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A COCAP Program for Estimating the Common Cause Failure Parameters

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1. Introduction

Up to now, PSA(Probabilistic Safety Assessment) in Korea has performed the CCF(Common Cause Failure) analysis using MGL(Multiple Greek Letter) model and mainly used the CCF parameter data provided by US NRC [1]. The CCF parameter data provided by US NRC, however, is currently the CCF parameter data of Alpha-Factor Model (AFM). Thus, the CCF parameters used for the CCF analysis in Korea have used MGL parameters converted form AFM parameters to MGL parameter. In this case, the PSA researchers have not performed the Bayesian updating for reducing uncertainty of the MGL parameters due to the fact that conversions of these CCF parameters cannot know the MGL parameters distribution. For this reason, the MGL parameter distribution has been used popularly to perform PSA for Korean NPPs.

In this study, therefore, the Bayesian-based CCF parameters distribution estimation program using α-factors parameter data has been developed for evaluating the CCF parameters and applied for the system of the reference plant to obtain the uncertainty data of the parameters in MGL model. The calculation algorithm of this program using the Bayesian method has been developed and programmed by the C# language in this study

2. Methods and Results

The assessment of common cause failure (CCF) is necessary for reducing the uncertainty during the process of probabilistic safety assessment. A basic unavailability assessment method is an approach for the quantitative analysis of CCF modeling using Bayesian probability, in which the estimation of parameters is more accurate by combining the failure information from system, component and cause level. In this chapter 2, the Bayesian method has been introduced and applied in the CCF's parameter estimation program.

2.1 Bayes' theory

Up to now, in Korea, there has been no detail guidance for estimating the CCF parameters using the Bayesian method in an uncertainty analysis. In this study the Bayesian method has been introduced and applied for reducing the uncertainty of the common cause failures. The basic equation of the Bayesian theory [2-3] is described as follows.

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

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.

Table 1: Conjugate families distribution of Bayes' operation

Likelihood	Conjugate prior	Posterior
Binomial distribution	Beta distribution	Beta distribution
Muti-nominal distribution	Dirichlet distribution	Dirichlet distribution

The likelihood function for the CCF parameters depends on the CCF models and has the corresponding conjugate distribution as shown in Table 1.

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

The posterior distribution is proportional to the product of prior distribution and the likelihood function as shown in Eq. 2. 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.

2.2 Parameter distribution

The C# program named COCAP (Common Cause Failure Parameter Estimation for PSA), has been developed and applied to obtain the CCF parameters distribution. The parameters distribution of the CCF models [4-6] can be obtained using the Beta conjugate family as sown in Table 1.

Table 2: Distribution of the CCF parameter

CCF models	CCF parameter distribution	
	Beta distribution (a, b)	
	Non-Staggered(NS) testing	Staggered(S) testing
MGL	$a = a_0 + \sum_{i=k}^{m} in_i$ $b = b_0 + \sum_{i=k-1}^{m} in_i - \sum_{i=k}^{m} in_i$	$a = a_0 + \sum_{i=k}^{m} n_i$ $b = b_0 + \sum_{i=k-1}^{m} n_i - \sum_{i=k}^{m} n_i$
	$2 \le k \le m$	
AFM	$a = a_0 + n_k$ $b = b_0 + (\sum_{k=1}^{m} n_k - n_k)$	
	$1 \le k \le m$	

The Bayesian approach results are shown in Table 2. It involves the systematic approach about how to combine the prior distribution and the likelihood function to produce the posterior distribution. Thus, the developed program, COCAP, can not only estimate the CCF parameter distribution but also perform the Bayesian updating of the CCF parameters of the important systems in the reference nuclear power plants.

2.3 COCAP program

To evaluate the parameter distributions and the CCF uncertainty, a computer program named COCAP, has been developed using the C# language. The COCAP computer program consists of four functions which are Input module, Conversion module, Bayesian module and Help module as shown in Table 3.

Table 3: Main functions of COCAP program

Main function	**Description**
Input data	Connect database
	Select of NRC CCF data (2007) Select of WACAP-16672 (2008)
Conversion	AFM to MGL conversion (CCF parameter)
	MGL to AFM conversion (CCF parameter)
Bayesian analysis	Bayesian analysis of AFM/MGL parameter distribution
	AFM /MGL multiplier calculation
Help	Description of program function and calculation formula used in COCAP program

Fig. 1 shows the main screen of the program developed in this study. This program could contribute to easy evaluation of the CCF analysis related to the Multiple Greek Letter model and Alpha-Factor Model.

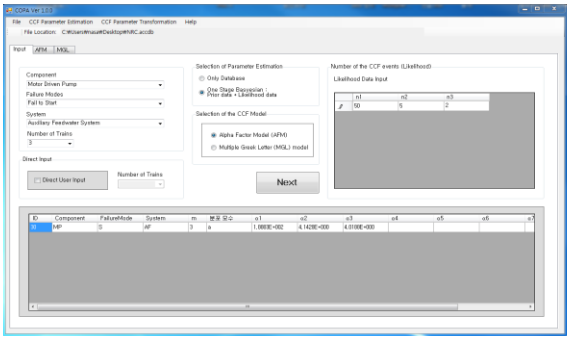
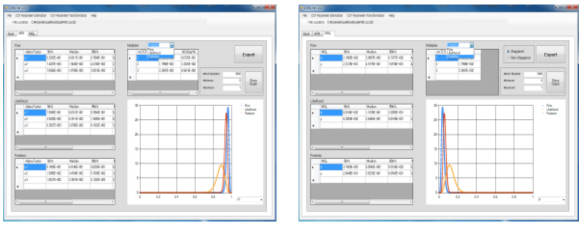


Fig. 1. Main screen of the COCAP program

The developed program involves the Common Cause Component Group (CCCG = m) which may be applied from a value of 2 to 8. The output data of the user-selected CCF parameters offered in this program provides prior, likelihood and posterior distribution for the parameters of the Multiple Greek Letter model and Alpha-Factor Model as shown in Fig. 2. Each distribution provides the confidence interval such as 5 %, 50 %, and 95 %, mean values for the Beta distribution (a, b).



(a) AFM parameter output frame (b) MGL parameter output frame

Fig. 2. Output of the CCF parameter distribution

2.4 Execution of COCAP program

The common cause failure parameters have been evaluated using the program, COCAP developed in this study under the particular assumed conditions. For demonstrating the program execution process, the prior data of the auxiliary feedwater system, motor driven pump, and “fail to start” for CCCG=3 are utilized. The U.S. NRC CCF parameter estimations [7] used in this study are shown in Table 4 while the likelihood data are shown in Table 5. To execute the developed program, the parameters data of the CCF models have been calculated individually using MGL model and AFM model and they are compared each other. Table 6 shows the Bayesian updating results showing that the calculated CCF multiplier values are exactly identical regardless of the model types depending on the conditions. It is shown that the program, COCAP might evaluate the parameter distributions of the MGL model and AFM model properly without any problems.

Table 4: Prior data

size	**Fail mode**	**α-factors**		**Alpha 1**	**Alpha 2**	**Alpha 3**
m=3	Fail to Start	Parameter of beta distribution	a	1.89E+02	4.14E+00	4.02E+00
			b	8.16E+00	1.93E+02	1.93E+02
		Percentiles	5%	9.33E-01	7.43E-03	7.06E-03
			50%	9.60E-01	1.94E-02	1.88E-02
			95%	9.79E-01	4.01E-02	3.92E-02
		Mean		9.59E-01	2.10E-02	2.04E-02

Table 5: Likelihood data

size	**Fail mode**	**α-factors**		**Alpha 1**	**Alpha 2**	**Alpha 3**
m=3	Fail to Start	Parameter of beta distribution	a	5.00E+01	5.00E+00	2.00E+00
			b	7.00E+00	5.20E+00	5.50E+01
		Percentiles	5%	7.99.E-01	3.58.E-02	6.38.E-03
			50%	8.82.E-01	8.29.E-02	2.98.E-02
			95%	9.40.E-01	1.56.E-01	8.19.E-02
		Mean		8.77.E-01	8.77.E-01	8.77.E-02

Table 6: Posterior data and CCF multiplier

CCF models	Size	Fail mode	CCF parameters		Alpha 1	Alpha 2	Alpha 3
AFM	m=3	Fail to Start	Parameter of beta distribution	a	2.39.E+02	9.14.E+00	6.02.E+00
				b	1.52.E+01	2.45.E+02	2.48.E+02
			Percentiles	5%	9.14.E-01	1.91.E-02	1.04.E-02
				50%	9.41.E-01	3.48.E-02	2.25.E-02
				95%	9.63.E-01	5.70.E-02	4.12.E-02
			Mean		9.40.E-01	3.60.E-02	2.37.E-02
			CCF multiplier	**NS**	**8.86E-01**	**3.32E-02**	**6.56E-02**
				S	**9.40E-01**	**1.80E-02**	**2.37E-02**
CCF models	**Size**	**Fail mode**	**CCF parameters**		**β**	**γ**	
MGL NS	m=3	Fail to Start	Parameter of beta distribution	a	1.00.E-01	3.62.E-01	
				b	1.31.E-01	4.97.E-01	
			Percentiles	5%	1.67.E-01	6.32.E-01	
				50%	1.32.E-01	4.97.E-01	
				95%	3.63.E+01	1.81.E+01	
			Mean		2.39.E+02	1.83.E+01	
			CCF multiplier	**NS**	**8.86E-01**	**3.32E-02**	**6.56E-02**
MGL S	m=3	Fail to Start	Parameter of beta distribution	a	3.74.E-02	2.04.E-01	
				b	5.85.E-02	3.92.E-01	
			Percentiles	5%	8.59.E-02	6.05.E-01	
				50%	5.97.E-02	3.97.E-01	
				95%	1.52.E+01	6.02.E+00	
			Mean		2.39.E+02	9.14.E+00	
			CCF multiplier	**S**	**9.40E-01**	**1.80E-02**	**2.37E-02**

3. Conclusions

The common cause failures in nuclear power plants are one of the significant factors to affect both the values of Core Damage Frequency and Large Early Release Frequency. Several investigators have made many efforts to attempt to reduce the common cause failure uncertainty. In this study a methodology using the Bayesian operation has been developed and applied for reducing the uncertainty of the common cause failures. The Bayesian-based CCF parameters estimation program called COCAP has also been developed for evaluating the common cause failures parameters. It is shown that COCAP program can obtain the parameter distributions for various common cause failure models for both the non-staggered and the staggered tests. It is also 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 developed program might contribute to supplying the efficient risk assessment procedures by evaluating the uncertainty of the relevant common cause failures parameters of the analyzing systems.

■ Acknowledgement

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REFERENCES

[1] KHNP, "Probabilistic Safety Assessment Report for SKN 3&4".
[2] Alfredo H-S. Ang, Wilson H. Tang, "Probability Concepts in Engineering Planning and Design", Volume I-Basic Principles, pp. 329-359, 1975.
[3] Peter M. Lee, "Bayesian Statistics An Introduction", Third Edition, pp. 56-81, 2004
[4] Mosleh and K. N. Fleming, Pickard, Lowe, and Garrick, A., U.S. NRC, "Procedure for Treating Common Cause Failures in Safety and Reliability Studies, Procedural Framework and Examples", NUREG/CR-4780 Vol 1, 1988.
[5] Mosleh and K. N. Fleming, Pickard, Lowe and Garrick, A., U.S. NRC, "Procedure for Treating Common Cause Failures in Safety and Reliability Studies, Analytical Background and Techniques", NUREG/CR-4780 Vol 2, 1989.
[6] Mosleh, A., INEEL, "Guidelines on Modelling Common-Cause Failures in Probabilistic Risk Assessment", NUREG/CR-5485, 1999.
[7] U.S.NRC (Nuclear Regulatory Commission), 2008, "CCF Parameter Estimations, 2007 Update. http://nrcoe.inel.gov/resultsdb/publicdocs/CCF/ccfparamest2007.pdf.