Preliminary Study for Developing Bayesian-based CCF Parameters Estimation Program

Baehyeuk Kwon[a], Moosung Jae[a*], Moon Goo Chi[b]
[a]*Hanyang University 17 Haengdang-Dong, Sungdong-Gu, Seoul, Korea*
[b]*Korea Hydro & Nuclear Power Co., Ltd. 25-1 Jang-Dong, Yuseong-Gu, Daejeon, Korea*
[*]*Corresponding author: jae@hanyang.ac.kr*

1. Introduction

The common cause failures in nuclear power plants are one of the significant factors to affect Core Damage Frequency. Several investigators have made many efforts to attempt to reduce the CCF uncertainty. Up to now there has been no detail guidance for estimating the CCF parameters using the Bayesian method. In this study the Bayesian method has been introduced and applied for reducing the uncertainty of the common cause failures. The preliminary version of the Bayesian-based CCF parameters estimation program has been developed for evaluating the CCF parameters and applied for obtaining the uncertainty of the beta factor in multiple Greek Letter CCF model. It is shown that this program might contribute to assessing the safety measures such as core damage frequency and large early release frequency for decision-making.

2. Methods and Results

2.1 Bayesian Theory

. Up to now there has been no detail guidance for estimating the CCF parameters using the Bayesian method. In this study the Bayesian method has been introduced and applied for reducing the uncertainty of the common cause failures [1-2]. The basic equation of the Bayesian theory is described as follows.

$$\pi(\theta / E) = \frac{L(E/\theta)\pi_0(\theta)}{\int L(E/\theta)\pi_0(\theta)} \qquad (1)$$

Where, $\pi(\theta / E)$ is posterior distribution of θ given evidence E, $\pi_0(\theta)$ is distribution of θ prior to the evidence, and $L(E/\theta)$ is likelihood function or the probability of the evidence E for the given θ [3]. The Bayesian method has been introduced and applied for reducing the uncertainty of the common cause failures in this study.

2.2 CCF Models

The preliminary version of the Bayesian-based CCF parameters estimation program developed in this study includes three CCF models: Basic Parameter Model (BPM), Multiple Greek Letter Model (MGL), and Alpha-Factor Model (AFM). Table 1 shows three CCF models, their parameters, and estimators for the parameters used in this study.

Table 1: CCF Models installed for the program

Models	Non-Staggered	Staggered
BPM	$Q_K^{NS} = \frac{n_k}{N_k^{NS}}$ $k = 1,\dots,m$	$Q_K^{S} = \frac{n_k}{N_k^{S}}$ $k = 1,\dots,m$
MGL	$\rho_k = \frac{\sum_{i=k}^{m} i * n_i}{\sum_{i=k-1}^{m} i * n_i}$	$\rho_k = \frac{\sum_{i=k}^{m} n_i}{\sum_{i=k-1}^{m} n_i}$
	$(2 \le k \le m)$ $(\rho_1 = 1, \rho_2 = \beta, \rho_3 = \gamma, \rho_4 = \delta, \dots, \rho_{m+1} = 0)$	
AFM	$\alpha_k = \frac{n_k}{\sum_{k=1}^{m} n_{ki}}$	
	$k = 1,\dots,m$ $\alpha_1 + \alpha_2 + \dots + \alpha_m = 1$	

2.3 Algorithm for Parameters Estimation

Table 2: Conjugate families for analyzing CCF Model parameters

Model	Likelihood	Conjugate prior	Posterior
BPM	Binomial distribution	Beta distribution	Beta distribution
MGL	Muti-nominal distribution	Dirichlet distribution	Dirichlet distribution
AFM	Muti-nominal distribution	Dirichlet distribution	Dirichlet distribution

The likelihood function for CCF parameters depends on the CCF models and has corresponding conjugate distribution as shown in Table 1. The posterior distribution is proportional to the product of prior distribution and the likelihood function. By applying the normalization factors into denominator, the Bayesian data analysis for the CCF parameters can be performed to result in determining the posterior distribution as shown in Eq. (2).

$$\pi(\theta / E) \propto L(E/\theta)\pi_0(\theta) \qquad (2)$$

Therefore, Bayesian analysis can be performed using equation 2. Table 2 shows the likelihood distribution, conjugate distribution, and posterior distribution in each CCF model, which were used in this study.

2.4 Estimation of CCF Parameters

The CCF parameters have been evaluated by utilizing the preliminary version of the program developed in this study under the several assumptions. The assumed conditions are described in Table 3. In order to test the developed program, the posterior failure probabilities for the parameters have been calculated individually. Table 4 describes the results representing the calculated failure probabilities. It shows that the calculated values are exactly identical regardless of the CCF models. The results show that the developed program is flexible in that it can be applied to any problems to determine the CCF parameters. As an example, Figure 1 and Figure 2 show the prior and posterior distribution for β parameter in the MGL model for both the non-staggered and the staggered tests, respectively.

Table 3: Properties specifying the particular conditions assumed in the present study

First Data				Second Data			
	n_1	n_2	n_3		n_1	n_2	n_3
n_k	30	2	1	n_k	10	2	1
M	3			M	3		
N_D	1200			N_D	240		

,where, n_k is the number of events involving k components in a failed state, and variable m is the total number of components, and N_D is the total number of tests or demands for the system of m components [4].

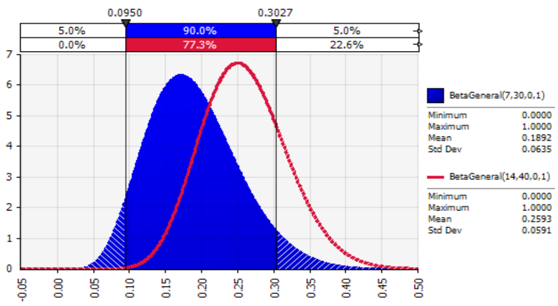

Fig. 1. Prior and posterior distributions for β parameter of MGL (Non-Staggered)

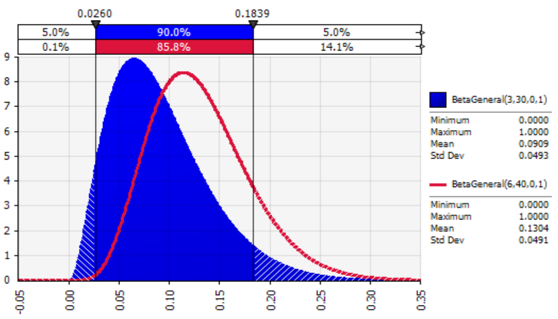

Fig. 2. Prior and posterior distributions for β parameter of MGL (Staggered)

Table 4: Properties under the particular condition assumed in the present study

Posterior distribution (Non-Staggered)			
Q_k^{NS}	Q_1	Q_2	Q_3
BPM	0.00926	0.00093	0.00139
MGL	0.00926	0.00093	0.00139
AFM	0.00926	0.00093	0.00139
Posterior distribution (Staggered)			
Q_k^{S}	Q_1	Q_2	Q_3
BPM	0.00926	0.00046	0.00046
MGL	0.00926	0.00046	0.00046
AFM	0.00926	0.00046	0.00046

3. Conclusions

The common cause failures in nuclear power plants are one of the significant factors to affect Core Damage Frequency. Several investigators have made many efforts to attempt to reduce the CCF uncertainty. In this study the Bayesian method has been introduced and applied for reducing the uncertainty of the common cause failures. The preliminary version of the Bayesian-based CCF parameters estimation program has also been developed for evaluating the CCF parameters and applied for obtaining the β parameter in the MGL model for both the non-staggered and the staggered tests, respectively. It is shown that this program might contribute to assessing the safety measures such as core damage frequency and large early release frequency. It is expected that the developing program might contribute to supplying the efficient procedure by obtaining the uncertainty of the relevant parameters

REFERENCES

[1] Mosleh, A., INEEL, NUREG/CR-5485, Guidelines on Modeling Common-Cause Failures in Probabilistic Risk Assessment, 1999.
[2] Meejeong Hwang., KAERI, KAERI/TR-2444, Cuidance for Common Cause Failure Analysis, 2003.
[3] Mosleh and K. N. Fleming, Pickard, Lowe, and Garrick, A., U.S.NRC, NUREG/CR-4780 Vol1 & Vol2, Procedures for Treating Common Cause Failures in Safety and Reliability Studies, 1987.
[4] Daeil Kang, KAERI, KAERI/TR-3268, Estimation of the Alpha Factor Parameters Using the ICDE Database, 2006
[5] Meejeong Hwang., KAERI, KAERI/TR-2916, Cuidance for System Modeling: Common Cause Failures (Rev. 1), 2005.
[6] D. M. Rasmuson, Mosleh, A., Presentation at the IAEA Technical Meeting, A Brief History of Common Cause Failure Analysis, 2007.