Developing Generic Prior Distributions for Common Cause Failure Alpha Factors

Zhegang Ma, Ph.D., PE
John Schroeder
Curtis Smith, Ph.D.

Idaho National Laboratory

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I. Introduction

- Common cause failures are significant risk contributors for commercial nuclear power plants
- Since 1980s, a series of reports have been published to provide guidelines for performing CCF modeling and performing CCF event data analysis
- A CCF database system has been developed and maintained by INL for the NRC for U.S. commercial nuclear power plants
  - CCF database: stores coded CCF events
  - CCF software: uses impact vectors and mapping methods to estimate CCF parameters
- Generic prior distributions were developed and included in the CCF software for CCF Alpha Factor Model (AFM) parameter estimations

I. Introduction (cont.)

- The CCF database system has been maintained since its development in late 1990s
- The CCF parameter estimations have been updated and published on a yearly basis
- However, the process for developing prior distributions has not been published
- The prior distributions have not been updated since early 2000s
- Let's
  - Review the CCF analysis history
  - Review the prior distribution development process
  - Update the prior distributions
  - Discuss issues in the process

II. History of CCF Analysis

- NUREG/CR-4780, *Procedures for Treating Common Cause Failures in Safety and Reliability Studies*, January 1988
  - Presents the framework for including CCFs in risk and reliability evaluations with four major stages
  - Introduces the concept of impact vectors and the mapping method
- NUREG/CR-6268, *Common Cause Failure Database and Analysis System*, June 1998
  - Method to collect data, characterize CCF events, and estimate CCF parameters and uncertainties
  - A CCF database system and the CCF software
- NUREG/CR-5497, *Common-Cause Failure Parameter Estimations*, October 1998
  - Quantitative results and insights
- NUREG/CR-5485, *Guidelines on Modeling Common-Cause Failures in Probabilistic Risk Assessment*, November 1998
  - Guidelines to model CCF events in PRA

II. History of CCF Analysis (cont.)

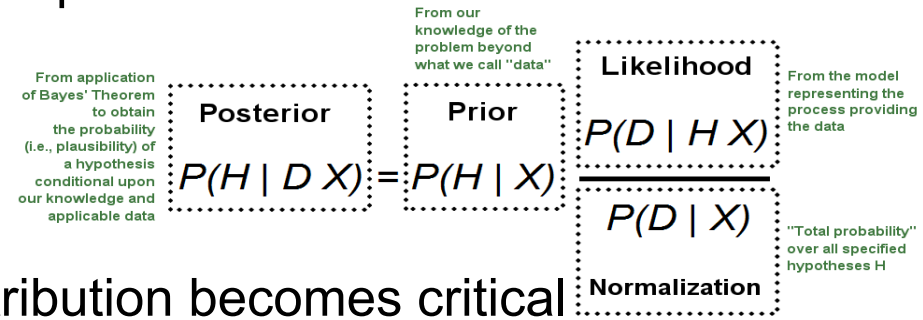
- NUREG/CR-6268, Revision 1, *Common Cause Failure Database and Analysis System, Event Data Collection, Classification, and Coding*, September 2007
  - Update the guidance for collecting, classifying, and coding CCF events described in its older version published in 1998
- A series of NRC/INL reports were published on the NRC web site, http://nrcoe.inl.gov/resultsdb, to update the CCF parameter estimations
  - *2003 Update*, data from 1985 to 2003
  - *2005 Update,* data from 1991 to 2005
  - *2007 Update*, data from 1991 to 2007
  - *2009 Update*, data from 1997 to 2009
  - *2010 Update*, data from 1997 to 2010
  - *2012 Update*, data from 1997 to 2012
  - *2015 Update*, data from 1997 to 2015

II. History of CCF Analysis (cont.)

- Quality control in the process of data classification, loading, and parameter estimation
  - All events are reviewed by two INL data analysts to make sure that the events are classified as CCF events and coded correctly
  - A PRA analyst reviews the CCF events and results for consistency and comparison with PRA experience
  - A final review is performed by independent CCF expert(s) outside of INL
- Still, the CCF event identification and characterization are subject to engineering judgement
  - Different analysts have different interpretations of the events
  - Different degrees of available information
- Uncertainty caused by data and methodology should be identified

III. Existing CCF Priors

- Bayesian estimation procedure is used to develop uncertainty distributions for CCF parameters



- Choice of prior distribution becomes critical
  - Analyst's subjective judgement or
  - Based on observed CCF data and applicable methodology
- NUREG/CR-5485 uses a mapping method to develop prior distributions for alpha factors
  - Utilize all CCF events in database by mapping to a given CCCG size.
  - MLE for each alpha factor is obtained and fit with constrained noninformative distribution
  - The estimates of the Dirichlet distribution parameters are calculated and combined to obtain an effective estimate
- No details on developing prior distributions

III. Existing CCF Priors (cont.)

Mean Values of Existing CCF Prior Parameters

Parameter	NUREG/ CR-5485	2003 CCF Update	2005 CCF Update	2007 CCF Update	2010 White Paper	2009, 2010, 2012, and 2015 CCF Update
Range of Data	1980–1995	1985–2003	1991–2005	1991–2007	1995–2005	1997–2009 (2010,2012,2015)
α2 (CCCG=2)	4.70E-02	3.09E-02	4.06E-02	2.57E-02	1.75E-02	Same as in the 2007 CCF Update Report
α3 (CCCG=3)	2.58E-02	7.17E-03	8.71E-03	5.79E-03	5.94E-03	
α4 (CCCG=4)	1.86E-02	3.72E-03	4.64E-03	2.98E-03	3.81E-03	
α5 (CCCG=5)	1.46E-02	6.26E-04	7.25E-04	5.33E-04	9.32E-04	
α6 (CCCG=6)	1.23E-02	6.15E-04	6.86E-04	4.07E-04	5.06E-04	
α7 (CCCG=7)	1.03E-02	1.29E-04	1.52E-04	1.17E-04	2.22E-04	
α8 (CCCG=8)	9.06E-03	1.38E-04	1.46E-04	1.25E-04	1.88E-04	

IV. Updating Priors for Alpha Factors

- Step 1. For each CCCG size, tabulate the number of CCF events and complete CCF events
- Step 2. For partial CCF events, calculate n_k for each group size with mapping methodology
- Step 3. For complete CCF events, perform a binomial regression to obtain the probability of complete CCF events and then estimate the number of complete CCF events for each group size
- Step 4. Add results from Step 3 to the final n_k for each group size (add the number to n_2 for group size 2, n_3 for group size 3, etc.)
- Step 5. Using the final n_k values, estimate the mean values of alpha factors for each group size
- Step 6. Using computer code, CalcPrior, developed by INL to estimate the distributions of the alpha factors with a procedure to calculate Dirichlet distribution parameters with noninformative prior distributions

IV. Updating Priors for Alpha Factors (cont.)

- Access CCF data
  - NRC CCF Database website https://rads.inl.gov/Pages/CCF.aspx
  - Query the CCF Database directly with SQL Server
- This prior update uses data from 1997 through 2015
- A total of 268 CCF events (56 complete, 212 partial CCF) and 7492.8 effective independent failure events

IV. Updating Priors for Alpha Factors (cont.)

CCF Data 1997-2015

Group Size	No. Partial CCF Events	No. Complete CCF Events	Total No. CCF Events	Prob. of Complete CCF Event - Data	Prob. of Complete CCF Event - Curve Fitting	Estimated No. Complete CCF Events
2	27	34	61	0.55738	0.51050	31.14031
3	27	12	39	0.30769		
4	61	2	63	0.03175		
5	7	0	7	0.00000		
6	30	5	35	0.14286		
7	3	0	3	0.00000		
8	30	2	32	0.06250		
9	0	0	0			
10	0	0	0			
11	5	0	5	0.00000		
12	7	1	8	0.12500	0.07153	0.57226
13	0	0	0		0.07151	0.00000
14	1	0	1	0.00000	0.07150	0.07150
15	0					
16	14					
Total	212					

n_k Values for Partial CCF Events

Group Size	n_1	n_2	n_3	n_4	n_5	n_6	n_7	n_8
2	115.61	31.164						
3	109.23	64.693	9.267					
4	96.47	80.938	25.857	4.038				
5	96.92	73.190	39.900	14.539	2.141			
6	98.05	65.654	46.584	23.001	8.533	1.209		
7	101.15	61.106	44.388	29.499	15.401	5.219	0.716	
8	102.97	59.825	41.221	31.486	20.828	10.368	3.197	0.453

Adjusted n_k

Group Size	n_t	n_l	n_1	n_2	n_3	n_4	n_5	n_6	n_7	n_8
2	3042.49	2864.58	115.61	62.304						
3	4491.83	4296.87	109.23	64.693	21.038					
4	5947.30	5729.16	96.47	80.938	25.857	14.873				
5	7388.92	7161.45	96.92	73.190	39.900	14.539	2.919			
6	8839.80	8593.74	98.05	65.654	46.584	23.001	8.533	4.237		
7	10283.74	10026.03	101.15	61.106	44.388	29.499	15.401	5.219	0.948	
8	11731.02	11458.32	102.97	59.825	41.221	31.486	20.828	10.368	3.197	2.807

IV. Updating Priors for Alpha Factors (cont.)

Updated Alpha Factor Mean Values (1997-2015)

Group Size	α_1	α_2	α_3	α_4	α_5	α_6	α_7	α_8
2	0.9795	2.048E-02						
3	0.9809	1.440E-02	4.684E-03					
4	0.9795	1.361E-02	4.348E-03	2.501E-03				
5	0.9823	9.905E-03	5.400E-03	1.968E-03	3.951E-04			
6	0.9833	7.427E-03	5.270E-03	2.602E-03	9.653E-04	4.793E-04		
7	0.9848	5.942E-03	4.316E-03	2.869E-03	1.498E-03	5.075E-04	9.214E-05	
8	0.9855	5.100E-03	3.514E-03	2.684E-03	1.775E-03	8.838E-04	2.725E-04	2.393E-04

IV. Updating Priors for Alpha Factors (cont.)

Updated Alpha Factor Prior Distributions (1997-2015)

Group Size	a1	b1	a2	b2	a3	b3	a4	b4
2	2.2413E+01	4.6853E-01	4.6853E-01	2.2413E+01				
3	5.7979E+01	1.1280E+00	8.5122E-01	5.8255E+01	2.7682E-01	5.8830E+01		
4	9.0676E+01	1.8936E+00	1.2597E+00	9.1310E+01	4.0244E-01	9.2167E+01	2.3148E-01	9.2338E+01
5	1.9084E+02	3.4322E+00	1.9242E+00	1.9235E+02	1.0490E+00	1.9322E+02	3.8224E-01	1.9389E+02
6	2.2522E+02	3.8349E+00	1.7011E+00	2.2735E+02	1.2070E+00	2.2785E+02	5.9596E-01	2.2846E+02
7	3.7180E+02	5.7474E+00	2.2432E+00	3.7530E+02	1.6295E+00	3.7591E+02	1.0829E+00	3.7646E+02
8	3.9002E+02	5.7256E+00	2.0181E+00	3.9373E+02	1.3905E+00	3.9436E+02	1.0621E+00	3.9469E+02
Group Size	a5	b5	a6	b6	a7	b7	a8	b8
2								
3								
4								
5	7.6743E-02	1.9420E+02						
6	2.2109E-01	2.2883E+02	1.0978E-01	2.2895E+02				
7	5.6537E-01	3.7698E+02	1.9159E-01	3.7735E+02	3.4801E-02	3.7751E+02		
8	7.0259E-01	3.9505E+02	3.4974E-01	3.9540E+02	1.0784E-01	3.9564E+02	9.4689E-02	3.9565E+02

V. Issues and Discussions

- Is the mapping method appropriate for CCF parameter estimations or prior determination? Are there any other alternative approaches to develop the prior distributions?
- Is the using of binomial regression treatment of complete CCF events in the current process appropriate? What should be the proper model to be used for curve fitting?
- Should different prior distributions be developed for different component groups?
- Will the testing scheme for various components impact priors?

Questions?

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