An Uncertainty Analysis Software to Treat State-of-Knowledge Correlation in PSA

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1. Introduction

The result of a PSA includes uncertainty. The sources of uncertainty are data uncertainty, model uncertainty and completeness uncertainty [1]. Uncertainties are distinguished as being either aleatoric or epistemic. Aleatoric uncertainty comes from "random variability in some parameter or measurable quantity", and the epistemic uncertainty comes from "an imprecision in the analyst's knowledge about models, their parameters, or their predictions". The aleatoric uncertainty can be estimated in quantitative values using the Monte Carlo approach.

Recently, ASME PRA Standard [2] requires propagating parameter uncertainties and those model uncertainties explicitly characterized by a probability distribution using the Monte Carlo approach. In addition, it requires also propagating uncertainties in such a way that the "state-of-knowledge" correlation between event probabilities is taken into account.

The same kinds of components are categorized as one group, for which probabilities are calculated from the same data. There exists the correlation between event probabilities because they are calculated from the same data. This correlation is called state-of-knowledge correlation. The grouping of the common cause failures (CCF) should be also considered in state-of-knowledge correlation.

There are several softwares to treat the correlated uncertainty such as KIRAP [3]. But, they are not suitable to treat the correlation in CCFs.

This article describes a software developed to treat correlation between independent events as well as correlation due to CCFs.

2. Monte Carlo Approach for State-of-Art Correlation

2.1 The Basic Monte Carlo Approach

Uncertainty of each event probability is expressed as a probability distribution. Suppose a top event y is a function of x_i's.

$$y = f(x_1, x_2, \dots x_m)$$

The Monte Carlo approach is a popular method to estimate the distribution of the top event y otherwise it is almost impossible to evaluate the distribution of y analytically. In the Monte Carlo approach, a random sample is extracted from a distribution of each x_j. A top event value is calculated using the samples. The process is repeated n times. n y's are used to represent uncertainty of the top event value.

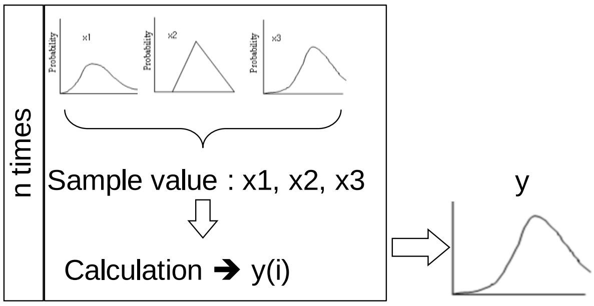

Fig. 1. The Monte Carlo approach is used to estimate uncertainty of a top event. A random sample is extracted for each x_j.

2.2 Monte Carlo Approach in case of Correlation

If there is no correlation, one distribution is used for each event, which means that one sample value is used for each event during the Monte Carlo simulation.

As far as the state-of-art correlation is considered, it is assumed that events whose probabilities are calculated based on the same data are totally correlated. One sample value is used for those events during the sampling process.

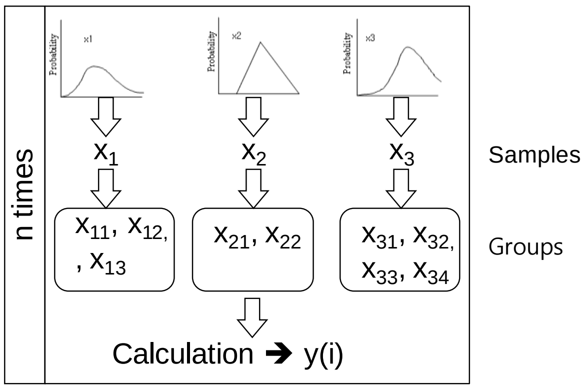

Fig. 2. Monte Carlo approach in case of correlation. X_{11}, X_{12} and X_{13} are correlated. One sample value is used for X_{11}, X_{12} and X_{13}.

3. Uncertainty Analysis Software for State-of-Art Correlation

3.1 Uncertainty Analysis Module of AIMS-PSA

The uncertainty analysis module of AIMS-PSA [4] is designed to handle the correlation between event probabilities for independent failures as well as CCFs. The CCF probabilities are calculated based on independent failure data and CCF factors. One thing difficult for CCF events is that all kinds of combinations exist between components. The sampling process is modified to handle correlation in CCF events.

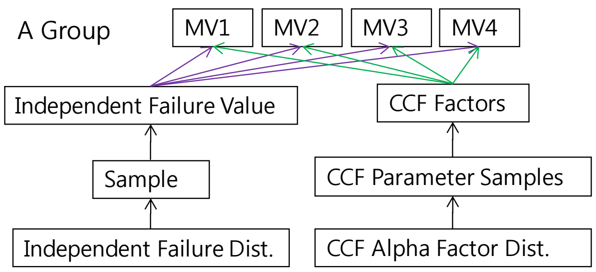

Fig. 3.Sampling processes for a 4 train redundant group. One sample is applied for independent failure value and a group of CCF factor samples are applied for all combinations of CCF events.

The uncertainty module uses 3 database tables to input the data. “Variable Table” stores information for distribution of each variable. “CCF Table” stores distributions for CCF parameters, where alpha factor method is assumed. “Event Table” stores information on each event.

Table 1. “Variable Table” describes the distribution for each variable. AFMPS_I is a lognormal distribution having a mean of 1e-3 and an error factor of 10, and AFMPM_M is a beta distribution having an alpha of 4 and a beta of 50.

VarName	DistType	para1	Para2	Remark
AFMPS_I	Lognormal	1.E-03	10	Mean, EF
AFMP_M	Gamma	10	1.E-05	α, β
AFMP_T	Beta	4	50	α, β
SIMPR_I	Lognormal	1.E-03	10	Mean, EF

Table 2. “CCF Table” describes the distribution for alpha factors for each CCF group. Note that SICCF_R represents a CCF group for 4 trains, which requires distributions for α_2, α_3 and α_4. 3 lines are used to describe the group for SICCF_R.

CcfDist Name	No Trains	Tr	Dist Type	para1	Para2	Remark
AFCCF_S	2	2	Beta	5	100	α_2
SICCF_R	4	4	Beta	0.5	25	α_4
SICCF_R	4	3	Beta	0.2	26	α_3
SICCF_R	4	2	Beta	0.5	25	α_2

Table 3. “Event Table” has information for events. Note that AFMP_M and SIMPR_I are variable names in “Variable Table” and SICCF_R is a variable name in “CCF Table”.

Name	Type	Lambda	Tau	CCF Factor	Lambda _Dist	Tau _Dist	Factor _Dist	Tr
AFMPS-1A	0	1.E-03			AFMPS_I			
AFMPS-1B	0	1.E-03			AFMPS_I			
AFMPM-1A	2	1.E-04	20		AFMP_M	AFMP_T		
AFMPM-1B	2	1.E-04	20		AFMP_M	AFMP_T		
AFMPW-1AB	0	1.E-03		0.05	AFMPS_I		AFCCF_S	2
SIMPK-ABCD	1	1.E-05	24	0.03	SIMPR_I		SICCF_R	4
SIMPK-ABC	1	1.E-05	24	0.02	SIMPR_I		SICCF_R	3
SIMPK-AD	1	1.E-05	24	0.04	SIMPR_I		SICCF_R	2

The sampling is performed for variables in “Variable Table” and “CCF Table”. Lambda_Dist, Tau_Dist and Factor_Dist of “Event Table” are fields to describe which variable is used for each event. For example during the Monte Carlo simulation, a sample value for SIMPR_I in “Variable Table” is used for Lambdas of events SIMPK-ABCD, SIMPK-ABC and SIMPK-AD which are in the sample group. CCF factors for those events are calculated by using sample values of SICCF_R group in “CCF Table”.

4. Conclusions

An uncertainty analysis software is developed to treat the correlation in independent events as well as CCF events, which is addressed in the ASME PRA Standard. The software has been successfully tested for small scale examples. It can be used to incorporate the state-of art correlation in uncertainty analysis of a PSA, which will to meet the quality of a PSA.

Acknowledgement

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