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Evaluation for Parachute Reliability Based on Fiducial Inference and Bayesian Network

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***Abstract*—Reliability is an important indicator for evaluating the performance of a parachute system. Verification of reliability often requires a large number of successful system-level airdrop tests, which is often difficult to accept in practice. This paper proposes a reliability analysis method based on Fiducial inference and Bayesian network. The method firstly decomposes the parachute into each group according to the system composition, and uses the layered BN to represent; secondly, based on the Fiducial inference method, the mean value and the lower confidence limit of the strength test data of each group are calculated. And apply the stress-strength model to calculate the probability that the intensity is greater than the stress, and as the reliability of each component; third, considering the conduction relationship between the nodes of each layer, respectively calculate the node conduction probability. The joint probability of the node with conduction relationship is calculated by the fusion node probability based Bayesian. Finally, based on the prior probability of the node, the posterior probability of each node is calculated and the parachute groups (parts) system are obtained. The analysis of the example shows that the calculation process of the method can fuse the reliability information of each layer of the system, which improve the accuracy of the system reliability. It can be used for the reliability analysis of the parachute system in the design stage, also can provide reference for inspection and acceptance of parachute system.**

Keywords—parachute; reliability; Bayesian network; fiducial inference; stress-strength model

I. INTRODUCTION

The reliability assessment of the parachute system often follows two methods: the first is to collect the reliability data of the parachute system through the success or failure system-level airdrop test, so as to evaluate the reliability of the parachute system; the second is to apply the reliability test data of the parachute module to evaluate the reliability of the parachute system based on the reliability model of the parachute system and components. The sample size was large in airdrop test of the success or failure parachute system, and data acquisition was very difficult. The comprehensive evaluation method of reliability of parachute system based on component reliability has become the research focus of scholars[1-5]. Based on the related research work, this paper proposes a reliability analysis method based on Fiducial statistical inference-Bayesian network. The research results can be used for the reliability analysis of the parachute system in the design stage, and can provide reference for the inspection and acceptance of the parachute system.

II. METHOD DESCRIPTION

A. Reliability Analysis Method

Reliability analysis of the parachute system based on the Fiducial inference-Bayesian network, the first is to decompose the parachute into parts according to the system composition, and expressed by Bayesian network; secondly, based on the Fiducial inference method, the mean value and the lower confidence limit of the strength test data of each group are calculated. And apply the stress-strength model to calculate the probability that the intensity is greater than the stress, and as the reliability of each component; third, considering the conduction relationship between the nodes of each layer, respectively calculate the node conduction probability. The joint probability of the node with conduction relationship is calculated by the fusion node probability based Bayesian.

B. Bayesian Network Model

It is assumed that the parachute system P(X(1,1)) is composed of three component systems A(X(2,1)), B(X(2,2)), and C(X(2,3)), where, in A consists of two component systems: A1(X(3,1)) and A2(X(3,2)). B consists of B1(X(3,3)) and B2(X(3,4)), B3(X(3,5)) three systems, C consists of two systems C1(X(3,6)), C2(X(3,7)). According to the analysis, there is a local conduction relationship between the system of each group (parts), and the Bayesian network model of the parachute system is shown in Figure 1.

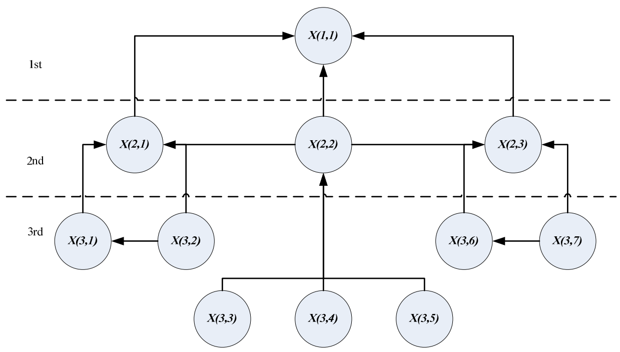

FIGURE I. BN MODEL OF PARACHUTE SYSTEM

III. RELIABILITY ANALYSIS ALGORITHM

A. Statistical Estimation of Node Reliability

- Fiducial Inference

Fiducial inference believes that [6-8], before extracting samples, knows nothing about statistical parameters. After obtaining samples, there is information on the parameters, but the is not reached parameters. However, only the "degree of trust" for taking various values is different, that is, a distribution of parameters can be obtained.

Let random variables $X_1, X_2, X_3, ..., X_n$ be independent and obey normal distribution, μ,σis unknown, then:

$\sqrt{n}\left(\overline{X}-\mu\right)/S$ compliance with the t(n-1) distribution (1)

$(n-1)S^2/\sigma^2$ compliance with the χ^2(n-1) distribution (2)

- Stress-Strength Model

Assuming that the stress and strength are subject to the probability density function $f_X(x)$ and $f_Y(y)$, the reliability R is defined as the probability that the strength is greater than the stress,

$$R = P(Y > X) = \int_{-\infty}^{+\infty} f_X(x)\left[\int_{x}^{+\infty} f_Y(y)dy\right]dx$$

If both stress X and strength Y obey the normal distribution, then

$$R = \Phi\left(\frac{m_2 - m_1}{\sqrt{\sigma_2^2+\sigma_1^2}}\right) \quad (3)$$

Where, m_1, σ_1^2 is the mean and variance of the normal distribution obeyed by the stress, m_2, σ_2^2 is the mean and variance of the normal distribution obeyed by strength.

- Estimating Reliability (prior probability)

Computational reliability cumulative distribution function $F(r)$, with $1 > \gamma > 0$, $P\{R \ge R_L(\gamma)\} = \gamma$,then,

$$f(r) = dF(r)/dr \text{ as } P\left(X_{(l,m)}\right).$$

B. Node Reliability Estimation

- Calculated conduction prior

For a node system with a conduction relationship, its reliability can be expressed as [9] according to the conditional probability formula:

$$P_r\left(X_{(l,m)}\right) = \sum_{P_{all}\left(X_{(l,m)}\right)} P_r\left[X_{(l,m)} \mid P_{all}\left(X_{(l,m)}\right)\right]\cdot P_r\left[P_{all}\left(X_{(l,m)}\right)\right]$$

- Calculating joint probability

Node priori probability and conduction prior probability of $X_{(l,m)}$ can be synthesized into a joint prior $p_{(l,m)}^c$, and $p_{(l,m)}^c \sim B\left(\alpha_{(l,m)}^c\right)$, in where, $\alpha_{(l,m)}^c = \omega_{(l,m)}\alpha_{(l,m)}$.

IV. CASE ANALYSIS

Assumed that the mean and std. of a parachute system P(X(1,1)) and A(X(2,1)), B(X(2,2)) and C(X(2,3)) are known, see Table I. Correspondingly, the Xbar and S of the data obtained by the strength test are shown in Table II.

TABLE I. STRESS MEAN AND STD. OF PARACHUTE SYSTEM

Para.	$X_{(1,1)}$	$X_{(2,1)}$	$X_{(2,2)}$	$X_{(2,3)}$	$X_{(3,1)}$	$X_{(3,2)}$
Mean	2832	1432	3217	2270	1520	1375
Std.	261	181	201	195	165	89
Para.	$X_{(3,3)}$	$X_{(3,4)}$	$X_{(3,5)}$	$X_{(3,6)}$	$X_{(3,7)}$	
Mean	2862	3150	3345	1752	2548	
Std.	154	186	212	191	189	

TABLE II. STRENGTH DATA OF PARACHUTE SYSTEM

Para.	$X_{(1,1)}$	$X_{(2,1)}$	$X_{(2,2)}$	$X_{(2,3)}$	$X_{(3,1)}$	$X_{(3,2)}$
Xbar	3520	1635	3545	2540	1720	1532
S	302	195	253	211	184	102
Para.	$X_{(3,3)}$	$X_{(3,4)}$	$X_{(3,5)}$	$X_{(3,6)}$	$X_{(3,7)}$	
Xbar	3310	3525	3872	1922	2752	
S	175	217	261	184	218	

A. Node Prior Probability Calculation

According to the steps described before of Fiducial inference, stress-strength model and prior probability estimation, the minitab software is used to generate 50 sets of t(n-1) andχ^2(n-1) distribution with a degree of freedom of 4 (n=5), according to the above conditions and formulas (1)-(3), calculating the prior probability of the system and each group (part) system. Taking the X(2,2) node as an example, Figure II and Figure III show the cumulative probability distribution of the strength mean and variance respectively. Figure IV and Figure V are the histograms of the mean and variance respectively.

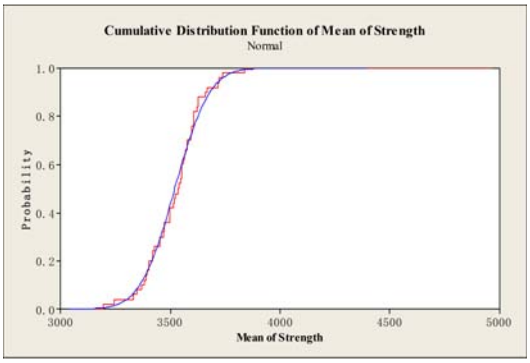

FIGURE II. STRENGTH MEAN CUMULAIVE PROBABILITY DISTRIBUTION

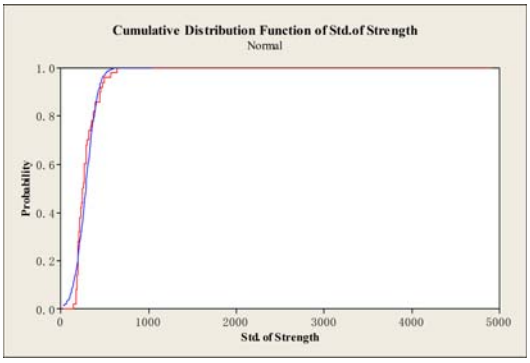

FIGURE III. STRENGTH VARIANCE CUMULATIVE PROBABILITY DISTRIBUTION

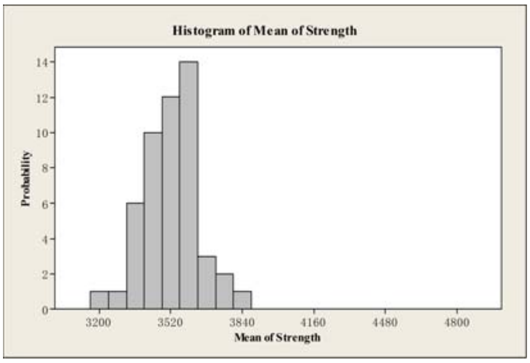

FIGURE IV. STRENGTH MEAN HISTOGRAM

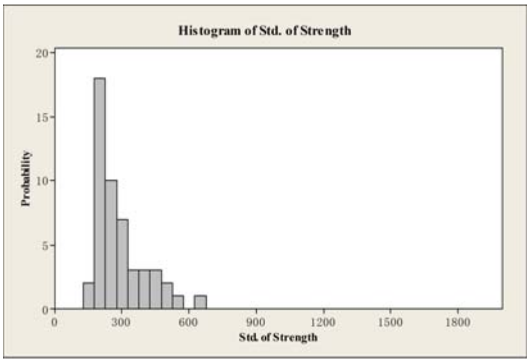

FIGURE V. STRENGTH VARIANCE HISTOGRAM

Table III shows the prior probabilities of the X(2,2).

TABLE III. PRIOR PROBABILITY OF EACH NODE

Nodes	K=0	K=1	Nodes	K=0	K=1
$P(X_{(1,1)})$	0.98	0.02	$P(X_{(3,3)})$	0.92	0.08
$P(X_{(2,1)})$	0.94	0.06	$P(X_{(3,4)})$	0.95	0.05
$P(X_{(2,2)})$	0.97	0.03	$P(X_{(3,5)})$	0.98	0.02
$P(X_{(2,3)})$	0.95	0.05	$P(X_{(3,6)})$	0.96	0.04
$P(X_{(3,1)})$	0.97	0.03	$P(X_{(3,7)})$	0.94	0.06
$P(X_{(3,2)})$	0.95	0.05			

B. Reliability Estimate

According to the Bayesian network of the parachute system, the conduction relationship between nodes is analyzed. With the steps of conduction prior and joint prior, combined with the prior probability results of nodes based on Fiducial inference, the joint prior probability of each node is calculated. Taking the X(2,2) node as an example, Table IV shows the results of the conduction prior probability calculation of the X(2,2). After calculating the prior probability of each node, the node prior and joint probability are calculated according to formula(8). Table V shows the joint joint prior probability calculation results.

TABLE IV. NODE CONDUCTION PRIOR PROBABILITY CALCULATION RESULTS (TAKE X (2, 2) NODE AS AN EXAMPLE)

Nodes	K=0	K=1
$P_r(X_{(2,2)}=k\|X_{(3,3)}=0,X_{(3,4)}=0,X_{(3,5)}=0)$	0.96	0.04
$P_r(X_{(2,2)}=k\|X_{(3,3)}=0,X_{(3,4)}=0,X_{(3,5)}=1)$	0.95	0.08
$P_r(X_{(2,2)}=k\|X_{(3,3)}=0,X_{(3,4)}=1,X_{(3,5)}=0)$	0.94	0.06
$P_r(X_{(2,2)}=k\|X_{(3,3)}=1,X_{(3,4)}=0,X_{(3,5)}=0)$	0.96	0.04
$P_r(X_{(2,2)}=k\|X_{(3,3)}=1,X_{(3,4)}=1,X_{(3,5)}=0)$	0.95	0.05
$P_r(X_{(2,2)}=k\|X_{(3,3)}=1,X_{(3,4)}=0,X_{(3,5)}=1)$	0.97	0.13
$P_r(X_{(2,2)}=k\|X_{(3,3)}=0,X_{(3,4)}=1,X_{(3,5)}=1)$	0.94	0.06
$P_r(X_{(2,2)}=k\|X_{(3,3)}=1,X_{(3,4)}=1,X_{(3,5)}=1)$	0.97	0.05
$P_r(X_{(2,2)}=k)$	0.9550	0.0450

TABLE V. CONDUCTED NODE JOINT PRIOR PROBABILITY

Nodes	K=0	K=1	Nodes	K=0	K=1
$P(X_{(1,1)})$	0.9725	0.0275	$P(X_{(2,3)})$	0.9363	0.0637
$P(X_{(2,1)})$	0.9312	0.0688	$P(X_{(3,1)})$	0.9528	0.0472
$P(X_{(2,2)})$	0.9640	0.0360	$P(X_{(3,6)})$	0.9355	0.0645

V. CONCLUSION

With the research on the reliability of parachute system based on the reliability model of parachute system and components, aims to determine the reliability data of each group, the reliability analysis method for parachute system based on Fiducial inference-Bayesian network. The method firstly decomposes the parachute into each group according to the system composition, and uses the layered BN to represent; secondly, based on the Fiducial inference method, the mean value and the lower confidence limit of the strength test data of each group are calculated. And apply the stress-strength model to calculate the probability that the intensity is greater than the stress, and as the reliability of each component; third, considering the conduction relationship between the nodes of each layer, respectively calculate the node conduction probability. The joint probability of the node with conduction relationship is calculated by the fusion node probability based Bayesian. Finally, based on the prior probability of the node, the posterior probability of each node is calculated and the parachute groups (parts) system are obtained. The example shows that the calculation process of this method is clear, and the reliability prediction analysis of the whole system can be carried out under limited conditions. The research results can be used for the reliability analysis of the parachute system in the design stage, and can provide reference for the inspection and acceptance of the parachute system.

It should be noted that the calculation of weight distribution is simplified. In practical applications, the scientificity and usability of the calculation results are further improved by adopting a more scientific weight distribution algorithm.

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