Measuring Risk Importance in a Dynamic PRA Framework

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Work Summary

• Risk Importance Measures (RIMs) in PRA
  – Fusel-Vessely, Risk Achievement Worth
  – Applied to Minimal Cut Sets

• Extension of classical RIMs for Dynamic PRA data
  – Large number of simulated accident scenarios

• Application to PWR LB-LOCA
  – Classical vs. Dynamic PRA
Classical RIMs from ET/FT Data

- All classical RIMs are calculated by determining:
  - $R_0$: nominal Core Damage Probability (CDP)
  - $R_i^-$: CDP for basic event $i$ assumed to be perfectly reliable
  - $R_i^+$: CDP for basic event $i$ assumed failed

- RIMs:
  - Risk Achievement Worth (RAW): $RAW_i = \frac{R_i^+}{R_0}$
  - Risk Reduction Worth (RRW): $RRW_i = \frac{R_0}{R_i^-}$
  - Birnbaum (B): $B_i = R_i^+ - R_i^-$
  - Fusel-Vessely (FV): $FV_i = \frac{R_0 - R_i^-}{R_0}$
Classic RIMs from Simulation-Based Data

• Dynamic PRA:
  – Large number of simulated accident scenarios
  – Timing/sequencing of events is dictated by:
    • System control logic
    • Sampled parameters
  – Sampled parameters are analogous of Basic Events

• Possible approaches:
  1. Perform an analysis for $R_o$ and for each basic event $i$ determine $R_i^-$ and $R_i^+$
     • For $N$ basic events, $2N + 1$ analyses are required
     • Tremendously computationally expensive
  2. Determine $R_i^-$ and $R_i^+$ from the simulations generated to calculate $R_o$
Classic RIMs from Simulation-Based Data

- How can $R_0$, $R_i^+$, $R_i^-$ be determined from simulation-based data sets?
- Define for each basic event $i$ (sampled parameter):
  - $I_i^-$ region where basic event $i$ is assumed to be perfectly reliable
  - $I_i^+$ region where basic event $i$ is assumed failed

\[
\text{Basic event perfectly reliable} \quad \text{pdf}_i \quad \text{Basic event assumed failed} \quad \text{Basic event assumed failed} \quad \text{Basic event perfectly reliable}
\]

\[
\begin{align*}
I_i^- & \quad \text{e.g., Grid recovery time} \\
I_i^+ & \quad \text{e.g., EDG failure time}
\end{align*}
\]
Classic RIMs from Simulation-Based Data

- Determine $R_0$, $R_i^+$, $R_i^-$ for each basic event $i$ (Monte-Carlo case):

  $R_0 = \frac{N_{CD}}{N}$

  $R_i^+ = \frac{N_{CD, x_i \in I_i^+}}{N_{x_i \in I_i^+}}$

  $R_i^- = \frac{N_{CD, x_i \in I_i^-}}{N_{x_i \in I_i^-}}$

- Note: special attention needs to be given to the sampling strategy.
Classic RIMs from Simulation-Based Data

- **Testing:**
  - Several *analytical tests* have been developed for different configurations
    - Parallel/series
    - Stand-by
    - K out of N
  - Initial comparison with SAPHIRE on more advanced cases has been started
  - Perfect agreement within statistical error
Application

• Test case:
  – 3-loop PWR system
  – Large break LOCA (LB-LOCA)

• Systems considered:
  – Accumulators (ACCs)
  – Low Pressure Injection System (LPI)
  – Low Pressure Recirculation (LPR)

• Scope of the analysis:
  – Validation step
  – Measure differences between Classical and Dynamic PRA analyses
Application

Set of basic events and associated probabilities

RAVEN coupled with RELAP5-3D

Comparison Metrics:
- CD probability
- Risk Importance of SSCs
- Event sequence probability

Associate each simulated scenario to a specific ET branch

SAPHIRE
Results

• CD probability:
  – Dynamic PRA (RAVEN-RELAP5): 8.24 E-3
  – Classical PRA (SAPHIRE): 8.13 E-3

• Event sequence probabilities:

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<tr>
<th>IE</th>
<th>ACC</th>
<th>LPI</th>
<th>LPR</th>
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Success criteria require 2 out of 2 ACCs to function
1 ACC is actually sufficient, but …
Results

- CD probability
  - Dynamic PRA (RAVEN-RELAP5): 8
  - Classical PRA (SAPHIRE): 8.13 E-3

- Event sequence probabilities:
  - LPR: 7.27 E-3
  - LPI: 8.12 E-4
  - SAPHIRE: 4.80 E-5
  - RAVEN: 0.99187

- Branch Probability

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Results

• RIMs:
  – Drastic decrease for basic events associated to ACC
  – RIM analysis considered a small subset of the simulated data

• What about the rest of the data?
  – Measure safety margin (SM):
    \[ SM = 2200 - \text{PCT} \]
  – Characterize the pdf of SM
    • mean, std. dev.
Summary

• Classical RIMs can be generated from simulation based data

• Rationale: classical and dynamic PRA can coexist
  – Reduce ET/FT conservatisms
  – Employs simulation-based success criteria
  – Measure safety margins

• Hybrid PRA:
  – Start from classical PRA model
  – Validate outcome and probability of all ET branches
    • measure safety margins
  – Perform UQ on simulation models for borderline ET branches
  – Introduce time-dependent elements (e.g. recovery) for specific event sequences