Development of Common Cause Failure Analysis Program for Analyzing the ICDE CCF Events

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1. Introduction

As common cause failure (CCF) events rarely occur, CCF analysis is generally performed by using the CCF event data of other nuclear power plants. The OECD/NEA is operating the International Common cause Data Exchange (ICDE) project to internationally collect and analyze CCF events. To get the data for the CCF events [1], KAERI has been participating in the ICDE project since 2002. In 2008, KAERI received 407 CCF evens for diesel generators, centrifugal pumps, check valves, motor operated valves, and breakers from the ICDE. However, there was no computerized tool for qualitative and quantitative analysis of the CCF events with the ICDE data. Thus, KAERI developed a CCF analysis program to qualitatively and quantitatively analyze the ICDE CCF events. In this paper, the estimation procedure [2] of the developed program and its function are presented.

2. Estimation Procedure of CCF Parameters

The developed CCF analysis program provides us with the estimation results of alpha factors, CCF factors, and Multiple Greek Letter (MGL) parameters. The CCF factors and MGL parameters are calculated from the estimated alpha factors. The estimation procedure of the alpha factor used in the developed calculator follows the approach of the NUREG/CR-5485[3]. Each CCF event in the ICDE database was represented by impact factors to classify events according to the level of impact of CCF events [1]. It has three impact vectors: component impairment factors, shared cause factors, and time factors.

First, qualitative and quantitative information for the CCF analysis was identified by reviewing the ICDE database. It includes the component type, testing strategies, the size of a CCCG, CCF event descriptions, number of independent events, impact vectors, CCF event types (lethal and non-lethal), etc. Second, CCCG components of the target plant were determined and their defenses for the previous CCF events of the original plant in the ICDE database were identified. Third, generic impact vectors of the CCF event were calculated by considering three impact vectors mentioned above. Fourth, the qualitative and quantitative differences between the original system and the target systems were adjusted by multiplying the generic impact vector by an event applicability factor and by mapping the original to the target system, respectively. Fifth, the number of events in each impact category was calculated by adding the corresponding elements of the impact vector. Sixth, the alpha factor likelihoods and the alpha factor priors were estimated. In the developed program, the alpha factor priors are the same values used in the process of CCF parameter estimations for the components for American NPPs [4]. Next, Bayesian updating for the estimation of the alpha factors is performed. Finally, CCF factors and MGL parameters are estimated with the estimated alpha factors.

The mean value of the alpha parameters is calculated by using the following equation:

$$\text{mean}(\alpha_k) = A_k/A_T = a/(a+b) \quad (1)$$

where, $A_T = \sum_{k=1}^{m} A_k$

$a = A_k$, $b = A_T - A_k$, k=1, 2, 3, 4,……

$A_k = P_k + L_k$, k=1, 2, 3, 4,……

$L_K = L_{0K}$, $P_K = P_{0K}$, k= 2,3,4,…

$L_1 = L_{01} + IN_L$, $P_1 = P_{01} + IN_P$, k= 1

L_{0K} = number of CCF events involving k specific components -likelihood

P_{0K} = number of CCF events involving k specific components - prior

IN_L =number of independent events - likelihood

IN_p= number of independent events - prior

The probability of a CCF event involving *k* specific components in a CCCG of size *m* for a staggered testing scheme, $Q_k^{(m)}$, is calculated by using the following equation[2,3]:

$$Q_k^{(m)} = (\alpha_k^{(m)} / {}_{m-1}C_{k-1}) * Q_t \quad (2)$$

where, Q_t = total failure probability of a component in a CCCG due to all independent and common cause events

From Eq.(2), CCF factors are defined as $(\alpha_k^{(m)} / {}_{m-1}C_{k-1})$. MGL parameters can be estimated from alpha parameters as follows:

$$\rho_K = (\textstyle\sum^{m}_{i=k} \alpha_i) / (\sum^{m}_{i=k-1} \alpha_i) . \quad (3)$$

$\rho_1 = 1$, $\rho_2 = \beta$, $\rho_3 = \gamma$, $\rho_4 = \delta$, $\rho_5 = \varepsilon$, $\rho_6 = \mu$, $\rho_7 = \upsilon$, $\rho_8 = \kappa$,

For the case of non-staggered testing, CCF factors are defined as $(k/{}_{m-1}C_{k-1})(\alpha_k^{(m)}/\alpha_t^{(m)})$, and MGL parameters are estimated from the alpha parameters as below:

$$\rho_K = (\textstyle\sum^{m}_{i=k} i\alpha_i) / (\sum^{m}_{i=k-1} i\alpha_i) . \quad (4)$$

3. Function of CCF analysis program

The developed CCF analysis program consists of three sub-programs: "ICDE DB", "Qualitative Analysis", and "Quantitative Analysis". It was programmed by Microsoft Visual Basic 2005 and .NET. In the "ICDE DB," the CCF data can be searched and reviewed. The data base structure of "ICDE DB" is almost the same as the data base program of the ICDE CCF events. In the "Qualitative Analysis", the root causes, shared causes, corrective actions, and detection methods for the stored CCF events can be qualitatively analyzed according to component types, sub-component types, or countries. In the "Quantitative Analysis", applicability factors of each CCF event, alpha factors, CCF factors, and MGL parameters are estimated. CCF parameters can also be estimated for each component type, system type, or country. Figure 1 shows an example of the quantitative analysis result of CCF events for motor operated valves.

4. Concluding Remarks

In this paper, the developed CCF parameter program with its estimation procedure is presented. The use of the developed CCF analysis program for domestic NPPs is expected to enable us to perform detailed quantitative CCF analysis, and to enhance the operation and maintenance of domestic NPPs through the qualitative analysis of the ICDE CCF events. As ICDE CCF event data are exchanged by an in-kind approach, more efforts are required for collecting and analyzing CCF events for the domestic NPPs to get more ICDE CCF events.

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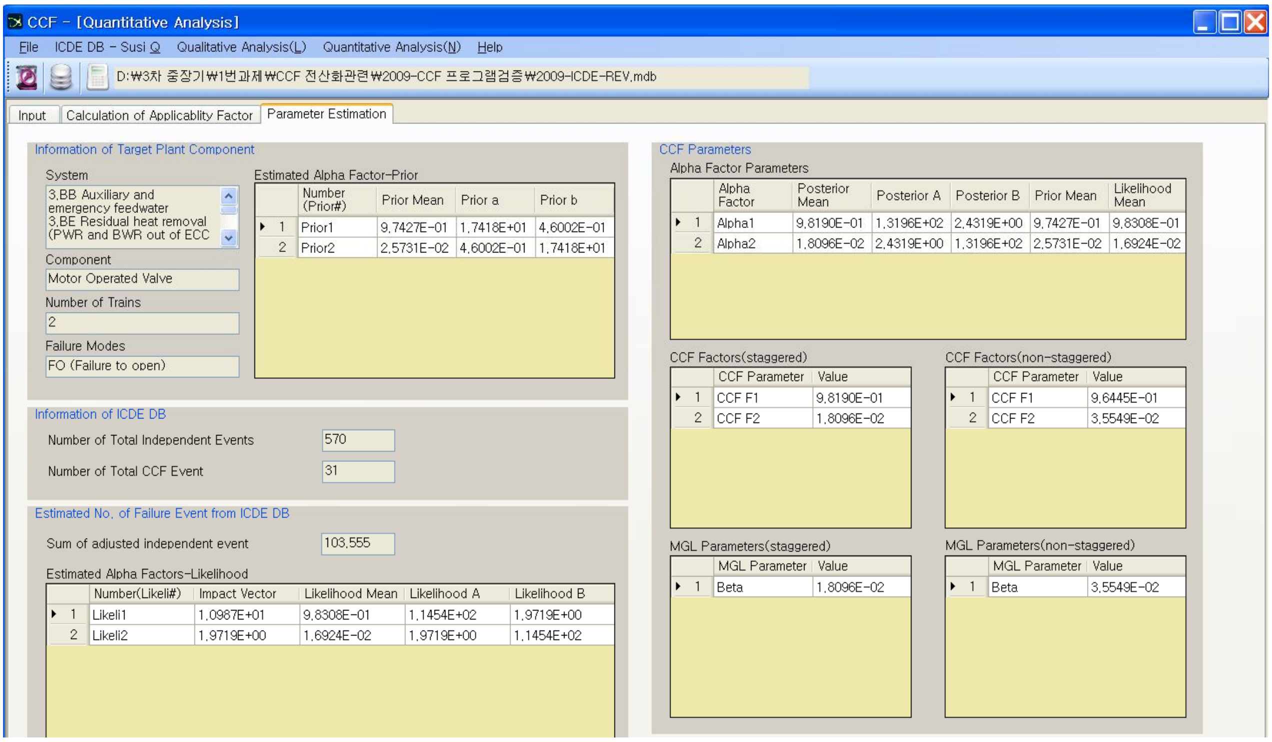

Figure 1. An example of a quantitative analysis result of the ICDE CCF events