fig.1. Distribution function of the end event is shown in Tabel.1.

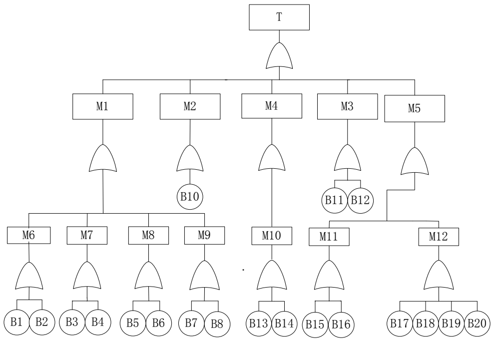

FIGURE I. FAULT TREE OF DOOR SYSTEM.

TABLE I. DISTRIBUTION FUNCTION AND CHARACTERISTIC VALUE OF BASIC EVENT.

Basic Event	**Event Description**	**Failure Distribution function**	**Characteristic value**	**Basic Event**	**Event Description**	**Failure Distribution function**	**Characteristic value**
B1	Latching relay fault	Weibull	m=0.727 η =24.529	B11	Switch S2 fault removal	Exponential	λ =30.476
B2	Position sensor fault	Exponential	λ =30.378	B12	Human error removal door	Exponential	λ =29.901
B3	Gate Enable relay fault	Weibull	m=0.679 η =23.429	B13	Emergency releases witch S3 failure	Exponential	λ =33.279
B4	Open button fault	Exponential	λ =33.267	B14	Unlock human error	Exponential	λ =18.796
B5	EDCU internal module fault	Exponential	λ =25.432	B15	length the guide post poor lubrication	Exponential	λ =29.398
B6	No unlock command EDCU	Exponential	λ =26.318	B16	Screw nut poor lubrication	Exponential	λ =28.875
B7	Locking switch S1 fault	Weibull	m=0.73 η=19.6	B17	Down rail deformation	Exponential	λ =24.590
B8	Switch S4 fault	Weibull	m=0.869 η =15.598	B18	Locating pin deformation	Exponential	λ =23.472
B9	Speed sensor fault	Weibull	λ =17.865	B19	Nut component fault	Exponential	λ =22.573
B10	Motor component fault	Exponential	λ =5.43307	B20	Screw bushing wear	Exponential	λ =20.328

B. Door System Fault tree Qualitative and Quantitative Analysis

FTA contains qualitative analysis and quantitative analysis. Qualitative analysis is used to find out minimal cut set which is defined as a set of basic events where the joint occurrence of these basic events results in the occurrence of the top events. Qualitative analysis can help the system to solve weal links from minimal cut set [5].

According to the downstream method for solving minimum cut sets, the minimum cut sets which cause door system failure are got:{B1} ,{B2},{B3},{B4},{B5},{B6},{B7},{B8},{B9},{B10},{B11},{B12},{B13},{B14},{B15},{B16},{B17},{B18},{B19},{B20}.

With the built fault tree model, quantitative analysis is used to calculate the probability of the top event from known occurring probability of each end event. Quantitative analysis is a method for adding each basic event probability, it is convenient for the simple system model calculation, but not for complex systems, which requires the introduction of computer simulation technology.

III. MONTE CARLO RELIABILITY SIMULATION ANALYSIS

A. Monte Carlo Method

Monte Carlo method is a numerical method based on probability theory [6].Monte Carlo simulation is based on the large number theory, and gets the reliability of system by calculating statistical features of the sampling samples. Door system failure time is random, so Monte Carlo method can be used to calculate sample failure time and solve the reliability indexes according to corresponding formulas. Because door system fault caused by the failure of basic components is various, the sample is aimed at the failure time of basic components.

B. Simulation Process

1) Each basic event is sampled through its failure function. The sampling value of the i basic event when it fails is:

$$t_i = F_i^{-1}(\eta) \tag{1}$$

Where η is the random number in (0,1).

2) Assume that there are k minimal cut sets in the system and each cut set has n basic components. Then the sampling time of the n basic events in the K-th minimum cut sets is ti(i=1,2,…n). The minimum cut set happens only when all the bottom events happen, so the occurrence time t_q of the minimum cut set can only be got if the max time of all bottom events cost to occur can be determined in the q-th minimal cut set, that is:

$$T_q = \max\{t_1,\ \ t_2,\cdots t_i \cdots t_n\} \tag{2}$$

3) Top event will occur only if one minimum cut set happens, if the minimum occurrence time of k minimal cut sets is required, then the occurrence time Y of the top events can get, that is:

$$Y = \min\{T_1,\ \ T_2,\cdots T_q \cdots T_k\} \tag{3}$$

4) Repeat step 1),2),3)*M* times, the *M* times simulation results $Y_m(m=1,2,\ldots M)$, can be acquired ,then compare the results with the given time $t_m(m=1,2,\ldots M)$.If $Y_m<t_m$, then top events occur in the given time. If not, that means the system fault. The system failure N_m times was added up in the time. t_m.

C. *Simulation Statistics Index*

Importance degree calculation [7].

①Importance degree of basic components $W(B_i)$

$$W(B_i) = \frac{N_1}{N_2} \tag{4}$$

Where N_1 is the system failure numbers caused by $\mathrm{B_i}$ and N_2 is the failure numbers of $\mathrm{B_i}$ .If $W(B_i)$=1, then it shows that system failure must happen as long as components B_i occur, indicating the components have a higher importance.

②Mode importance degree of basic component $W_N(B_i)$

$$W_N(B_i) = \frac{N_1}{N_3} \tag{5}$$

Where N_3 is the total system failure number.

Mode importance is commonly used to judge the weak link of system reliability. The larger $W_N(B_i)$ is, the weaker $W(B_i)$ and $W_N(B_i)$ reflect the component importance at different angles. In all, importance is determined by the failure probability and the place in system structure [8].

IV. ANALYSIS OF SIMULATION RESULTS

The simulation process needs (0,1) random numbers to solve sample values of event failure time, given the MATLAB software proprietary function for numerical analysis, so we use it to simulation programming. Set simulation 5000 times, the system maximum working hours 3000h, simulation flow chart is shown in Figure 2.

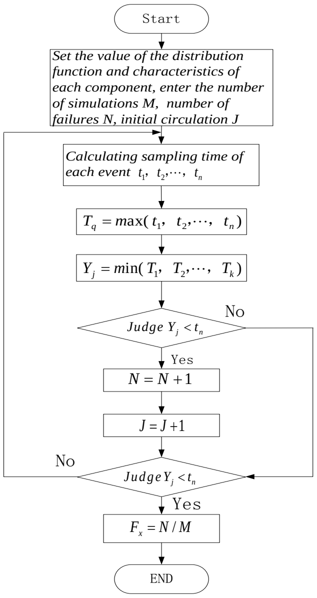

FIGURE II. SIMULATION FLOW CHART.

The simulation results of importance degree are shown in Table 2

According to mode importance degree, it obtains that B5, B6, B7, B19 the four events are the weak link in the system, named EDCU internal module failure, EDCU no unlock command function fails, the trip switch S1 damaged, and nut assembly fault, corresponding with actual diagnose.

As can be seen from Table 2, in addition to B15, B15, B17, B18 .The importance degree of the other end event are 1, according with qualitative analysis. From figure 3, the maximum reliability probability is decreasing gradually with the simulation of time, indicating simulation is correct.

TABLE II. SIMULATION RESULTS OF IMPORTANCE.

Basic event	$W(B_i)$	$W_N(B_i)$	**Basic event**	$W(B_i)$	$W_N(B_i)$
B1	1.000	0.0112	B11	1.000	0.0715
B2	1.000	0.0201	B12	1.000	0.0501
B3	1.000	0.0137	B13	1.000	0.0562
B4	1.000	0.0245	B14	1.000	0.0450
B5	1.000	0.1624	B15	0.620	0.0260
B6	1.000	0.1548	B16	0.435	0.0231
B7	1.000	0.0832	B17	0.046	0.0145
B8	1.000	0.0315	B18	0.075	0.0214
B9	1.000	0.0156	B19	1.000	0.1780
B10	1.000	0.0067	B20	1.000	0.0330

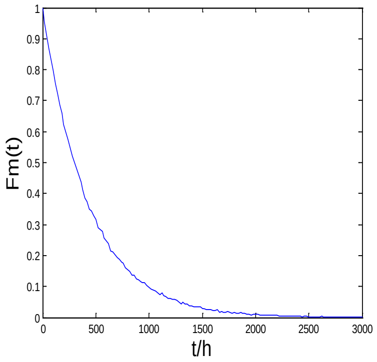

FIGURE III. SYSTEM RELIABILITY CURVE.

V. CONCLUSION

The paper established the door system fault tree, then using the Monte Carlo method reliability simulation results determine the importance of each door system components, and further determine the weaknesses of the system. The result is consistent with maintenance experts in the field, and is capable of providing technical support for design and maintenance of door system.

REFERENCE

[1] X. J. Zhu, J. B. Wang, Z. M. Yin. On the Reliability of Passenger Compartment Door in Shanghai Metro Trains [J]. *Urban Rail Transportation Research*. 9(3):31-34,2006.

[2] J. Z. Dong, J. W. Yang, Q. Huang. Reliability Evaluation on metro vehicle compartment door based on GO method [J]. *Urban Rail Transportation Research*. 16(4): 28-31,2013.

[3] Y. M. Zhu, J. Huang, Y. Zhang. Reliability simulation of a ship gear box based on fault tree analysis[J].*Journal of Jiangsu University of Science and Technology (Natural Science Edition)*. 26(4): 350-355,2012.

[4] A. P. Zhou, X. H. Wang, Z. J. Song .The simulation analysis for hydraulic system reliability of heavy transport vehicle based on fault tree analysis. *MACHINE TOOL & HYDRAULICS*. 39(19): 151-154,2011.

[5] D. Quan, X. F. Sun, M. Wang. Study on Reliability of identity module based on fault tree analysis. *Model Manufacturing Engineering*. 4: 122-125,2012

[6] B. Du. Monte Carlo methods application in Systems Engineering [M].Xi An. Xi'an Jiao tong University Press.2007

[7] F.M. Lin. Study of Application of Fault Tree Analysis & Simulation in Ball Mill Transmission system [D]. Beijing: North China Electric Power University.2004.

[8] Durga Rao K, Gopika V, Sanyasi Rao V V S, et al. Dynamic fault tree analysis using Monte Carlo simulation in probabilistic safety assessment[J]. *Reliability Engineering & System Safety*. 94(4): 872-883,2009,.