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Data analysis for a Global Common Cause Failure Event

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1. Introduction

In PRA model, a common cause event is defined as the failure or unavailable state of more than one component during the mission time and due to the same shared cause. Common cause failure (CCF) results from the coexistence of two main factors, a root cause and a coupling factor (or coupling mechanism) that creates the condition for multiple components to be affected by the same cause. The most efficient approach to identifying common cause system vulnerabilities is to focus on identifying coupling factors. Examples of coupling mechanism are as follows:

1) Same design
2) Same hardware
3) Same function
4) Same installation, maintenance, or operation staff
5) Same procedures
6) Same system/component interface
7) Same location
8) Same environment

A group of components identified to share coupling mechanism is called a common cause component group (CCCG). Common Cause Basic Event (CCBE) is an event involving failure of a specific set of components due to a common cause, and the number of CCBE (n) is dependent on the size of CCCG (m). And, it is given by

$$\mathrm{n} = 2^{m} - 1 \qquad (1)$$

Table 1 shows the number of unique CCBE with increase of CCCG size.

Table 1. Number of unique CCBE
(With increase of CCCG size)

CCCG size (m)	Number of unique CCBE (n)
3	7
4	15
5	31
6	63
7	127
8	255
9	511
10	1023

As shown in Table 1, the number of unique CCBE dramatically increases with increasing number of CCCG size. When CCCG size is big, it would cause modeling issue that the number of CCBE that needs to be modeled is too many to be manageable. For example, 255 unique CCBEs need to be modeled when CCCG size is eight (8).

This number of CCBE can be reduced by eliminating some combinations and modeling a global CCBE. In this case, the global CCBE accounts for any other common cause events. Therefore, it is very important to analyze the data in a consistent manner.

In section 2, the method of analyzing the data for a global CCBE is studied using generic CCF data. In the analysis, Alpha Factor model [1] and CCF Parameter Estimations 2010 [2] are used.

2. Methods and Results

2.1 Method to calculate the data for a global CCBE

Alpha-factor model develops CCF probability from a set of failure ratios and the total component failure rate. The failure probability of a CCBE involving failure of k components in a system of m components is given by

For a staggered testing scheme:

$$Q_k^m = \frac{1}{\binom{m-1}{k-1}} \alpha_k Q_t \qquad (2)$$

For a non-staggered testing scheme:

$$Q_k^m = \frac{k}{\binom{m-1}{k-1}} \frac{\alpha_k}{\alpha_t} Q_t, \text{ when } \alpha_t = \sum_{k=1}^{m} k\alpha_k \qquad (3)$$

The binomial coefficient of $\binom{m-1}{k-1}$ above indicates that generic alpha factors are divided by the number of combination involving k components to be applied for failure probability calculation of CCBE. Single failure alpha factor of α_1 can be neglected in CCBE data analysis meaning that failure probability data can be solely applied for single failure event without applying the single failure alpha factor. This would be conservative in terms of data calculation, but, be acceptable since uncertainty for data of industry based generic CCF and generic component failure exists when they apply for PSA model for a specific plant.

For the data of a global CCBE, the alpha factor parameters that are divided by the number of combination need to be multiplied by the number of combination. And, the multiplied values need to be summed to be one value for the global CCBE data. This is because the data for a global CCBE should account for data of any other CCBEs.

Given that single failure alpha factor of α_1 is neglected, the global CCBE data for a staggered and non-staggered testing scheme can be calculated by

$$Global\ CCBE\ Parameter = \sum_{k=2}^{m}(Q_k^m \times \binom{m-1}{k-1}) \quad (4)$$

Table 2 and 3 show an example of analyzing the data of a global CCBE for a staggered testing scheme and a non-staggered testing scheme. The example uses the CCCG size of eight (8) for convenience. However, the data analysis method can be applicable for any size of CCCG. Alpha factors for generic demand CCF from CCF Parameter Estimation 2010 [2] are used.

Table 2. Data of a global CCBE for a staggered testing scheme (CCCG size = 8)

Alpha Factor (mean value)		Alpha Factor Parameter[a)]	Global CCBE Parameter[b)]
a1	9.68E-01	-	3.19E-02
a2	1.26E-02	1.80E-03	
a3	7.92E-03	3.77E-04	
a4	6.14E-03	1.75E-04	
a5	3.28E-03	9.37E-05	
a6	1.39E-03	6.62E-05	
a7	4.64E-04	6.63E-05	
a8	1.25E-04	1.25E-04	
Note : a) alpha factor parameter is estimated by formula (2) b) global CCBE parameter is estimated by formula (4)			

Table 3. Data of a global CCBE for a non-staggered testing scheme (CCCG size = 8)

Alpha Factor (mean value)		Alpha Factor Parameter[c)]	Global CCBE Parameter[d)]
a1	9.68E-01	-	9.58E-02
a2	1.26E-02	3.36E-03	
a3	7.92E-03	1.06E-03	
a4	6.14E-03	6.55E-04	
a5	3.28E-03	4.38E-04	
a6	1.39E-03	3.71E-04	
a7	4.64E-04	4.33E-04	
a8	1.25E-04	9.34E-04	
Note : c) alpha factor parameter is estimated by formula (3) d) global CCBE parameter is estimated by formula (4)			

As described in table 2 and 3, the data of a global CCBE for CCCG = 8 is greater than those of any other alpha factor parameters for CCF combination. This is because a global CCBE needs to account for any other CCBEs for CCF combination. The data of a global CCBE for non-staggered testing scheme is greater than that of staggered testing scheme due to the inherent characteristic of calculating alpha factor parameter in non-staggered testing scheme.

3. Conclusions

Common cause failure is one of the significant contributors to PSA result. And, it is recommended that CCBEs for a CCCG are explicitly modeled in fault tree analysis. However, modeling all the CCBEs of CCF combination for a CCCG would be difficult due to the number of CCBEs when CCCG size is big, e.g., CCCG $\geq$ 8. In case that CCCG size is big, a global CCBE that accounts for any other CCBEs can be considered. When a global CCBE is considered, it is very important to analyze the data of a global CCBE that accounts for data of any other CCBEs. Therefore, the data calculation method introduced here would be useful when industry based generic CCF data is used.

REFERENCES

[1] Mosleh, A., INEEL, Guidelines on Modeling Common-Cause Failures in Probabilistic Risk Assessment, NUREG/CR-5485, 1999.

[2] U.S. Nuclear Regulatory Commission, CCF Parameter Estimations 2010, 2012.