ANALYSES METHODS AND PILOT APPLICATIONS OF SACADA DATABASE

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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 was used in this study for developing methods and showing the feasibility of using it for empirical HRA estimation
OBJECTIVES

- 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

- For each procedural steps or Training Objective Element
  - Identifies a set of macro cognitive functions (MCF)
  - Defines situational factors (SFs) for a set of Performance Influencing Factors (PIF) relevant to the MCF
- Each operator action is simulated repeatedly under different conditions (scenarios) such that result in slightly different SFs.
- Operator Performance is recorded in four categories (SAT+, SAT, SATΔ, and UNSAT)
- Data Statistics therefore is generated for Human performance resulting from performing an MCF with its associated SFs.
Basic Concept for Categorical Data

[Context Similarity]

- Each set of SF defines a categorical data set
- Same sets of categorical data associated with a specific are expected to show similar human performance
- Context similarity is therefore defined by a set of SACADA data for a specific MCF and with the similar (same) set of SFs
- SACADA data that are similar in context can be pooled together for the purpose of HRA estimation by focusing on the UNSAT performance measure
Context Similarity-Process

- 31 PIFs with a total of 134 SFs
- Complete context similarity is achieved when the SFs associated with all 31 PIFs matches [needs very large database]
- When complete context similarity is not achieved, valid partial matches are to be considered
- Partial matches requires an understanding of
  - What are the drivers for human performance for each MCF [Critical SFs]
  - How good is the estimate from the partial matches
- This requires
  - Methods to define critical SFs for each MCF
  - Methods to address the goodness of our estimate
Process flow chart for use of SACADA database for HRA Estimation

1. HFE to be evaluated
2. Determine SFs for each relevant PIFs
3. Search SACADA Database (SDMS)
4. Apply Context Similarity (CS)
5. Tabulate performance data for different CS index
6. Verify the best CS index best
7. Perform Bayes Estimation
Context Similarity - Issues

- How do we determine critical SFs?
- How do we perform HRA estimates based on different combination of critical SFs?
  - How do we define prior for different combinations of critical SFs?
    - What is the concept of MCF tree?
- When is a partial matches considered good enough?
  - What is the best CS index to use.
    - What is meant by “Approximately the same context”
      - What is meant by “Closely estimated HEP values”
Critical SFs/MCF tree/Bayes prior

Basic Concept

- Five Macro-Cognitive Function: (1) Monitoring/Detection, (2) Diagnosis, (3) Response Planning, (4) Manipulation, and (5) External communication
- Statistical Significance tests are applied to the SACADA data for each MCF to identify critical SFs [currently limited to five (5) SFs for each MCF]
- MCF plus the critical SF are expected to drive HRA estimates
  - For example: Detection using indicators when there is strong deviation from normal
- Each MCF with different combination of critical SFs are examined using the statistical significance tests to see if they are different from other combinations
- All combinations that can not be differentiated with each other are presented by the same prior distribution for Bayes updates
- A **MCF tree** is used for compact presentation of the group combinations and to support Bayes estimation of HEP values
MCF Tree for grouping prior distributions for Bayes updates

- Each MCF with different combination of critical SFs are examined using the statistical significance tests to see if they are different from other combinations
- All combinations that can not be differentiated from each other are presented by the same prior distribution for Bayes updates
- A **MCF tree** is used for compact presentation of the group combinations and to support Bayes estimation of HEP values
Example of MCF Tree for Manipulation
HEP Estimates and final grouping of the MCF tree for Manipulation

<table>
<thead>
<tr>
<th>SF States combination</th>
<th>Observation</th>
<th>Prior LN(mean, EF)-Beta (α,β)</th>
<th>Beta Posterior (α, β)</th>
<th>Posterior 5% Lower Bound</th>
<th>Posterior 95% Upper Bound</th>
<th>Posterior Mean</th>
<th>Point Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>AD2</td>
<td>(84, 4)</td>
<td>LN(0.1, 10)</td>
<td>(5.1,91.7)</td>
<td>2.2E-2</td>
<td>4.5E-3</td>
<td>1.0E-1</td>
<td>5.5E-2</td>
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<tr>
<td>AD2*AK3</td>
<td>(15,0)+</td>
<td></td>
<td>(1.3, 26.8)</td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>AD2*AJ3</td>
<td>(15,0)</td>
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<td>(1.3, 26.8)</td>
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<tr>
<td>AD2<em>AK3</em>AM1</td>
<td>(15,0)</td>
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<td>(1.3, 26.8)</td>
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<tr>
<td>AD2<em>AK3</em>AM1*AJ3</td>
<td>(15,0)</td>
<td></td>
<td>(1.3, 26.8)</td>
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</tr>
<tr>
<td>AD2<em>AK3</em> AM1* AJ3</td>
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<tr>
<td>AF3</td>
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<td>2.4E-2</td>
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<td>2.0E-2</td>
<td>1.8E-2</td>
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<td>AJ3</td>
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<td>(21.3, 769.8)</td>
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<td>3.7E-2</td>
<td>2.7E-2</td>
<td>2.6E-2</td>
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<td>(210,7)</td>
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<td>AK3*AK3</td>
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<tr>
<td>AM1</td>
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<td>7.3E-2</td>
<td>5.0E-2</td>
<td>4.7E-2</td>
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<td>AM1*AJ3</td>
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<td>AM1*AD2</td>
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<td>AM1*AK3</td>
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<td>1.3E-1</td>
<td>1.4E-1</td>
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<tr>
<td>AF3<em>AM1</em>AK3</td>
<td>(48, 6)</td>
<td>(7.3, 53.8)</td>
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<td>AF3*AK3</td>
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<td>4.2E-2</td>
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<tr>
<td>AF3<em>AK3</em>AJ3</td>
<td>(107, 6)</td>
<td>(7.3, 112.8)</td>
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<tr>
<td>AF3<em>AJ3</em>AM1</td>
<td>(16,5)</td>
<td>LN(0.1, 10)</td>
<td>(6.3, 22.8)</td>
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<td>3.6E-1</td>
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<td>0.312</td>
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<tr>
<td>AF3<em>AJ3</em>AM1*AK3</td>
<td>(16,5)</td>
<td>(6.3, 22.8)</td>
<td>6.5E-2</td>
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<tr>
<td>Other Combinations</td>
<td>(1970, 14)</td>
<td>LN(0.03, 10)</td>
<td>(15.2, 1995)</td>
<td>4.8E-3</td>
<td>1.1E-2</td>
<td>7.6E-3</td>
<td>7.1E-3</td>
</tr>
</tbody>
</table>

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Empirical HEP Point Estimate of FB actions

<table>
<thead>
<tr>
<th>Actions</th>
<th>Applicable # of data points, # UNSAT</th>
<th>Number of Matches: # of data points, # of UNSATS</th>
<th>HEP point estimate</th>
<th>Mean HEP estimate</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>31 30 29 28 27 26 25</td>
<td></td>
<td></td>
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<tr>
<td>oPOP05-EO-E000-1</td>
<td>1018.3</td>
<td>0.0 0.0 14.0 147.1 282.1 323.1 252.0</td>
<td>2.9E-3</td>
<td>2.5E-3</td>
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<td>oPOP05-EO-E000-2</td>
<td>1018.3</td>
<td>0.0 0.0 28.1 201.1 461.1 297.0 31.0</td>
<td>2.9E-3</td>
<td>2.5E-3</td>
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<tr>
<td>oPOP05-EO-E000-3</td>
<td>23.0</td>
<td>0.0 0.0 0.0 14.0 9.0 0.0 0.0</td>
<td>2.4E-3</td>
<td>2.5E-3</td>
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<tr>
<td>oPOP05-EO-E000-4</td>
<td>23.0</td>
<td>0.0 0.0 0.0 0.0 23.0 0.0 0.0</td>
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<tr>
<td>oPOP05-EO-ES01/F003-1</td>
<td>430.0</td>
<td>0.0 0.0 0.0 29.0 129.0 252.2 20.0</td>
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<td>3.0E-3</td>
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<tr>
<td>oPOP05-EO-FRH1-2</td>
<td>196.0</td>
<td>0.0 0.0 41.0 26.0 79.0 36.0 14.0</td>
<td>2.0E-3</td>
<td>3.0E-3</td>
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<tr>
<td>oPOP05-EO-FRH1-4</td>
<td>196.0</td>
<td>0.0 0.0 41.0 26.0 79.1 36.0 14.0</td>
<td>2.0E-3</td>
<td>3.0E-3</td>
</tr>
<tr>
<td>oPOP05-EO-FRH1-1</td>
<td>1970.14</td>
<td>43.2 147.1 586.2 436.3 492.6 170.0 96.0</td>
<td>7.1E-3</td>
<td>3.0E-3</td>
</tr>
<tr>
<td>oPOP05-EO-FRH1-3</td>
<td>1772.14</td>
<td>38.0 248.4 241.2 516.3 289.2 314.3 99.0</td>
<td>8.0E-3</td>
<td>3.0E-3</td>
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<tr>
<td>oPOP05-EO-E000-5</td>
<td>2760.14</td>
<td>0.0 0.0 0.0 355.0 1104.4 892.5 235.5</td>
<td>5.4E-3</td>
<td>3.0E-3</td>
</tr>
<tr>
<td>oPOP05-EO-F003-2</td>
<td>2760.14</td>
<td>0.0 0.0 0.0 0.0 14.0 1222.4 976.3</td>
<td>3.2E-3</td>
<td>3.0E-3</td>
</tr>
<tr>
<td>HEP for overall Feed and Bleed Action</td>
<td></td>
<td></td>
<td>~3.9E-2</td>
<td>~3.0E-2</td>
</tr>
</tbody>
</table>

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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
Path Forward

- Application and further automation of the methods to be applied to a larger SACADA data base
- Expand SACADA data base by populating more data and improve consistency
- Perform additional pilot application including full integration into an existing full scope PRA
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

\[
z = \frac{\hat{p}_1 - \hat{p}_2}{(\hat{p}(1 - \hat{p})\left(\frac{1}{n_1} + \frac{1}{n_2}\right))^0.5}
\]

where \(n1\) and \(n2\) are

# of data points and \(\hat{p}_1\) and \(\hat{p}_2\) are the HEP values and

\[
\hat{p} \text{ is defined by}
\]

\[
\hat{p} = \frac{n1 * \hat{p}_1 + n2 * \hat{p}_2}{n1 + n2}
\]

Eq – 1
HEP Estimation-Prior

- Change prior from lognormal to Beta parameters

\[ \beta = \frac{1}{\{ ML \ast \left[ \exp \left( \ln \left( \frac{EF}{1.645}\right)^2 \right) - 1 \} \}} \]
\[ = \alpha \ast \frac{1 - ML}{ML} \]

\[ \alpha = \frac{1 - ML}{\left[ \exp \left( \ln \left( \frac{EF}{1.645}\right)^2 \right) - 1 \} \] \]
HEP Estimation-Posterior using Beta distribution

- Conjugate Bayes

\[
\alpha^* = \alpha + Nf \quad \text{and} \quad \beta^* = N - Nf + \beta
\]

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

- What is HFE name? limited to 16
  - FeedBleed
  - OK
  - Cancel

- Do you want null be treated as missing data
  - Yes
  - No

- No. Of Critical SF to
  - Zero
  - One
  - Two
  - Three
  - OK
  - Cancel
Example Output

NDATA = 2
NDATA2 =

HRA# = 1
--------- TOTAL