Proposed Methods for Using SACADA DATA for Empirical HRA Estimation

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NRC Workshop

BACKGROUND

- The U.S. Nuclear Regulatory Commission (NRC) is collecting the licensed operator performance information in simulator exercise of nuclear power plants (NPPs)
- Scenario Authoring, Characterization, and Debriefing Application (SACADA) system collects the routine operator simulator training to collect performance information
- A limited SACADA database is available for developing methods and showing the feasibility of using it for empirical HRA estimation

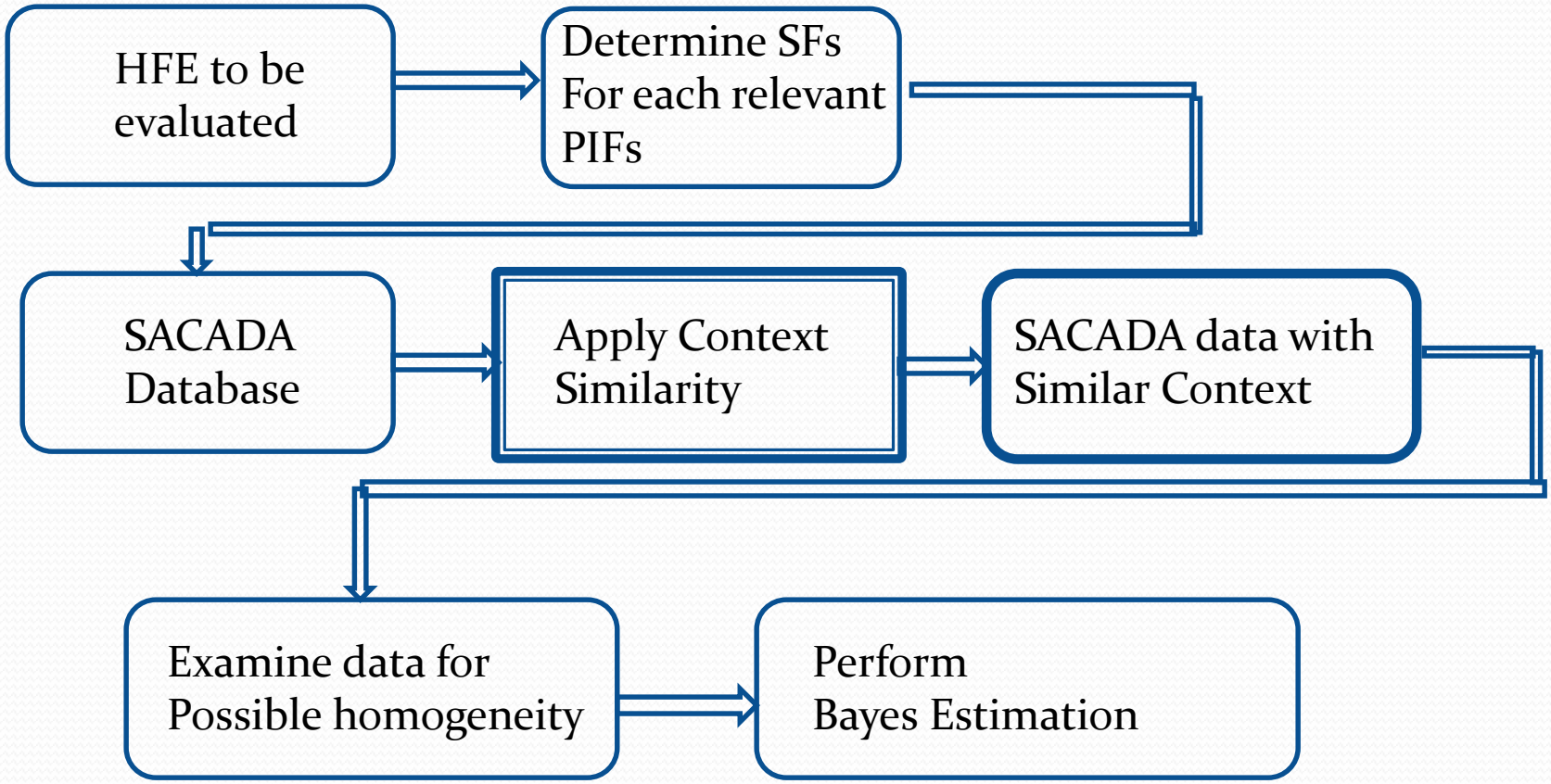
OBJECTIVE

- To develop methods and demonstrate their feasibility for:
  - Empirical HRA estimation
  - A better understanding of the elements affecting operator performance
  - Demonstrate Feasibility by performing pilot applications

SACADA Contains Categorical Data

- Performance Influencing Factors (PIF) are defined by a set of situational factors (SFs).
- The PIFs and SFs are categorical data and they can not be numerically aggregated (e.g. averaged, summed, integrated, etc.)
- Context similarity is defined by a set of SACADA data that have common categories (PIFs and SFs).
- SACADA data that are similar in context can be pooled together and the performance measure (SAT/UNSAT) can be used for HRA estimation

Process flow chart for use of SACADA database for HRA Estimation



Context Similarity -Issues(1)

- What if not all relevant SFs matches ?
- What are the minimum SFs that have to absolutely match (critical SFs)?
- How do we decide when sufficient number of SFs are matched before we consider the SACADA data set for estimating the HRA?
- How do we estimate the HRA and the associated uncertainties?
- What do the uncertainties include ?

Context Similarity-Process (2)

- 31 PIFs with a total of 134 SFs
- Complete context similarity is achieved when the SFs associated with all 31 PIFs matches [unlikely event]
- A Data Mainlining Software (SDMS) searches SACADA data base and identifies and ranks all data in SACADA data base with context similarity index of 31, 30, 29, etc.
- All SACADA entries that do not match critical SFs are screened out
- The remainder SACADA entries that match critical SFs, and partially match the other SFs (for example 28 out of 31) are statistically tested to determine if they are homogenous and can be pooled as evidential data for Bayes estimation

Context Similarity-Parameters (3)

PIF Name	Range of SFs	Variable names in SDMS program	SACAD A Row ID
1. Importance	Range from 0 to 4	V1 to V5	I
2. Cognitive Type	Range from 0 to 4	V6 to V10	J
3. Monitoring/Detection: Detection Type	Range from 0 to 7	V11 to V18	K
4. Alarms/Status Tile: Detection Mode	Range from 0 to 4	V19 to V23	L
5. Status of Alarm board	Range from 0 to 3	V24 to V27	M
6. Status of Alarm: Expectation	Range from 0 to 3	V28 to V30	N
7. Meter/Light/Flag: Detection Mode	Range from 0 to 4	V31 to V35	O
8. Meter/Light/Flag: Individual Indicator	Range from 0 to 2	V36 to V38	P
9. Meter/Light/Flag : Mimic/Display	Range from 0 to 3	V39 to V42	Q
10.Diagnosis: Response Planning	Range from 0 to 2	V43 tov45	R

29. Overarching Issues: Time criticality	Range from 0 to 3	V120 to V123	AK
30. Overarching Issues: Extent of Communications Required	Range from 0 to 3	V124 to V127	AL
31. Overarching Issues: Other Demands/Factors	Range from 0 to 6	V128 to V134	AM

context similarity-Example (4)

# Matches	# SACADA Data points	# SACADA UNSAT	HEP value: individual	HEP value: running average
31	14	0	0	Not Evaluated
30	15	0	0	Not Evaluated
29	129	1	7.8E-3	6.3E-3
28	106	0	0	3.8E-3
27	87	0	0	2.8E-3
26	60	0	0	2.4E-3
25	26	1	3.8E-2	4.6E-3
24	14	0	0	4.4E-3
23	0	0	NA	4.4E-3
22	0	0	NA	4.4E-3

Challenging Issues

- What is meant by “Approximately the same context”?
- What is the choice of prior for Bayes Estimation?
- What is meant by “Closely estimated HEP values”?

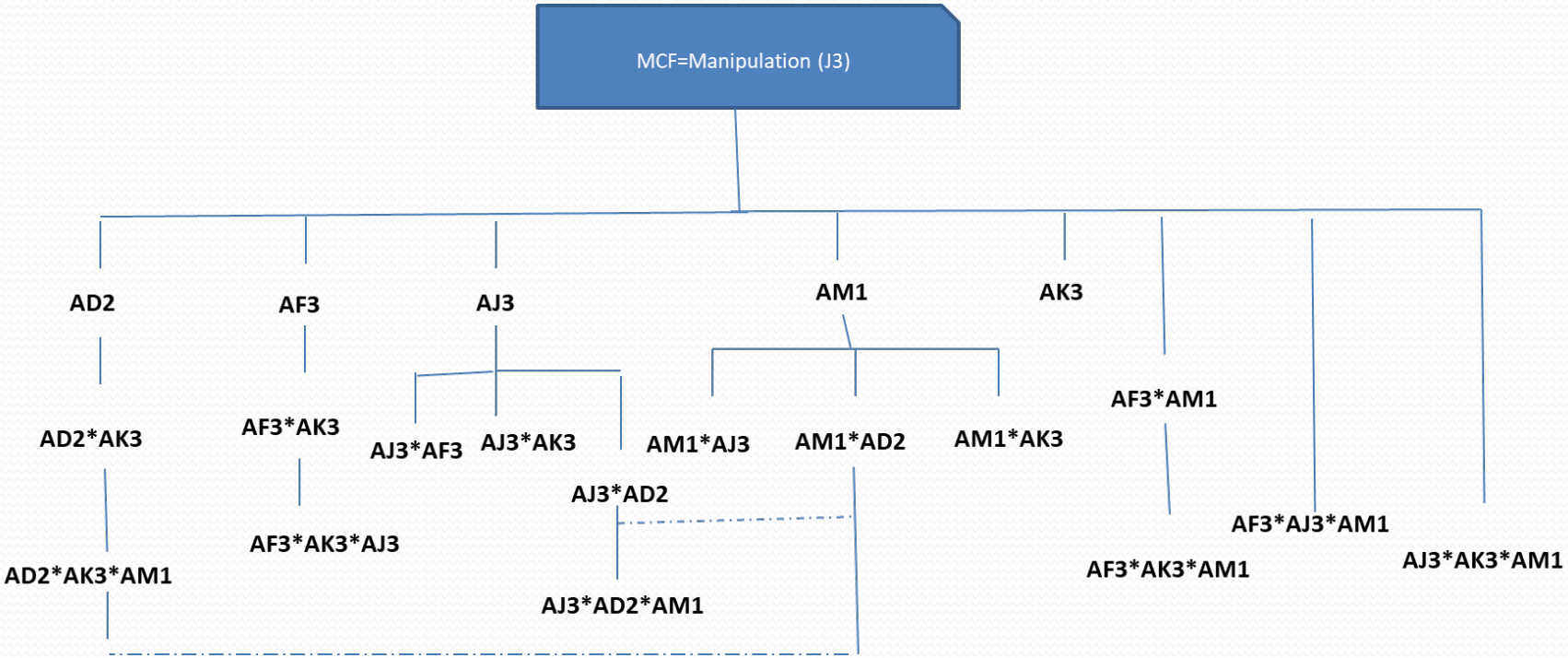
CRITICAL SFs

In SUPPORT OF
CONTEXT SIMILARITY APPROACH

Critical SFs –Basic Concept

- Not all Performance Influencing factors have the same effect on HEPs for a given MCF (Macro-Cognitive Function)
- Critical SFs are expected to have major effect on the estimated HEP values for a MCF
- Statistical Significance tests is used to identify critical SFs; Currently is limited to five (5)SFs
- The Combined SFs are also differentiated from each individual SFs using the statistical significance tests
- A **MCF tree** is used for presentation and to support Bayes estimation of HEP values if the analysis is limited to critical SFs only

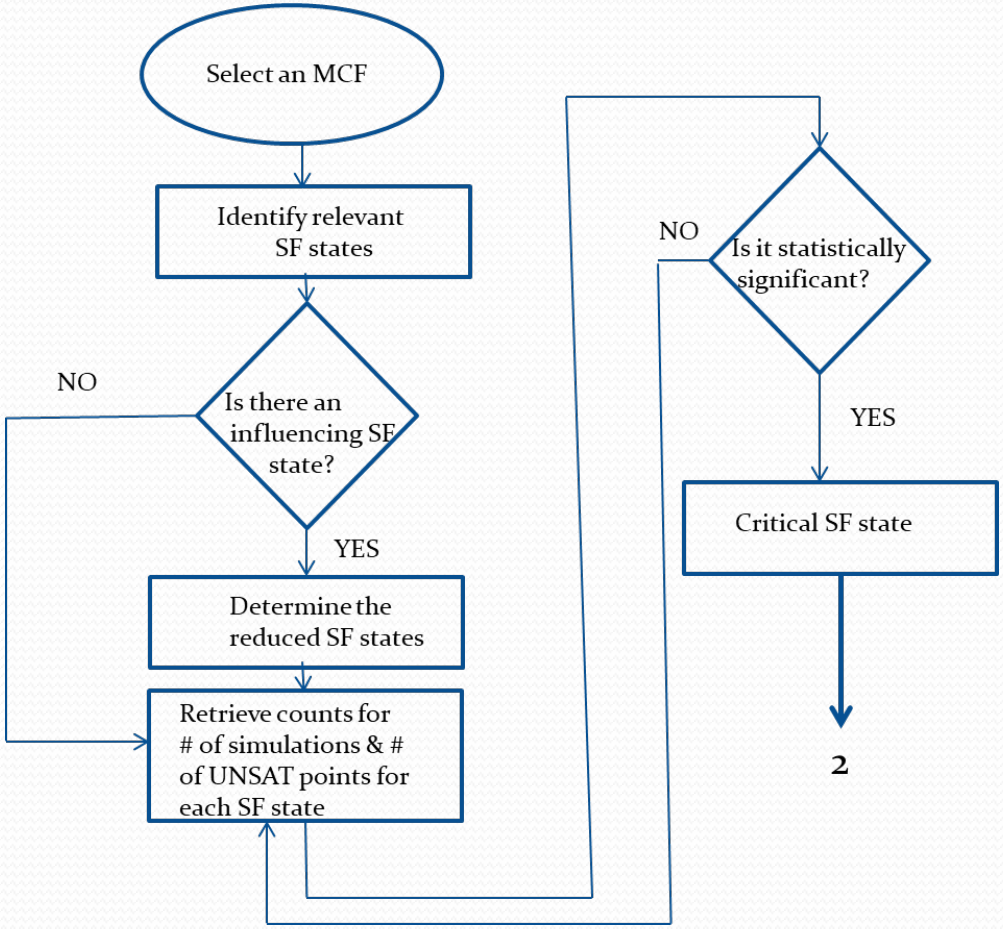
Example of MCF Tree for Manipulation



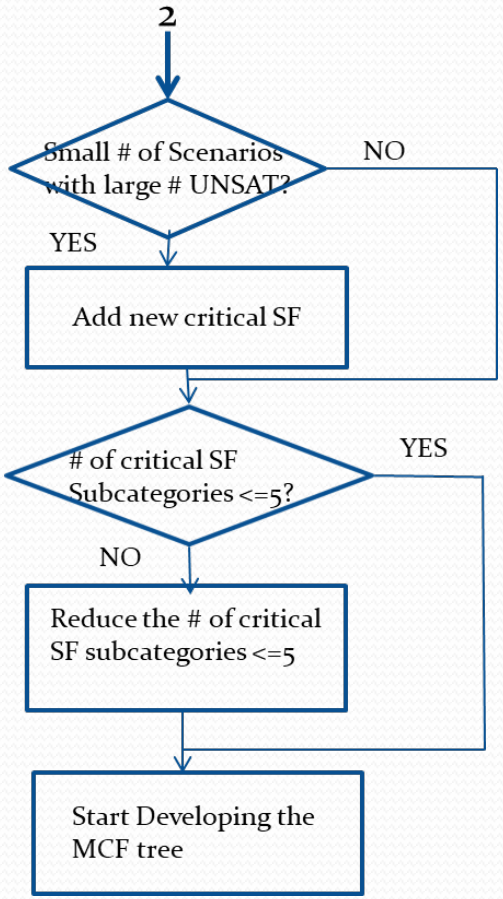
HEP Estimates and final grouping of the MCF tree for Manipulation

SF States combination	prior LN(mean, EF)-Beta (α,β)	Beta Posterior (α , β)	Posterior 5% Lower Bound	Posterior 95% Upper Bound	Posterior Mean	Point Estimate
AD2	LN(0.1, 10)	(4.05, 80.4)	1.7E-2	9.0E-2	4.8E-2	4.8E-2
AF3	LN(0.1, 10)	(16, 656.4)	1.5E-2	3.5E-2	2.4E-2	2.4E-2
AJ3	LN(0.1, 10)	(20, 758.4)	1.7E-2	3.6E-2	2.6E-2	2.6E-2
AM1	LN(0.1, 10)	(13 , 261.4)	2.9E-2	7.2E-2	4.7E-2	4.7E-2
AK3	LN(0.1, 10)	(8.05, 443.4)	9.0E-3	2.9E-2	1.8E-2	1.8E-2
AD2*AK3	B(4.05, 80.4)	(4.05, 95.4)	1.4E-2	7.8E-2	4.1E-2	0
AF3*AK3	B(16, 656.4)	(23, 81.5)	1.91E-2	3.7E-2	2.74E-2	4.2E-2
AJ3*AF3	B(20, 758.4)	(27, 961)	1.9E-2	3.6E-2	2.73E-2	3.3E-2
AJ3*AK3	B(20, 758.4)	(23,96.9)	1.6E-2	3.2E-2	2.32E-2	2.2E-2
AJ3*AD2	B(20, 758.4)	(20, 773)	1.7E-2	3.5E-2	2.52E2	0
AM1*AJ3	B(13 , 261.4)	(18, 332)	3.4E-2	7.2E-2	5.1E-2	6.6E-2
AM1*AD2	B(13 , 261.4)	(13, 276)	2.7E-2	6.7E-2	4.5E-2	0
AM1*AK3	B(13 , 261.4)	(20,574)	2.2E-2	4.7E-2	3.4E-2	7.1E-2
AF3*AM1	LN(0.1, 10)	(13.05,83.4)	1.3E-1	2.0E-1	1.4E-1	1.4E-1
AD2*AK3*AM1	B(4.05, 95.4)	(4.05,95.4)	1.3E-2	6.9E-2	3.5E-2	NA
	B(13, 276)	(13, 291)	2.6E-2	6.5E-2	4.3E-2	NA
	Selected parents: AM1*AD2		**2.6E-2**	**6.5E-2**	**4.3E-2**	**0**
AF3*AM1*AK3	B (13.05,83.4)	(19.05, 125)	8.9E-2	1.8E-1	1.3E-01	1.3E-01
AF3*AK3*AJ3	B (23, 81.5)	(29,183)	1.0E-1	1.8E-1	1.4E-1	5.6E-2
AJ3*AD2*AM1	B (20, 773)	(20, 778)	1.66E-2	3.47E-2	2.52E-2	NA
	B (13, 276)	(13, 291)	2.6E-2	6.4E-2	4.5E-2	NA
	Selected Parents: AM1*AD2		**2.6E-2**	**6.4E-2**	**4.5E-2**	**0**
AJ3*AK3*AM1	LN(0.1, 10)	(5.05,11.4)	0.138	5.1E-1	3.1E-1	3.1E-1
AF3*AJ3*AM1	LN(0.1, 10)	(5.05, 11.4)	0.138	5.1E-1	3.1E-1	3.1E-1
AJ3*AK3*AM1	LN(0.1, 10)	(5.05, 11.4)	0.138	5.1E-1	3.1E-1	3.1E-1
AD2*AK3*AM1*AJ3	B(13, 291)	(13, 291)	2.6E-2	6.4E-2	4.5E-2	0
	Selected parents: AM1*AD2*AJ3, No New data-child and parent have the same Data					
AF3*AM1*AK3*AJ3	B (5.05, 11.4)	(5.05, 11.4)	1.4E-1	5.1E-1	3.1E-1	3.1E-1
	Selected parents: AF3*AK3*AM1, No new Data					

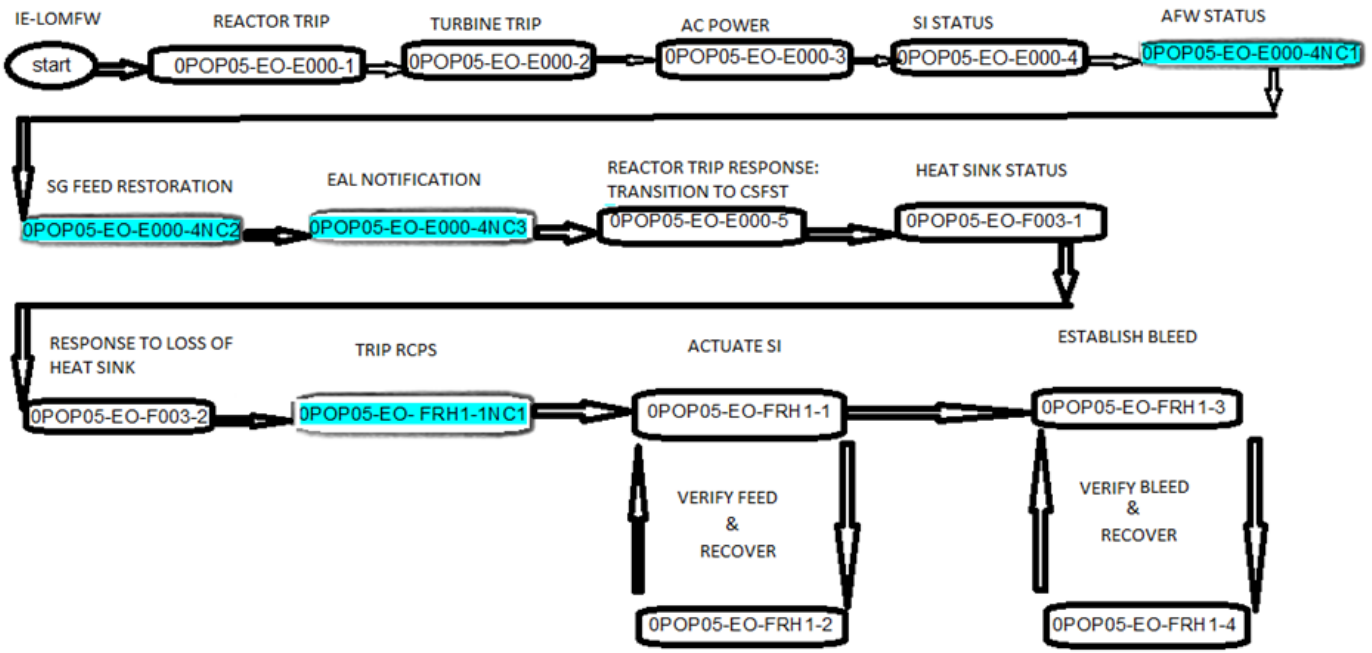
Critical SFs for a Micro-Cognitive Function (MCF)- Flow Chart (1)



Critical SFs for a Micro-Cognitive Function (MCF)- Flow Chart (2)



Pilot Application-Feed and Bleed empirical HEP estimation (FB); in response to loss of secondary cooling (CRD)



Pilot Application-Feed and Bleed empirical HEP estimation (FB); in response to loss of secondary cooling

Subtask–ID	Summary description
0POP05-EO-E000-1	Monitoring Indications to determine Reactor Trip
0POP05-EO-E000-2	Monitoring Indications to determine Turbine Trip
0POP05-EO-E000-3	Monitoring Indications to determine AC Power Available
0POP05-EO-E000-4	Monitoring Indications to determine SI Status
0POP05-EO-E000-4NC1	Detect AFW discharge Low pressure alarm and invoke 0POP09-AN-06M3
0POP05-EO-E000-4NC2	Primary and alternate actions to establish or control AFW Flow. There are also manipulations required to respond to the reactor and turbine trip. Operator would be busy at this time performing many checks and manipulations.
0POP05-EO-E000-4NC3	External Communications and NRC notifications based on Emergency Classification.
0POP05-EO-E000-5	Monitoring Indications to determine whether SI is Required and to Initiate 0POP05-EO-F003 Heat Sink Critical Safety Function Status Tree (while Transitioning to 0POP05-EO-ES01 Reactor Trip Response)
0POP05-EO-F003-1	Determining the status of Heat Sink Critical Safety Function Status Tree
0POP05-EO-F003-2	Diagnosis and transition to 0POP05-EO-FRH1 Response to Loss of Secondary Heat Sink
0POP05-EO- FRH1-1NC1	Trip RCPs
0POP05-EO-FRH1-1	Actuate SI
0POP05-EO-FRH1-2	Verify feed path [If feed path is not properly aligned, it could initiate the recovery action for SI actuation]
0POP05-EO-FRH1-3	Establish bleed Path; Open PORVs and make sure the Block valves are open
0POP05-EO-FRH1-4	Verifying Adequate Bleed Path consisting of 2 Open PORVs and 2 Open [If bleed path is not properly aligned, it could initiate the recovery action for establishing the bleed path, e.g., opening PORV Isolation Valves (Step 13)]

0POP05-EO-FRH1-3 Loss of Secondary Heat Sink

Relevant SFs	SF Subcategories	Applicable SF/Notes
TOE – Manipulation Description: step-12; establish bleed Path Col. I: Importance	0: NULL	
	1: Other	
	2: Significant	X
	3: Safety Sig	
	4: Critical	
Column J: MCF: Macro-Cognitive Function	0:NULL	
	1:Monitoring/Detection	
	2:Diagnosis & Response Planning	
	3:Manipulation	X: Manipulation; step-12: establish bleed Path
	4:External Communication	
Column AC: Manipulation Type of Action	0: NULL	
	1: Simple and distinct	X
	2: Order	
	3: Maintaining	
Column AK: Overarching Issues: Time criticality	0: NULL	
	1: Expansive Time Available	X
	2: Nominal Time Available	
	3: Barely Adequate Time Available	
Column AL: Overarching Issues: Extent of communication	0: NULL	
	1: Nominal Communication	X
	2: Extensive Onsite Communication	
	3: Extensive Communication within the Control Room	
Column AM: Overarching Issues: Others	0: NULL	X
	1: Non-Standard	
	2: Noisy Background	
	3: Coordination	
	4: Communicator Unavailable	
	5: Multiple Demands	
	6: Memory Demands	

Empirical HEP Point Estimate of FB actions

Actions	Applicable # of data points, # UNSAT	Number of Matches: # of data points, # of UNSATs							HEP point estimate (running average – All AFs)	Mean HEP estimate (Critical SFs)
		31	30	29	28	27	26	25	Relaxed Applicability by 3 SFs	phase-1 Analysis
0POP05-EO-E000-1	1018,3	0,0	0,0	14,0	147,1	282,1	323, 1	252,0	2.9E-3	2.5E-3
0POP05-EO-E000-2	1018,3	0,0	0,0	28,1	201,1	461,1	297,0	31,0	2.9E-3	2.5E-3
0POP05-EO-E000-3	23,0	0,0	0,0	0,0	14,0	9,0	0,0	0,0	2.4E-3	2.5E-3
0POP05-EO-E000-4	23,0	0,0	0,0	0,0	0,0	23,0	0,0	0,0	3.2E-3	3.4E-3
0POP05-EO-ES01/F003-1	430,0	0,0	0,0	0,0	29,0	129,0	252,2	20,0	1.4E-3	3.0E-3
0POP05-EO-FRH1-2	196,0	0,0	0,0	41,0	26,0	79,0	36,0	14,0	2.0E-3	3.0E-3
0POP05-EO-FRH1-4	196,0	0,0	0,0	41,0	26,0	79, 1	36,0	14,0	2.0E-3	3.0E-3
0POP05-EO-FRH1-1	1970,14	43,2	147,1	586,2	436, 3	492,6	170,0	96,0	7.1E-3*	3.0E-3
0POP05-EO-FRH1-3	1772,14	38,0	248,4	241,2	516,3	289,2	314,3	99,0	8.0E-3*	3.0E-3
0POP05-EO-E000-5	2760,14	0,0	0,0	0,0	355,0	1104,4	892,5	235,5	5.4E-3*	3.0E-3
0POP05-EO-F003-2	2760,14	0,0	0,0	0,0	0,0	14,0	1222,4	976,3	3.2E-3	3.0E-3
HEP for overall Feed and Bleed Action									~3.9E-2	~3.0E-2

CURRENT STATUS (1)

- CONTEXT SIMILARITY
  - Current status
    - Initial methods developed
    - Software for in-house use is developed (SDMS/worksheets)
    - Bayes estimation and different options for resolving issues related to context similarity are being examined
    - Performed one comprehensive pilot application
  - Work remaining as a part of this project
    - Finalize the methods for pooling evidence data and resolving the remaining issues for Context Similarity Approach
    - Complete formal Bayes Estimation Method for Context Similarity Approach

CURRENT STATUS (2)

- CRITICAL SFs
  - Current status
    - Initial methods developed
    - Statistical testing methods and initial estimation methods completed
    - Critical SFs were identified for three out of five MCFs.
    - Application of methodologies were mainly done manually (no integrated software were developed)

Path Forward

- Within the Scope of current Project
  - Complete documentation and provide NRC a formal report
- Future Path
  - Application and further automation of the methods to be applied to a larger SACADA data base
  - Expand and complete the work of critical SFs for all MCFs with a larger SACADA database
  - Expand SDMS software to account for the updated critical SFs
  - Perform several more pilot application including application to a full scope PRA

CONCLUSION

- Approaches, methods, and tools to support empirical estimation of human error probabilities using SACADA database were developed
- Feasibility and reasonableness of Methods were demonstrated via a comprehensive pilot application
- The results are encouraging and the methods are promising
- Path forward to enhance the methods including their application to a full scope PRA was delineated

BACKUP SLIDES

Statistical Test of Significance

- Small Data
  - Binomial Bounds assuming base case estimated P value
    - Upper bound from Inv-Bin(95%, P, N)<k
    - Lower bound from Inv-Bin (5%,P,N)>k
- Large data

$$z = \frac{\widehat{p1} - \widehat{p2}}{(\hat{p}(1-\hat{p})\left(\frac{1}{n1} + \frac{1}{n2}\right))\text{^}0.5} \quad where\ n1\ and\ n2\ are\ \#\ of\ data\ points\ and\ \widehat{p1} and\ \widehat{p2}\ \ are\ the\ HEP\ values\ \ and\ \hat{p}\ is defined\ by$$

$$\hat{p} = \frac{n1 * \widehat{p1} + n2 * \widehat{p2}}{n1 + n2} \qquad Eq - 1$$

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HEP Estimation (1)

- Change prior lognormal (from SPAR-H or THERP) to Beta parameters

$$\beta = 1/\{ML * [(\exp(\ln(EF/1.645)\text{^}2) - 1]\}$$
$$= \alpha * (1 - ML)/ML$$

$$\alpha = (1 - ML)/[(\exp(\ln(EF/1.645)\text{^}2) - 1]$$

HEP Estimation 2

- Conjugate Bayes

$$\alpha^* = \alpha + Nf \qquad and$$
$$\beta^* = N - Nf + \beta$$
$$Where\ Nf\ is\ the\ number\ of\ UNSAT\ and\ N\ is\ the\ number\ of\ datapoints$$

Approximately the Same Context

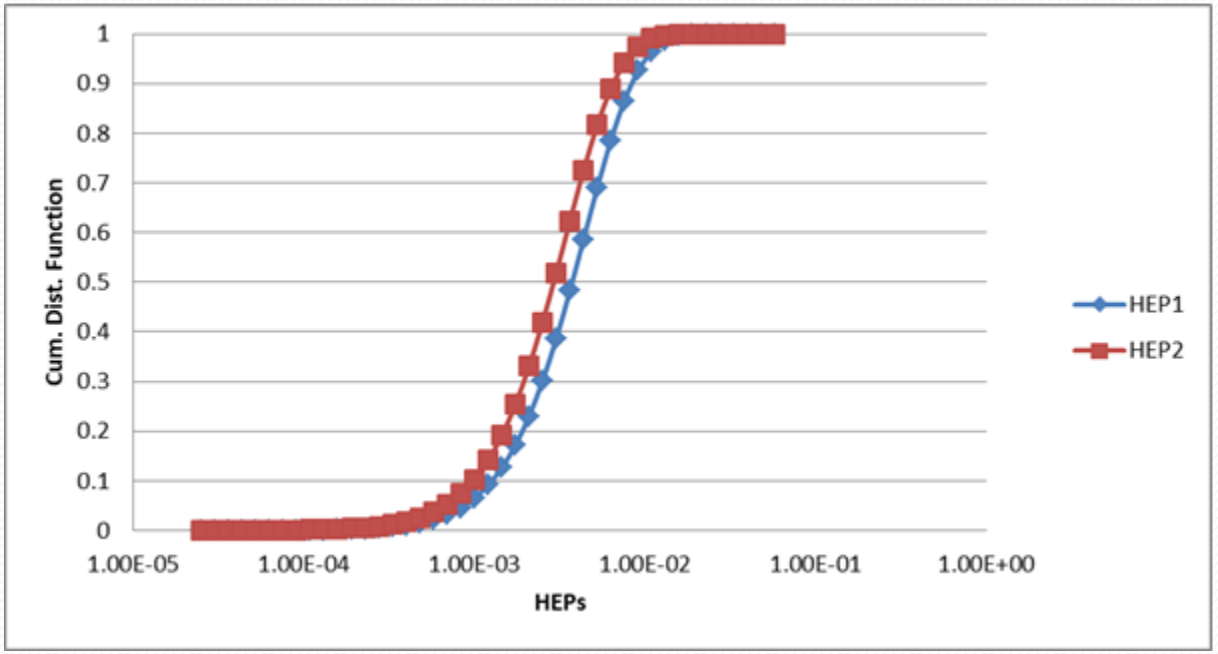
- Matching Critical SFs

- Performance of lower level matches (selected)do not significantly deviate from those of higher level matches
  - Statistical Significance test
    - At what significance level?

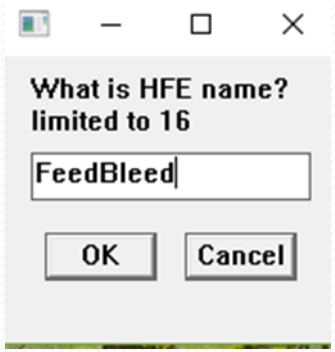
Closely Estimated HEP Values

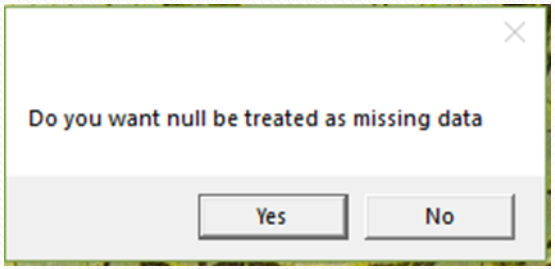
- Two HEP distributions
  - One estimated based on performance data from higher level matches (HEP1)
  - The other estimated based on performance data from higher plus (+) the lower level data (HEP2)
- Large overlap between HEP1 and HEP2
  - A sample taken from ninety percentile interval of HEP1 has 90% probability to be within the 90 percentile interval of HEP2

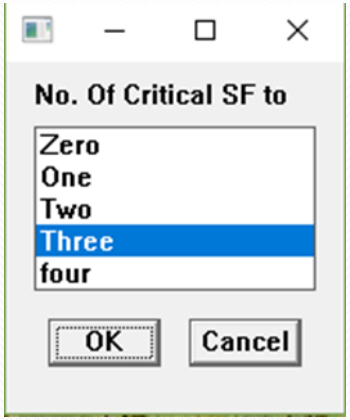
Example of Closely Estimated HEP values



Example of Interactive Input







Example Output

```
NDATA=       2012
 NDATA2=         11

HRA#=       1   HRA Name=0POP05-EO-E000-1
--------TOTAL NUMBER OF APPLICABLE DATA------
No. UNSAT, No. Datapoints, Avg. HEP
    6.0    1279.00    0.00469
                          CUMUL.      CUMUL.      Running
 No. OF   DATA    NO. OF     HEP       NO.OF       DATA        AVG
MATCHES   POINTS  UNSAT   VALUE      UNSAT      POINTS       HEP

   31.0     0.0     0.0   -1.0000     0.0000     0.0000   -1.0000
   30.0     0.0     0.0   -1.0000     0.0000     0.0000   -1.0000
   29.0    14.0     0.0    0.0000     0.0000    14.0000    0.0000
   28.0   161.0     1.0    0.0062     1.0000   175.0000    0.0057
   27.0   330.0     1.0    0.0030     2.0000   505.0000    0.0040
   26.0   430.0     1.0    0.0023     3.0000   935.0000    0.0032
   25.0   341.0     3.0    0.0088     6.0000  1276.0000    0.0047
   24.0     3.0     0.0    0.0000     6.0000  1279.0000    0.0047
   23.0     0.0     0.0   -1.0000     6.0000  1279.0000    0.0047
   22.0     0.0     0.0   -1.0000     6.0000  1279.0000    0.0047
   21.0     0.0     0.0   -1.0000     6.0000  1279.0000    0.0047
   20.0     0.0     0.0   -1.0000     6.0000  1279.0000    0.0047
   19.0     0.0     0.0   -1.0000     6.0000  1279.0000    0.0047
   18.0     0.0     0.0   -1.0000     6.0000  1279.0000    0.0047
   17.0     0.0     0.0   -1.0000     6.0000  1279.0000    0.0047
   16.0     0.0     0.0   -1.0000     6.0000  1279.0000    0.0047
   15.0     0.0     0.0   -1.0000     6.0000  1279.0000    0.0047
   14.0     0.0     0.0   -1.0000     6.0000  1279.0000    0.0047
   13.0     0.0     0.0   -1.0000     6.0000  1279.0000    0.0047
   12.0     0.0     0.0   -1.0000     6.0000  1279.0000    0.0047
   11.0     0.0     0.0   -1.0000     6.0000  1279.0000    0.0047
   10.0     0.0     0.0   -1.0000     6.0000  1279.0000    0.0047
    9.0     0.0     0.0   -1.0000     6.0000  1279.0000    0.0047
    8.0     0.0     0.0   -1.0000     6.0000  1279.0000    0.0047
    7.0     0.0     0.0   -1.0000     6.0000  1279.0000    0.0047
    6.0     0.0     0.0   -1.0000     6.0000  1279.0000    0.0047
    5.0     0.0     0.0   -1.0000     6.0000  1279.0000    0.0047
    4.0     0.0     0.0   -1.0000     6.0000  1279.0000    0.0047
    3.0     0.0     0.0   -1.0000     6.0000  1279.0000    0.0047
    2.0     0.0     0.0   -1.0000     6.0000  1279.0000    0.0047

HRA#=       2   HRA Name=0POP05-EO-E000-2
```