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A Case Study of the Plant-specific CCF Parameter Estimation for the Safety-related I&C Components Using Bayesian Update Technique

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1. Introduction

Common cause failure (CCF) is defined as failure of multiple equipment items occurring from some single cause that is common to all of them [1]. In the probabilistic safety assessment (PSA) community, it is a general conclusion that common cause failure has the most significant contribution to safety system failures. Even though there are many CCF methods and guidelines in the world ([1],[2],[3]), however, it is a basic problem that PSA practitioners have no CCF experience data enough for estimating CCF parameters significant statistically.

To lessen the shortage of CCF evidence in the estimation of plant-specific CCF parameters, the author suggests the use of a practical approach like the reference [4], which is based on the Bayesian updating technique of generic CCF parameters with plant-specific CCF event. As a case study, the plant-specific alpha factors for the safety-related I&C components at Korean standard nuclear power plant (KSNP) are estimated by the practical approach with the plant-specific CCF evidences observed for a period of 2003 through 2007. Recently, the result of the work was used for the development of the PSA base model to improve risk-informed surveillance test interval (RI-STI) of the KSNP safety-related I&C systems [5].

2. Bayesian Update Method for CCF Parameters

Mathematically Bayesian update method for CCF parameters (e.g., alpha factor model) can be simply formulated as follows [4].

$$\hat{\alpha}_{k:m} = \alpha_{k:m} \cdot \frac{\delta}{\delta + d} + \frac{f_k}{d} \cdot \frac{d}{\delta + d} \qquad \text{(Eqn. 1)}$$

where,

$\hat{\alpha}_{k:m}$: posterior alpha factor for exactly k failures of common cause component group(CCCG) of size m,

$\alpha_{k:m}$: k^{th} prior alpha factor for CCCG m,

δ : a constant to be calculated by the sum of prior distribution parameters (Dirichlet distribution) or by a geometric mean of δ_k, for $k=1,...m$, which is defined as the sum of two parameters (α, β) given a beta prior distribution for $\alpha_{k:m}$.

f_k : the sum of the k^{th} impact vector elements for all of the observed plant-specific CCF data,

d : the sum of all the impact vector elements ($= \sum_{k=1}^{m} f_k$).

The mean of posterior alpha factor $\hat{\alpha}_{k:m}$ is a weighted average of the mean of prior distribution ($\alpha_{k:m}$) and the maximum likelihood estimate (f_k/d) from the plant-specific CCF data. If the analysts have the above generic prior information for the component of interest, the estimation of plant-specific alpha factors can be relatively easy work from Eqn.1 after an impact vector analysis of the plant-specific evidence (see [2],[3],[4]). Note that the posterior CCF parameters with no plant-specific CCF data are identical to the generic prior parameters in Eqn.1.

3. The Result of a Case Study

As a case study, the plant-specific CCF parameters for the KSNP safety-related I&C components are estimated. All kind of the prior information needed is available from the reference [4]. As the results of the investigation of the experience data (the records of the order) for a period of 2003 through 2007, Table 1 shows the plant-specific CCF evidence in part.

According to the CCF procedure [3], a root cause analysis for the trip circuit breaker (TCB) CCF data was performed and the result of the impact vector analysis is illustrated in Table 2. Finally, the alpha parameters for the safety-related I&C components were estimated as shown in Table 3. Note that a few of the additional technique were used for the estimation of CCF parameters, such as mapping up-down technique [3], the system level CCF modeling technique [4], etc.

Table 1 CCF data for the safety-related I&C components

Components	CCCG	No. Failure	Fail. date	Severity	Plant	Event Description	Remarks
Trip Circuit Breaker	4	3	'05.6.9	Failure	A	TCB Ch.D fail to reset after open	No safety issue (fail to close)
			'06.1.9	Failure	A	TCB Ch.B motor cut-off switch lever failure (RTSG replacement)	No safety issue (fail to close)
			'06.5.22	failure	A	TCB Ch.C fail to close during RSPT dynamic test	No safety issue (fail to close)
Interface Relay	8	2	'06.07.18	degraded	A	CSAS Tr.B 2-4leg hunting (several times)	
RCP speed Sensor	16	3	'06.12.24	failure	A	SE-133A sensor connector part abnormal (CPC Ch.A trip)	
			'06.12.28	failure	A	SE-113A sensor connector part abnormal(CPC Ch.A Trip)	
			'06.12.30	failure	A	Pulse Shaper card failure (CPC Ch.A Trip)	
Pressure Transmitters	4	2	'07.10.11	degraded	B	CV Wide-Pressure bias occur (352A, 352B)	

Table 2. Impact factor analysis of CCF data for TCB

Hypothesis	Prob.	F0	F1	F2	F3	F4
Indep. Failure (3)	0.5	0	1	0	0	0
2 of 4 Failure	0	0	0	0	0	0
3 of 4 Failure	0.4	0	0	0	1	0
4 of 4 Failure	0.1	0	0	0	0	1
Ave. Impact Vector		0	1.35	0	0.04	0.01

3. Conclusions

The plant-specific system-level alpha factors for the KSNP safety-related I&C components (Table 3) were presented with some CCF events investigated from operating experience of the total of 24.24 reactor years for the period of 2003 through 2007. The results of the study can be useful for the risk-informed applications like the RI-STI for the KSNP analog and digital I&C systems.

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Table 3. The results of the failure probabilities or rates for the KSNP safety-related I&C components

CCCG	System success Criteria	Components	CCF factors*)	Remark
4	selective 2-out-of-4 (1/2 twice)	Trip Circuit Breaker	0.0979	Bayesian update
4	2-out-of-4	Pressure Sensor (Hi-Hi CTMT)	0.0652	Bayesian update
8	selective 2-out-of-4 (1/2twice, 1/2trains)	Interface Relays	0.101	Bayesian update
16	3-out-of-16	RCP speed sensor	0.169	Bayesian update
2	1-out-of-2 (1/2)	Level sensor, Hand switch, Signal processor, MG set control circuit, Measurement loop, Pressure sensor for DPS	0.0537	
4	selective 2-out-of-4 (1/2 twice)	Interposing Relays, RPS initiation relay, Shunt trip device, Under-voltage trip device, hand switch for RPS & ESFAS	0.0963	
4	2-out-of-4 (2/4)	Level sensor, Pressure sensor, Measurement loop, Ex-core neutron flux detectors, Sub-channel power calculators, Calibrated average power calculators, CPC analog input and CPU module	0.0492	
4	1-out-of-4 (1/4)	Interposing relay within a relay card	0.191	
8	selective 2-out-of-4 (1/2twice, 1/2trains)	initiation relay for ESFAS	0.0921	
8	2-out-of-4 (1/2variables)	Bistable, Bistable output relays	0.0155	
24	1/6 (intra-channel) & selective 2-out-of-4 (inter-channel)	Logic matrix relays	0.00305	
28	23 or more-out-of-28	CEAC	0.0642	
16	1-out-of-16	SIAS sub-group relay	0.213	Based on YGN 3,4
11	1-out-of-11	CIAS sub-group relay	0.189	Based on YGN 3,4
4	1-out-of-4	AFAS-1 and RAS sub-group relay	0.11	Based on YGN 3,4
10	1-out-of-10	MSIS sub-group relay	0.181	Based on YGN 3,4
3	1-out-of-3	AFAS-2and CSAS sub-group relay	0.0876	Based on YGN 3,4

*) System level alpha factors