Using limited data to construct Bayesian Networks for Human Reliability Analysis

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LABORATORY DIRECTED RESEARCH & DEVELOPMENT

Early Career R&D Program

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Problem

Building a data-informed model to assess human error probability (HEP) as part of safety assurance for nuclear power plants.

Current **Human Reliability Analysis (HRA)** methods use models to infer HEP for use in Probabilistic Risk Assessment. However:

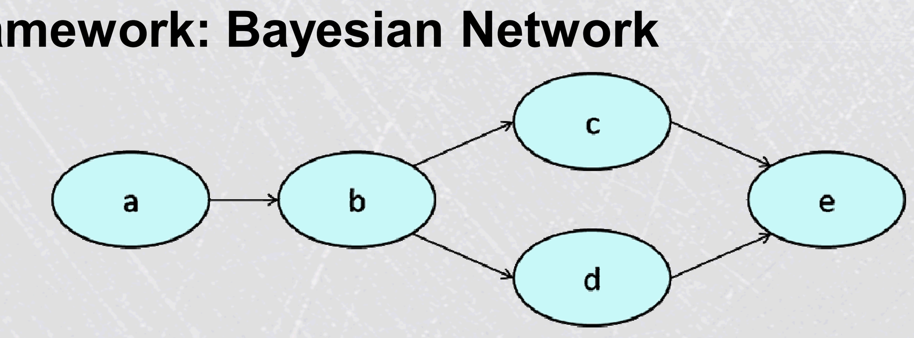
1. Existing HRA methods are heavily reliant on expert judgment due to lack of data – this results in models that are subjective.
2. Current HRA models can only be used by analysts with complete information – partial information (epistemic uncertainty) cannot be used, despite being prevalent in HRA applications.
3. International HRA data-collection efforts offer the opportunity to improve HRA, but data is sparse.

Approach

- Combine a current HRA method with expert information and HRA data to produce a robust model for estimating HEP.
- Use a Bayesian Network (BN) model – integrates multiple types of information and permits expansion as knowledge increases.

Modeling framework: Bayesian Network

- A tool for encoding the knowledge base (probability distribution), in terms of:
  - Relevant variables and states
  - Dependency among variables
  - The simplified joint probability distribution of the system



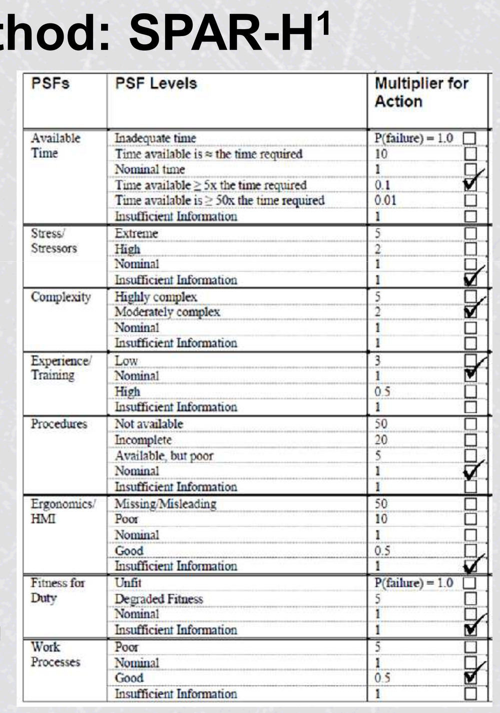
$$P(a,b,c,d,e) = P(e|a,b,c,d,) * P(d|a,b,c,) * P(c|a,b) * P(b|a) * P(a)$$
$$= P(e|c,d) * P(d|b) * P(c|b) * P(b|a) * P(a)$$

Existing method: SPAR-H[1]

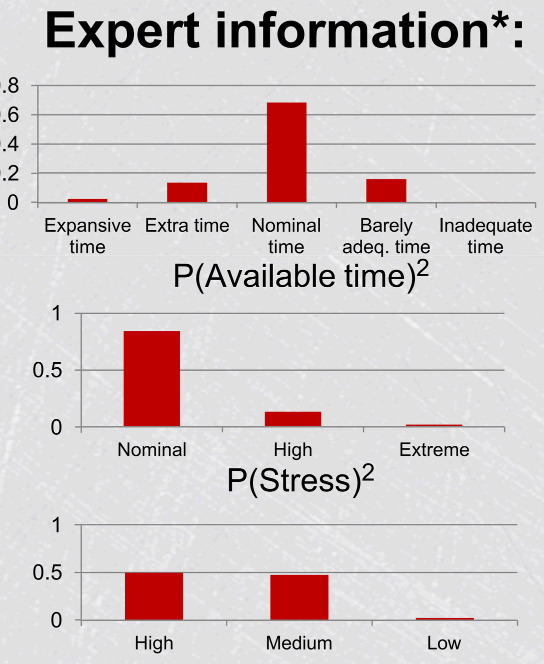
1. **Assess context in terms of 8 Performance Shaping Factors (PSFs)** – Select one state for each factor in table at right.
2. **Calculate Human Error Probability (HEP)** – Use following equation:

$$HEP = NHEP \cdot \prod_{i=1}^{8} PSF_i$$

Where NHEP = 0.001 for action and 0.01 for diagnosis tasks



Expert information*:



HRA data: Halden Reactor Project simulator data

Photo Credit: Halden Reactor Project

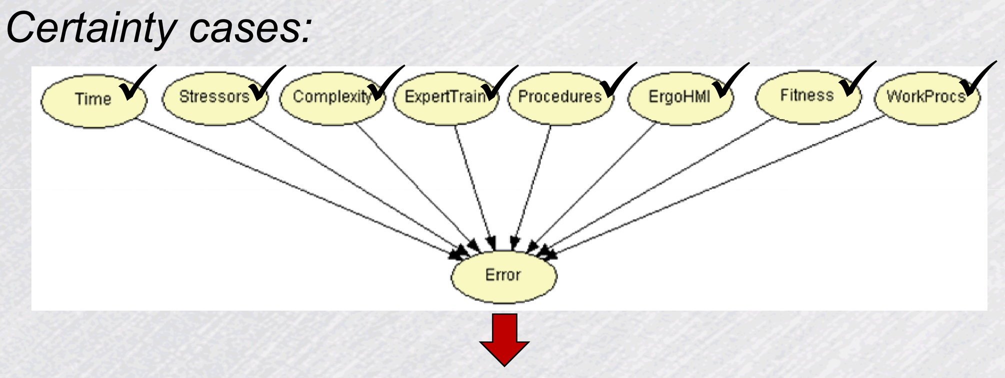
Experiment	SGTR Complexity Study		
Scenario	Basic SGTR	Complex SGTR	
Variant	None	Clear Indicators	Misleading Indicators
Crew	1 – 10	1 – 5	6 – 10

*Information for remaining PSFs available from (2)

1. Gertman, D. et al. *The SPAR-H Human Reliability Analysis Method.* NUREG/CR-6883, Nuclear Regulatory Commission, **2005**.
2. Hallbert, B. & Kolaczkowski, A. *The Employment of Empirical Data and Bayesian Methods in Human Reliability Analysis: A Feasibility Study.* NUREG/CR-6949, Nuclear Regulatory Commission, **2007**.
3. Extrapolated from Spurgin, A.J., et al., "Operator Reliability Experiments Using Power Plant Simulators," EPRI NP-6937, Vol. 1, Electric Power Research Institute, Monterey, CA, 1990.

Results

Certainty cases:

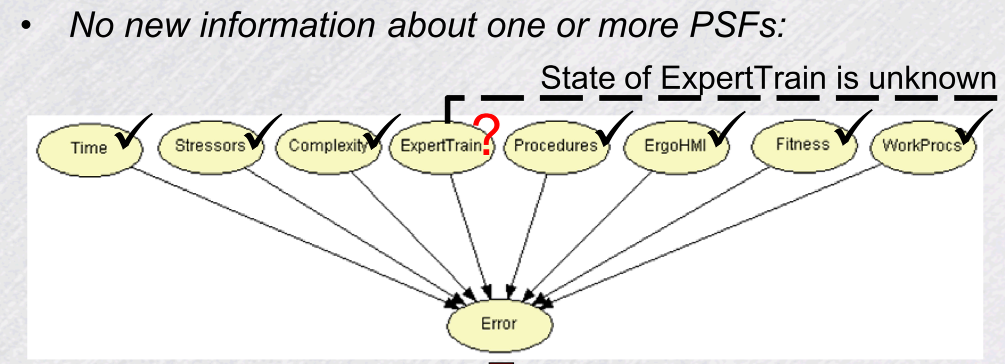


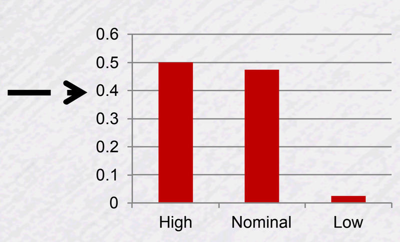
HEP Identical to SPAR-H model

Time	Stressors	Complexity	ExpertTrain	Procedures	ErgoHMI	Fitness	Work Procs	HEP
1	1	1	1	1	1	1	1	1.00E-03
1	1	1	1	1	10	1	1	1.00E-02

Insufficient information cases:

- *No new information about one or more PSFs:*



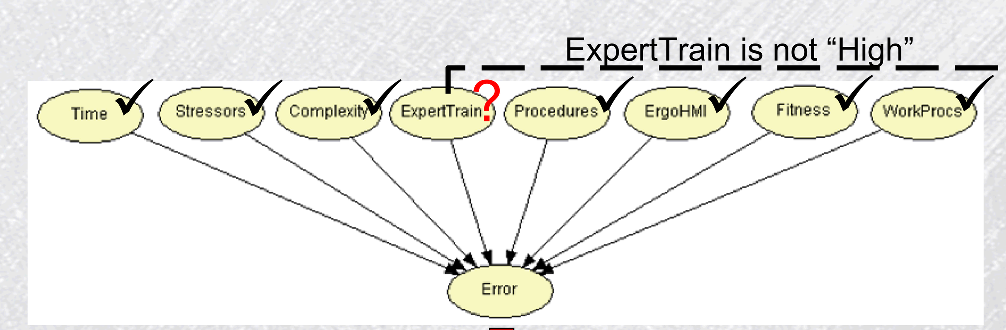


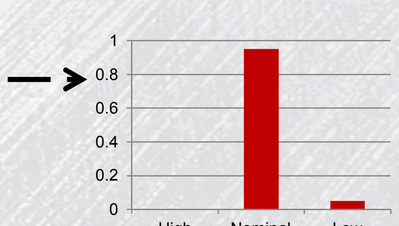
Uses prior distribution for unknown PSFs

HEP based on SPAR-H model , known PSFs, *and* prior distribution of unknown PSFs

Time	Stressors	Complexity	ExpertTrain	Procedures	ErgoHMI	Fitness	Work Procs	HEP
1	1	1	?	1	1	1	1	8.00E-02
1	1	1	1	1	?	1	1	3.27E-03
?	?	?	?	?	?	?	?	5.67E-02

- *Partial information about one or more PSFs:*





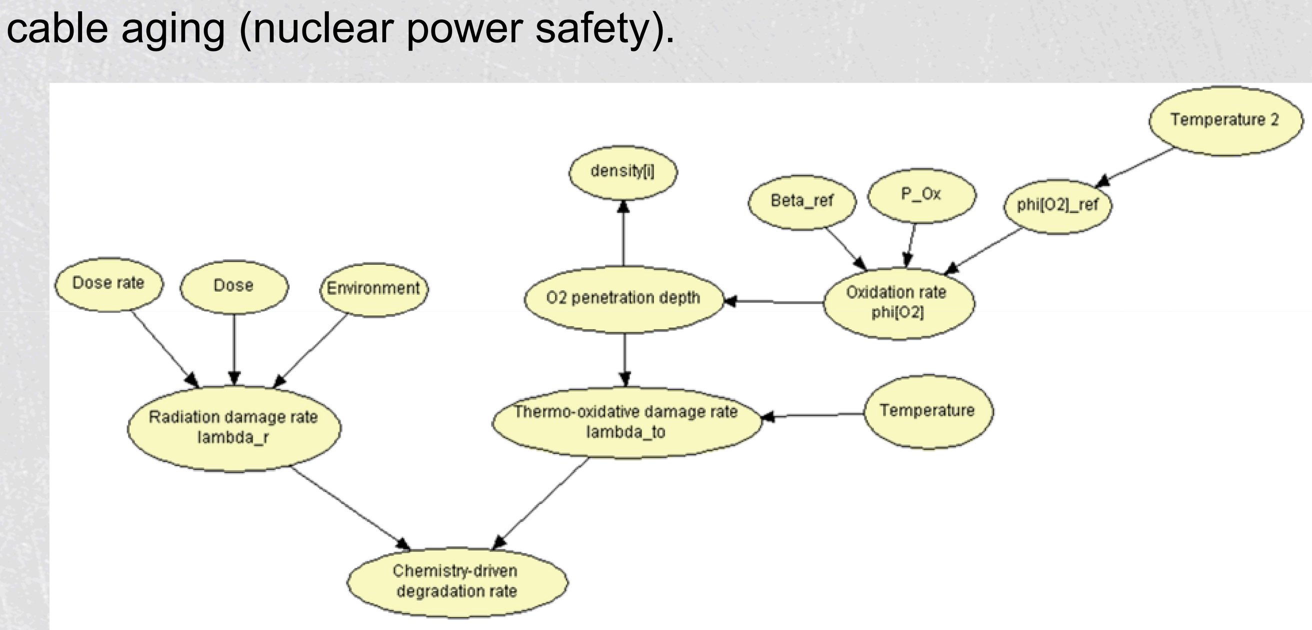
Updates prior distribution with new, partial information

HEP based on SPAR-H model , known PSFs, *and* prior distribution of unknown PSFs, updated with partial information

Time	Stressors	Complexity	ExpertTrain	Procedures	ErgoHMI	Fitness	Work Procs	HEP
1	1	1	?	1	1	1	1	1.10E-01

Significance

- **Advances the state-of-the-art in HRA application areas**
  - This research is the only activity transforming an existing HRA method into a model compatible with simulator data – approach balances HRA-community acceptance with insights from new data.
  - BN-based HRA model can accept partial observations – maximizes use of information available to HRA analysts.
  - Model is expandable in scope and depth – model can be incrementally updated as HRA knowledge and data increases.
  - Model is gathering interest from NRC, NASA, other industries where human error is significant.
- **Enhances SNL capability to use different types of information to build BNs for other mission areas**
  - Created BN-development approach and real-time decision tool (in MATLAB) that can be applied to aid decision making in national security applications.
  - Developed prototype models for hydrogen ignition (fuel cell safety) and cable aging (nuclear power safety).



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