Sensitivity Analysis of Software Reliability for Component-Based Software Applications

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Abstract

The parameters in these software reliability models are usually directly obtained from the field failure data. Due to the dynamic properties of the system and the insufficiency of the failure data, the accurate values of the parameters are hard to determine. Therefore, the sensitivity analysis is often used in this stage to deal with this problem. Sensitivity analysis provides a way to analyzing the impact of the different parameters. In order to assess the reliability of a component-based software, we propose a new approach to analyzing the reliability of the system, based on the reliabilities of the individual components and the architecture of the system. Furthermore, we present the sensitivity analysis on the reliability of a component-based software in order to determine which of the components affects the reliability of the system most. Finally, three general examples are evaluated to validate and show the effectiveness of the proposed approach.

1. Introduction

Software designers are motivated to integrate commercial off-the-shelf (COTS) software components for rapid software development. To ensure high reliability for such applications using software components as their building blocks to construct a software system, dependable components have to be deployed to meet the reliability requirements. Therefore, it is necessary to assess the reliabilities of such systems by investigating the architectures, the testing strategies, and the component reliabilities [1-3]. The parameters in these software reliability models are usually obtained from the failure data. Sensitivity analysis provides an approach to analyzing the impact of the parameters [2-5]. In general, one difficulty in estimating the reliability of a system in the testing stage is the insufficiency of the failure data and therefore the accurate values of the parameters are hard to get. Sensitivity analysis is often used in this stage to deal with this problem. In this paper, we investigate the sensitivity analysis of the reliability for a component-based software system. The method is very useful in practice. For example, if we use the approach to determine that a parameter or a component in a system is the most sensitive, it is critical for the software testing-team to have this parameter estimated as accurately as possible or allocate more resources for this component. The organization of this paper is as follows. Section 2 presents an analytical approach to estimating the reliability of a system. Sensitivity analysis is discussed in Section 3. Experimental results are depicted in Section 4. Conclusions are presented in Section 5.

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2. Reliability assessment

In this section, we propose an approach to estimating the reliability of a component-based system by taking the architecture of the software system and the reliabilities of the components into consideration. For example, if a system consists of n components with reliabilities denoted by $R_1,\ldots, R_n$ respectively, the reliability of an execution path, 1, 3, 2, 3, 2, 3, 4, 3, n, is given by $R_1 \times R_2^{\,2} \times R_3^{\,4} \times R_4 \times R_n$. Thus, the objective here is to estimate the reliability of a system by averaging over all path reliabilities [6]. Therefore, we consider systems with different architecture styles and utilize the Markov process to model the failure behaviors of the applications. Three general input-output cases were employed. In addition, we develop three methodologies to estimating the reliability of a software system.

Definition : Let $\{X_n$, n=0, 1, 2…$\}$ be a Markov process with some absorbing states and some transient states. Define the random variable, N_{ij}, to represent the number of visits to state j before entering an absorbing state given $X_o=i$. The expected value of N_{ij} , $E(N_{ij})$, is denoted by μ_{ij} . Moreover, let η_k denote the probability of absorption when a process terminates at an absorbing state k.

The proofs of the following theorems can be found in our previous results [7].

Theorem 1 (single-input/single-output system): Consider a single-input and single-output system consisting of N components with reliabilities $R_1,\ldots, R_N$. Let $\{X_n\}$ be the Markov process where state N is an absorbing state, i.e., an output node, while states $\{1, 2, ..., N-1\}$ are transient states. In particular, assume state 1 is the input node. Therefore, we have the system reliability: $R_s= R_1 \times R_N \times \prod_{i=2}^{N-1} pow(R_i, \mu_{1i})$, where the $pow(x, y)$ is the power function, i.e., $pow(x, y)=x^y$.

Proceedings of the 27th Annual International Computer Software and Applications Conference (COMPSAC'03)
0730-3157/03 $ 17.00 © 2003 IEEE

Theorem 2 (single-input/multiple-output system): Consider a single-input and r-output system consisting of N components with individual reliabilities denoted by $R_1,\ldots, R_N$. Let $\{X_n\}$ be the Markov process where $\{N, N-1, ..., N-r+1\}$ are absorbing states (i.e. r output nodes) and $\{1, 2, ..., N-r\}$ are transient states. In particular, assume state 1 is the input node. Therefore, we have the reliability of the system:

$$R_s = R_1 \times \prod_{i=2}^{N-r} pow(R_i, \mu_{1i}) \times \prod_{k=N-r+1}^{N} pow(R_j, \eta_j).$$

Theorem 3 (multiple-input/multiple-output system): Consider an s-input and r-output system consisting of N components with reliabilities $R_1,\ldots, R_N$. Let $\{X_n\}$ be a Markov process where $\{N, N-1, ..., N-r+1\}$ are absorbing states (i.e. r output nodes) and $\{1, 2, ..., N-r\}$ are transient states. In particular, assume states $\{1, 2, ..., s\}$ are the input nodes with probability $p_1, p_2, ..., p_s$, respectively. Therefore, the system reliability, R_s, equals

$$\prod_{i=1}^{s} pow(R_i, p_i) \times \prod_{j=s+1}^{N-r} pow(R_j, \sum_{l=1}^{s} p_l \mu_{lj}) \times \prod_{k=N-r+1}^{N} pow(R_k, \eta_k)$$

3. Sensitivity analysis

The reliability of a component-based software system is often higher through the improvement of some components in the system. Therefore, considering such a system we are often interested to know which component is more important than others. Thus, the improvement of that important component will increase the system reliability more than others. Sensitivity analysis gives an approach to analyze the relative importance of input model parameters in determining the value of an assigned output value [8]. That is this method can help make a reasonable decision for this problem. Furthermore, a number of software reliability models have been developed to evaluate the reliability of a system. The parameters in these models are usually obtained from the field failure data. In general, one difficulty in estimating the reliability of a system in the testing stage is the insufficiency of failure data that makes the exact values of the parameters hard to get. Sensitivity analysis is often used in this stage due to the deviations of parameters [4, 5, 9, 10]. That is, sensitivity analysis can help in investigating the effect of the uncertainty in parameters on the reliability estimated from model. In this paper, we will study the sensitivity analysis of the reliability of the component-based software applications in order to know which of the components affects the reliability of the system most. Consequently, from Theorem 1, Theorem 2, and Theorem 3 in Session 2, the reliability of this system can be expressed as the general form:

$$R_s = \prod_{i=1}^{N} pow(R_i, \theta_i) \qquad (1)$$

where R_i is the estimated reliability of component i and θ_i is the expected value of the number of visits to component i. Here R_s can be regarded as a function of parameters R_i and θ_i, i=1,.. ,N. From the above discussion, in order to estimate the parameters in Eq. (1) by using the hierarchical approach, it is necessary for software testers to know the information regarding a particular application: architecture of the application (structure of component interactions), software usage profile (the exchange of controls among components determined by transition probabilities), and component failure behaviors (component reliabilities or failure intensity). However, the estimates may not always be accurate, especially in the early stage of the testing phase when a limited amount of information is available. Therefore, it is essential to know the sensitivity of required knowledge regarding the estimated parameters.

3.1 The most sensitive parameter

Considering the parameter θ_i of Eq. (1), it would be helpful to know which of the parameters affects the reliability of the system most, so that more accurate measurements can be made for the most important one [11]. That is, we are concerned whether the condition of the following formula is sufficed:

$$\left|\frac{\partial R_s}{\partial \theta_i}\right| \ge \left|\frac{\partial R_s}{\partial \theta_j}\right|, \text{ for all } j=1, 2,.., N. \qquad (2)$$

In practice, the frequency of a component being executed affects the overall system reliability. A higher frequency indicates a greater effect of that component on the performance of the system. This fact shows that the components should have distinct weights according to the architecture of the software system. In other words, the change in the intercomponent transition probabilities of the software architecture manifests the change in the parameter θ_i of Eq. (1). On the other hand, define T_{p,θ_i} as the relative change of the system reliability, R_S, when θ_i is changed by 100p%. That is

$$T_{p,\theta_i} = \frac{|R_s(\theta_1,..,\theta_i + p\theta_i,..,\theta_N) - R_s(\theta_1,..,\theta_N)|}{R_s(\theta_1,..,\theta_N)} 100\%. \qquad (3)$$

Comparatively, let S_{p,θ_i} be the sensitivity of the relative change of the system reliability to θ_i when θ_i is changed by 100p% as the ratio of relative change for the two quantities. That is

$$S_{p,\theta_i} = \frac{\Delta R_s / R_s}{\Delta \theta_i / \theta_i} = \frac{T_{p,\theta_i}}{p} 100\%. \qquad (4)$$

Then, from Eq. (2)-(4), the sensitivity analysis can be conducted and the most sensitive parameter, θ_i, in discrete situation can also be found. That is

$$S_{p,\theta_i} \ge S_{p,\theta_j}, \text{ for all } j=1, 2,..,N. \qquad (5)$$

Therefore, we have the desired results:
if $power(R_j, \theta_j) \ge power(R_i, \theta_i)$, for all j=1, 2,..,N., then θ_i is the most sensitive parameter.

3.2 The most sensitive component reliability

Similar to the reasoning in Section 3.1, for comparing the estimated component reliability R_i in Eq. (1), it would be useful to know which of the components affects the reliability of the system most. That is, we are concerned whether the condition of the following formula is sufficed:

$$\left|\frac{\partial R_s}{\partial R_i}\right| \le \left|\frac{\partial R_s}{\partial R_j}\right|, \text{ for all } j=1, 2,..,N. \quad (6)$$

Again, define T_{p,R_i} as the relative change of the system reliability, R_S, when R_i is changed by 100p%, and also let S_{p,R_i} be the sensitivity of the relative change of the system reliability to R_i when R_i is changed by 100p%, that is,

$$T_{p,R_i} = \frac{|R_s(R_1,..,R_i + pR_i,..,R_N) - R_s(R_1,..,R_N)|}{R_s(R_1,..,R_N)} 100\% \quad (7)$$

$$S_{p,R_i} = \frac{T_{p,R_i}}{p} 100\%. \quad (8)$$

Thus, the sensitivity analysis with respect to the relative change of component reliability can be performed and the most sensitive component, R_i, in discrete situation can also be found. That is

$$S_{p,R_i} \ge S_{p,R_j}, \text{ for all } j=1, 2,..,N. \quad (9)$$

According to Eq. (9), we have the result that the one with the maximum parameter value is the most sensitive.

3.3 The most sensitive transition flow

In Section 3.1, we have found the way to deal with the sensitive parameter problem in Eq. (1). Here, we will work on the sensitivity analysis of system reliability resulting from the relative change of transition probability. For a component-based software, different users will have different reliability performances, because they use the system in various ways or use different parts of the system. This dynamic knowledge about the probabilities for different uses in a component-based software is determined by the transition probabilities and apparently depends on the software usage, i.e., operational profile. In general, the operational profile is an estimated description of how the system will be used. One can characterize the usage by the operational profile, the set of operations available on the system and their associated probabilities of occurrences [2-5]. In order to study the sensitivity of the system reliability to an error in one of the transition probability in the software usage, the method is carried out and the following definitions and symbols are used as follows. Suppose the transition probability, p_{ij}, is incorrect, and let ε_{ij} be the error. Therefore, we have

$$\varepsilon_{ij} = p_{ij}^F - p_{ij}^T \quad (10)$$

where p_{ij}^E is the erroneous transition probability with respect to the estimated software usage used in the test, and p_{ij}^T indicates the true transition probability regarding the true software usage. And let ρ_{ij} be the relative error, $\rho_{ij} = \frac{\varepsilon_{ij}}{p_{ij}^T}$. To go a step further, from the property of Markov process, we have $\sum_{j=1}^{N} p_{ij}^T = 1$ and $\sum_{j=1}^{N} p_{ij}^E = 1$ for component i. In particular, we assume that ρ_{ij} does not have an effect on other ρ_{ik} so that they all have the same relative error ρ_i. Therefore, from Eq. (10), $\sum_{j=1}^{N} p_{ij}^T = 1$, and $\sum_{j=1}^{N} p_{ij}^E = 1$ we have

$$\sum_{j=1}^{N} \varepsilon_{ij} = \rho_{ij} p_{ij}^T + \sum_{\substack{k=1 \\ k\ne j}}^{N} \rho_{ik} p_{ik}^T = \rho_{ij} p_{ij}^T + \rho_i \sum_{\substack{k=1 \\ k\ne j}}^{N} p_{ij}^T = 0 \quad (11)$$

Finally, we obtain $\rho_i = \frac{-\rho_{ij} p_{ij}^T}{1 - p_{ij}^T}$.

- **The most sensitive interaction**

Afterward, we can define $T_{p,P_{ij}}$ as the relative change of the system reliability when the transition probability p_{ij}^T is changed by 100p%, and also let $S_{p,P_{ij}}$ be the sensitivity of the relative change of the system reliability to p_{ij}^T when p_{ij}^T is changed by 100p%, that is,

$$T_{p,P_{ij}} = \frac{|R_s(P_{11}^T,..,P_{ij}^T + pP_{ij}^T,..,P_{NN}^T) - R_s(P_{11}^T,..,P_{NN}^T)|}{R_s(P_{ij}^T,..,P_{ij}^T)} 100\% \quad (12)$$

$$S_{p,P_{ij}} = \frac{T_{p,P_{ij}}}{p} 100\%. \quad (13)$$

Thus, the sensitivity analysis with respect to the relative change of transition probability can be conducted and the most sensitive interaction between components can be found.

- **The most sensitive relative error component**

On the other hand, we define T_{p,ρ_i} as the relative change of the system reliability when the relative error of transition probability in Component i, ρ_i, is changed by 100p%, and also let S_{p,ρ_i} be the sensitivity of the relative change of the system reliability to ρ_i when ρ_i is changed by 100p%, that is,

$$T_{p,\rho_i} = \frac{|R_s(\rho_1,..,\rho_i + p\rho_i,..,\rho_N) - R_s(\rho_1,..,\rho_N)|}{R_s(\rho_1,..,\rho_N)} 100\% \quad (14)$$

$$S_{p,\rho_i} = \frac{T_{p,\rho_i}}{p} 100\%. \quad (15)$$

Thus, the sensitivity analysis with respect to the relative change of the relative error of transition probability in one component can be conducted and the most sensitive relative error in component can be found.

4. Experimental results

4.1. Reliability evaluation of component-based systems

The following examples adapted from [2, 7, 11] are used to illustrate the three architecture cases discussed in

Section 2. Without loss of generality, we use the terminating application reported in [7, 11] as a running example and let the estimated reliabilities of the components be regarded as unchanged throughout the following three subsections and listed in Table 1.

4.1.1 Example 1: a single-input/single-output system.

The first example is a single-input/single-output system. It consists of 10 components where component 1 is the input component and component 10 the output component. The transition probabilities among the components are given as follows: $P_{1,2}$ = 0.6, $P_{1,3}$ = 0.2, $P_{1,4}$ = 0.2, $P_{2,3}$ = 0.7, $P_{2,5}$ = 0.3, $P_{3,5}$ = 1.0, $P_{4,5}$ = 0.4, $P_{4,6}$ = 0.6, $P_{5,7}$ = 0.4, $P_{5,8}$ = 0.6, $P_{6,3}$ = 0.3, $P_{6,7}$ = 0.3, $P_{6,8}$ = 0.1, $P_{6,9}$ = 0.3, $P_{7,2}$ = 0.5, $P_{7,9}$ = 0.5, $P_{8,4}$ = 0.25, $P_{8,10}$ = 0.75, $P_{9,8}$ = 0.1, $P_{9,10}$ = 0.9. Therefore, the expected number of visits on each transient state before absorption from the input node (component 1) and the probability of absorption can be derived as follows:

$\mu_{11} = 1, \mu_{12} = 1.4717, \mu_{13} = 1.3254, \mu_{14} = 0.5289, \mu_{15} = 1.9784,$
$\mu_{16} = 0.3173, \mu_{17} = 1.7433, \mu_{18} = 1.3155, \mu_{19} = 0.9669, \eta_{10} = 1.$

Thus, the system reliability is estimated as R_1= 0.7715.

Table 1: The estimated reliabilities of the components.

1	2	3	4	5	6	7	8	9	10
0.99	0.98	0.99	0.96	0.98	0.95	0.98	0.96	0.97	0.99

4.1.2. Example 2: a single-input/multiple-output type.

In this example, we delete two links of Example 1. The modification is a simple transformation from a single-output system to a multiple-output system and the corresponding transition probabilities are similar to Example1 except $P_{1,3}$=0 and $P_{1,4}$=0. Therefore, following the same approach we can have following results: $\mu_{11} = 1, \mu_{12} = 0.6, \mu_{13} = 0.6845,$ $\mu_{14} = 0.3581, \mu_{15} = 1.0077,$ $\mu_{16} = 0.2149, \mu_{18} = 0.6326,$ $\mu_{19} = 0.0645,$ $\eta_7 = 0.4676,$ $\eta_{10} = 0.5324$. Thus, the system reliability, R_2, is 0.8890.

4.1.3. Example 3: a multiple-input/multiple-output type.

In this example, the process will start from one of the two input components (components 1 and 2) with equal probability and terminates at the output components (components 7 and 10). That is, the modification is a transformation from a single-input system to a multiple-input system. The transition probabilities are similar to Example 2 except $P_{1,3}$=0.5 and $P_{1,4}$=0.5. Therefore, according to Theorem 3, portion of the vector of weights in Eq. (3) can be obtained by $w_k = \sum_{l=1}^{2} p_l \mu_{lk}$. Therefore, we have ($w_1$, w_2, w_3, w_4, w_5, w_6, w_8, w_9) = (0.5, 0.5, 0.673, 0.4057, 0.9853, 0.2434, 0.6228, 0.073). On the other hand, with the aim to computing the probability of absorption at each absorbing state, the following information about the two absorbing states is obtained based on Theorem 3: $w_7 = 0.4672, w_{10} = 0.5327$. Thus, we have the reliability of the system is R_3= 0.8929.

4.2 Sensitivity analysis results

- **The most sensitive parameter**

As for the example of the software architecture with single-input/single-output in Section 4.1.1, we apply the results (the component reliability and the estimated expected visits for each component, i.e., μ_{1i}) to Eq. (5). After some computations, we can figure out which of the parameters affects the system reliability more than the other so that more accurate estimates can be obtained for the most important one. In this case, the parameter of Component 5 (μ_{15}) is the most sensitive parameter because it has the minimum value (*power*(0.98,1.3504)=0.9731) than others. Furthermore, the relationship between the sensitivity, S_{p,θ_i}, and the relative change of component parameter θ_i is depicted in Figure 1. In order to present the importance of each parameter, the curves in the figures are ordered by its sensitivity decreasingly. We also apply the same approach to Example 2 and Example 3 and conclude that the parameter of Component 8 is the most sensitive parameter.

- **The most sensitive component reliability**

Similarly, we use the estimated vector, μ_{1i}, in Section 3.1 for Eq. (9). Because Component 5 has the maximum parameter value (μ_{15} =1.3504), thus from the result in Section 4.2 we know Component 5 is the most sensitive. As for Example 2, the parameter value of Component 5 is 1.0077 and is larger than the others. That is Component 5 is the most sensitive in Example 2. For Example 3, the most sensitive component is also Component 5 because its parameter value is 0.9853 and is the largest. Figure 2 illustrates the relationship between the sensitivity, S_{p,R_i}, and the relative change of component reliability in Example 1.

- **The most sensitive interaction**

Figure 3 depict the relationships between the sensitivity, $S_{p,P_{ij}}$, and the relative change of P_{ij} for Example 1. This figure presents the first six sensitive interactions and the first one is the most sensitive. For example, the transition from Component 8 to Component 4 is the most sensitive in these three examples. In particular, a 10 % change of P_{84} will imply a 0.39 % change of the system reliability in Example 1. This means that it is much more important to obtain an accurate estimate of P_{84} than others.

- **The most sensitive relative error component**

Figure 4 shows the results about the relationships between the sensitivity, S_{p,ρ_i}, and the relative change of the relative error, ρ_i. The most sensitive relative error of transition probability in Example 1-3 is Component 8. For example, a 10% change of ρ_8 will imply a 0.63 % change of the system reliability in Example 2.

Finally, we list the results for all of the most sensitivity case in Table 5-7.

5. Conclusions

In this paper we have presented an approach for assessing the reliability of a component-based software. Besides, we also present the sensitivity analysis on the reliability of a component-based software in order to determine which of the components affects the reliability of the system most. Sensitivity analysis provides a way to analyzing the impact of the parameters. In particular, we define several metrics on how to assess the most sensitive parameter in a system and derive some useful mathematical properties for the sensitivity analysis of system reliability. Finally, three different architecture styles are utilized to validate the proposed approach. For the future works, we will focus on topics including comparisons with different approaches, sensitivity analysis of resource allocation problems, and other sensitivity of software attributes.

Acknowledgment

This research was supported by the National Science Council, Taiwan, ROC., under Grant NSC 91-2213-E-002-042 and also substantially supported by a grant from the Research Grant Council of the Hong Kong Special Administrative Region, China (Project No. CUHK4360/02E). Further, we thank the anonymous referees for their critical review and comments.

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Table 2: The most sensitive cases in Example 1

	The Most Sensitive Parameter Case			The Most Sensitive Component Reliability Case			The Most Sensitive Interaction Case			The Most Sensitive Relative Error Case		
$p\%$	R_S	$T_{p/2,\theta_5}$	$S_{p/2,\theta_5}$	R_S	$T_{p/2,R_5}$	$S_{p/2,R_5}$	R_S	$T_{p,P_{8,4}}$	$S_{p,P_{8,4}}$	R_S	T_{p,ρ_8}	S_{p,ρ_8}
20%	0.8459	0.0027	0.0272	0.9659	0.2010	1.3693	0.8413	0.0081	0.1160	0.8271	0.0249	0.1244
15%	0.8465	0.0020	0.0273	0.9423	0.1371	1.3647	0.8430	0.0061	0.1148	0.8335	0.0174	0.1206
10%	0.8471	0.0014	0.0273	0.9188	0.0920	1.3600	0.8447	0.0039	0.1136	0.8395	0.0103	0.1171
5%	0.8477	0.007	0.0273	0.8955	0.0213	1.3554	0.8463	0.0022	0.1117	0.8451	0.0036	0.1131
-5%	0.8488	0.0007	-0.0273	0.8265	0.0123	-1.3459	0.8495	0.0015	-0.0999	0.8531	0.0024	-0.0980
-10%	0.8494	0.0014	-0.0273	0.8039	0.0609	-1.3411	0.8511	0.0035	-0.1123	0.8580	0.0053	-0.1026
-15%	0.8500	0.0020	-0.0273	0.7814	0.1302	-1.3363	0.8526	0.0056	-0.1110	0.8628	0.0084	-0.1040
-20%	0.8506	0.0027	-0.0273	0.7590	0.1762	-1.3314	0.8541	0.0078	-0.1099	0.8650	0.0144	-0.1060

Table 3: The most sensitive cases in Example 2.

	The Most Sensitive Parameter Case			The Most Sensitive Component Reliability Case			The Most Sensitive Interaction Case			The Most Sensitive Relative Error Case		
$p\%$	R_S	$T_{p/2,\theta_5}$	$S_{p/2,\theta_5}$	R_S	$T_{p/2,R_5}$	$S_{p/2,R_5}$	R_S	$T_{p,P_{8,4}}$	$S_{p,P_{8,4}}$	R_S	T_{p,ρ_8}	S_{p,ρ_8}
20%	0.8867	0.0026	0.0258	0.9598	0.0796	1.0080	0.8994	0.0124	0.0593	0.8774	0.0131	0.0623
15%	0.8873	0.0019	0.0258	0.9401	0.0575	1.0079	0.8970	0.0093	0.0584	0.8804	0.0096	0.0606
10%	0.8879	0.0013	0.0258	0.9204	0.0353	1.0078	0.8945	0.0062	0.0570	0.8834	0.0063	0.0585
5%	0.8884	0.0006	0.0258	0.9006	0.0131	1.0078	0.8920	0.0031	0.0537	0.8862	0.0031	0.0544
-5%	0.8896	0.0006	-0.0258	0.8612	0.0312	-1.0077	0.8866	0.0026	-0.0572	0.8913	0.0026	-0.0567
-10%	0.8901	0.0013	-0.0258	0.8415	0.0534	-1.0076	0.8838	0.0060	-0.0627	0.8938	0.0054	-0.0565
-15%	0.8907	0.0019	-0.0258	0.8218	0.0756	-1.0075	0.8808	0.0090	-0.0611	0.8967	0.0087	-0.0593
-20%	0.8913	0.0026	-0.0259	0.8021	0.0977	-1.0074	0.8778	0.0119	-0.0601	0.8992	0.0114	-0.0578

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Table 4: The most sensitive cases in Example 3.

	The Most Sensitive Parameter Case			The Most Sensitive Component Reliability Case			The Most Sensitive Interaction Case			The Most Sensitive Relative Error Case		
$p\%$	R_S	$T_{p/2,\theta_5}$	$S_{p/2,\theta_5}$	R_S	$T_{p/2,R_5}$	$S_{p/2,R_5}$	R_S	$T_{p,P_{8,4}}$	$S_{p,P_{8,4}}$	R_S	T_{p,ρ_8}	S_{p,ρ_8}
20%	0.8906	0.0025	0.0254	0.9808	0.0985	0.9846	0.8891	0.0120	0.0572	0.8816	0.0126	0.1244
15%	0.8912	0.0019	0.0254	0.9588	0.0739	0.9848	0.8901	0.0090	0.0560	0.8846	0.0093	0.1206
10%	0.8918	0.0013	0.0254	0.9369	0.0492	0.9850	0.8910	0.0059	0.0540	0.8874	0.0061	0.1171
5%	0.8923	0.0006	0.0254	0.9149	0.0246	0.9851	0.8918	0.0030	0.0493	0.8902	0.0030	0.1131
-5%	0.8935	0.0006	-0.0254	0.8709	0.0246	-0.9855	0.8936	0.0024	-0.0611	0.8950	0.0023	-0.103
-10%	0.8940	0.0013	-0.0254	0.8489	0.0493	-0.9857	0.8944	0.0058	-0.0646	0.8976	0.0053	-0.104
-15%	0.8946	0.0019	-0.0254	0.8269	0.0739	-0.9859	0.8953	0.0087	-0.0620	0.9004	0.0084	-0.106
-20%	0.8952	0.0025	-0.0255	0.8049	0.0986	-0.9861	0.8961	0.0115	-0.0606	0.9028	0.0111	-0.105

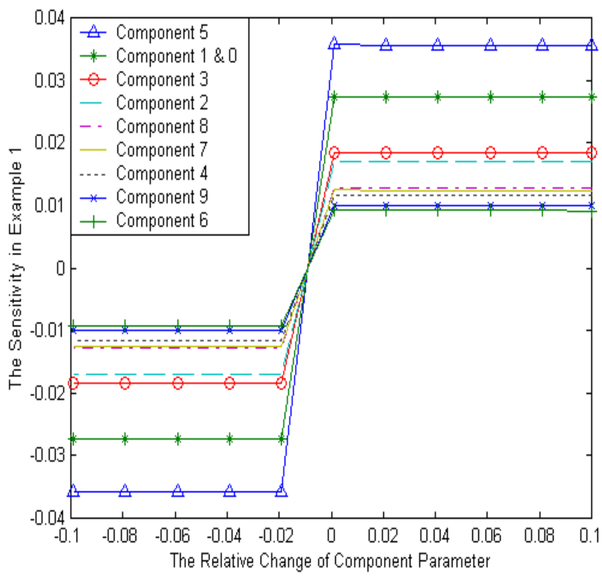

Figure 1: The most sensitive parameter in Example 1.

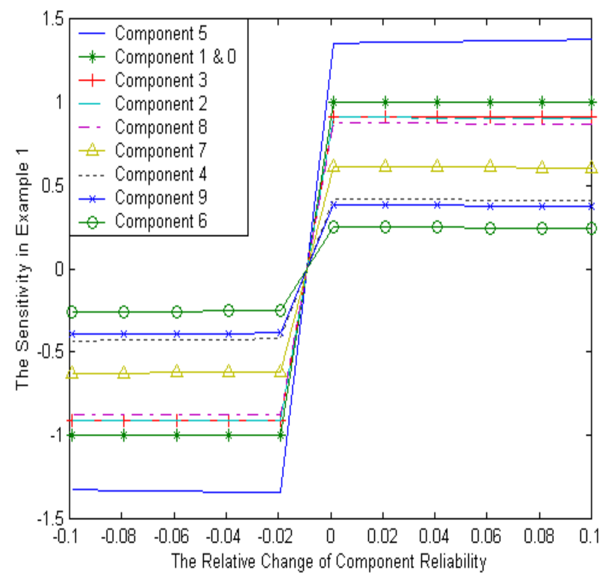

Figure 2: The most sensitive component reliability in Example 1

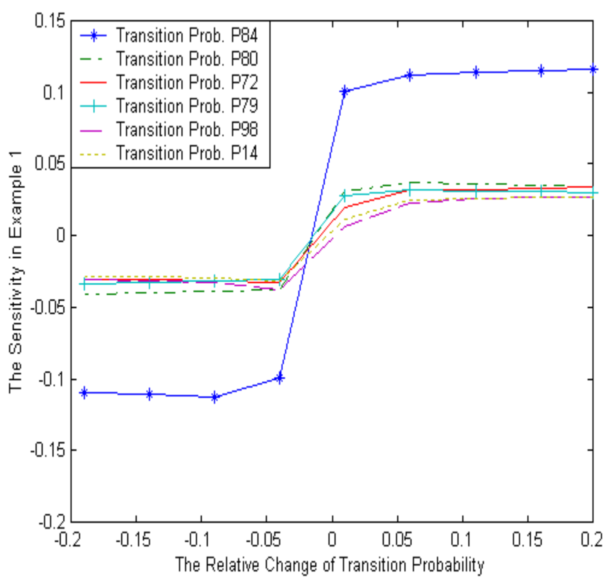

Figure 3: The most sensitive transition in Example 1.

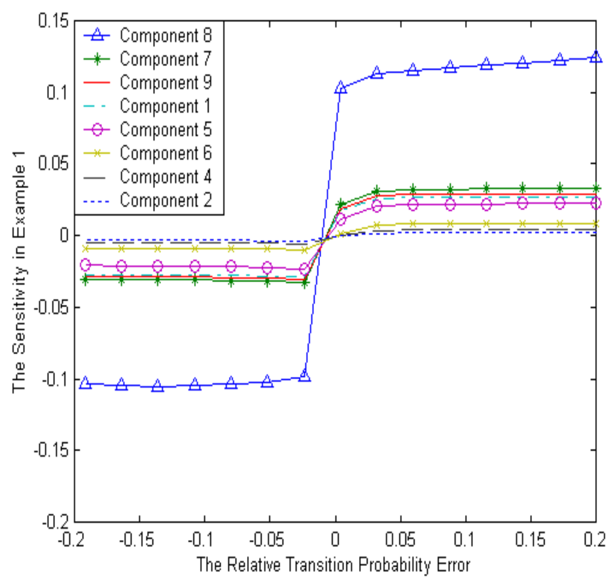

Figure 4: The most sensitive relative error in Example 1

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