Prediction of system reliability using failure types of components based on Weibull lifetime distribution

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ABSTRACT

Nowadays, products are complicated and standards of reliability are higher than ever before. In contrast, the time available for developing products has gradually decreased. In this context, assessment of the system reliability of products is an active field of study. In this paper, an experimental design was used to investigate the effect of the failure type of components on the whole system's failure type. For this, a general procedure for estimating system reliability based on the Weibull distribution was adopted.

1. INTRODUCTION

With advances in technology, the structures of systems have become increasingly complex, and the numbers of components constituting systems have also increased. Consequently, manufacturers are faced with the problem of predicting the reliability of more complex and diverse products.

Evaluation of the reliability of systems in the field of product development is used to compare many design alternatives when verifying or developing the target reliability of a system. This also enables manufacturers to predict in advance how long a product will typically operate without failure in a given environment. For this reason, system reliability has become a criterion to evaluate design compatibility and the possibility of implementing reliability requirements for an initial design specification and planning in the stage of product development.

There are many mechanisms to assess system reliability based on the statistical properties of the lifetime distribution, such as the exponential and Weibull distributions. Rutemiller (1966) obtained the minimum variance unbiased estimator of system reliability for series and parallel systems when the lifetime of components follows an exponential distribution. Adding to this, Chao (1981) provided a useful approximation for the mean squared errors of the maximum likelihood and minimum variance unbiased estimators of system reliability. Gonzalez-Lopez et al. (2016) introduced an E-Bayesian approach for flexible assessment of system reliability-availability based on an exponential distribution.

The purpose of this study was to evaluate system reliability using the reliability information of components comprising various failure types, and to analyze the effect of selection of these components on system failure types. In this study, the failure distribution of each component was assumed to follow a Weibull distribution that can express all failure types, including initial failure, random failure, and wear-out failure, to perform research under the assumption of statistical independence among components in a series system. Based on the information on failure types, a mixed experiment was performed to investigate the effects of the percentages of components with different failure types on a system's failure type. Finally, the reliability of the proposed procedure was verified by analyzing warranty data to determine whether assessing system reliability by analyzing the effects of components' failure types is feasible.

This paper is organized as follows. Section 2 introduces the existing procedure for evaluating system reliability and provides reliability evaluation procedures based on the Weibull distribution. Section 3 presents the effects of the failure type of components on the system's failure type using an experimental design, including a mixed experiment. Finally, Section 4 summarizes this work.

2. DEVELOPMENT OF METHODOLOGY FOR ESTIMATING SYSTEM RELIABILITY

The following section outlines general (non-formatting) guidelines to follow. These guidelines are applicable to all authors and include information on the policies and practices relevant to the publication of your manuscript.

2.1. Existing processes for evaluating system reliability

The evaluation of system reliability is the process of calculating system reliability for an entire product using a theoretical approach based on data on the reliability of its components. In general, system reliability evaluation at the stage of product development is performed as shown in Figure 1.

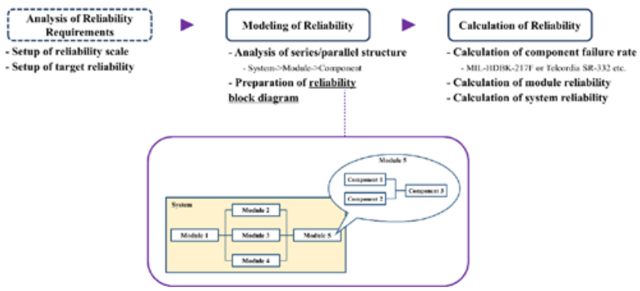

Figure 1. System reliability evaluation process

The first stage of the process of evaluating system reliability involves analyzing the reliability requirements. The reliability scale of a product is set at this stage to determine the target reliability. Next is the stage of modeling the reliability; at this stage, series and parallel structures of a system are identified to prepare a reliability block diagram. Reliability block diagrams are prepared for both system units and module units. The last stage involves calculating the reliability; the system reliability is calculated for the last time after calculating the failure rates of the components, the lowest level of a system, and calculating the reliability of modules.

2.2. Development of a methodology for estimating system reliability assuming the Weibull distribution

In existing estimation of system reliability using components, the failure rates of components are assumed to follow an exponential distribution. In contrast, in this paper, a Weibull distribution is used that can express various failure types for each part, and the development of a methodology for estimating system reliability based on this assumption is described.

Step 1: Calculation of parameters of each component

First, the shape and scale parameters, which are also parameters of the Weibull distribution, were calculated.

Step 2: Calculation of reliability of each component

The reliability of each component up to a target period was calculated.

Step 3: Calculation of system reliability

The system reliability up to the target period was calculated.

Step 4: Estimation of system parameters

The parameter of the calculated system reliability was estimated using the least squares method.

3. ANALYSIS OF SYSTEM FAILURE TYPES ACCORDING TO THE COMPONENT FAILURE TYPES

Analysis of the effects on system reliability of cases where the components comprise various failure types, including initial, random, and wear-out, was performed using a mixed experiment design. The analysis was performed using a simplex centroid design within the mixed experiment design. The total number of mixtures was designated as 96. This means that a total of 96 components were included in one system. The mixed experiment design was composed of four factors (initial: $0.7 \leq \beta < 0.9$, random: $0.9 \leq \beta < 1.1$, wear-out 1: $1.1 \leq \beta < 2$, and wear-out 2: $2 \leq \beta < 3$) according to the range of β, the shape parameter. Since the range of the wear-out type is very wide, taking the example where the shape parameter of the Weibull distribution is greater than 1, analysis was performed by classification into two levels, wear-out 1 and wear-out 2, after designating the maximum value as 3. The derived experimental points are shown in Table 1.

Table 1. Experimental points of mixed experiment design

Factors				Experimental Point
Initial	Random	Wear-out (1, 2)		
$0.7 \leq \beta < 0.9$	$0.9 \leq \beta < 1.1$	$1.1 \leq \beta < 2$	$2 \leq \beta < 3$	
96	0	0	0	1
0	96	0	0	2
0	0	96	0	3
0	0	0	96	4
48	48	0	0	5
48	0	48	0	6
48	0	0	48	7
0	48	48	0	8
0	48	0	48	9
0	0	48	48	10
32	32	32	0	11
32	32	0	32	12
32	0	32	32	13
0	32	32	32	14
24	24	24	24	15
60	12	12	12	16
12	60	12	12	17
12	12	60	12	18
12	12	12	60	19

4. CONCLUSION

We have attempted to identify the impact of a mixture of components with various failure types on the overall system. Previous evaluations of system reliability using components had limitations in reflecting various failure types due to the assumption that the failure rate of components follows an exponential distribution. To overcome these limitations, in this study, research was performed under the assumption that the failure rate of components follows a Weibull distribution that can express all failure types, including initial failure, random failure, and wear-out failure.

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