SAND2015-8954PE

A brief intro to Human Reliability Analysis

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IEA HIA Hydrogen Safety Task 37
23 October 2015

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U.S. DEPARTMENT OF ENERGY
NNSA National Nuclear Security Administration

Questions:

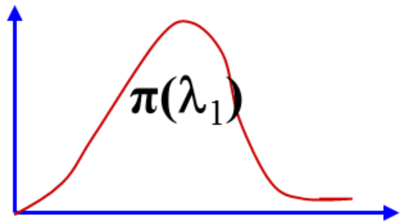
- What element of a system contributes to most serious failures? And what element is hardest to quantify?
- Human failure contribute to an estimated ___% of in industrial accidents
- How do we reduce the occurrence of accidents in nuclear power plants and other industrial systems?
- How can we allocate limited resources to maximally improve safety?

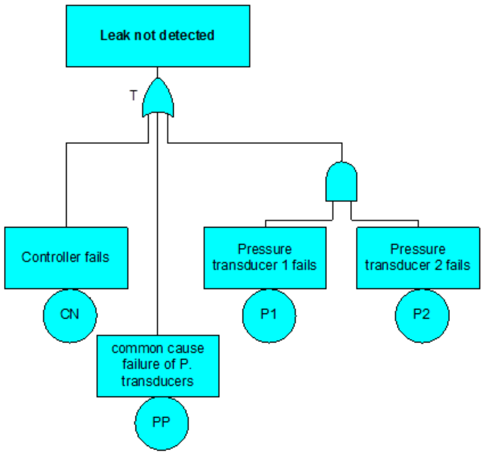
Human Reliability Analysis (HRA)

- **What**: A structured approach to understand the role of humans in complex system failures
  - Important part of PRA for nuclear power, aviation, etc.
- **Why**: To gain insight into how to reduce human contribution to risk

Causal Models

- HRA is one of several areas of PRA that use causal models instead of statistical models.
  - Statistical models: “How often?”
    - Predictions for static, uncertain conditions
    - Require data
      - Classical statistics: large (infinite) number of exchangeable observations
      - Bayesian statistics: sparse data
  - Causal models: “Why?”
    - Predictions for changing (uncertain) conditions
    - May or may not use data





Hybrid HRA/PRA model

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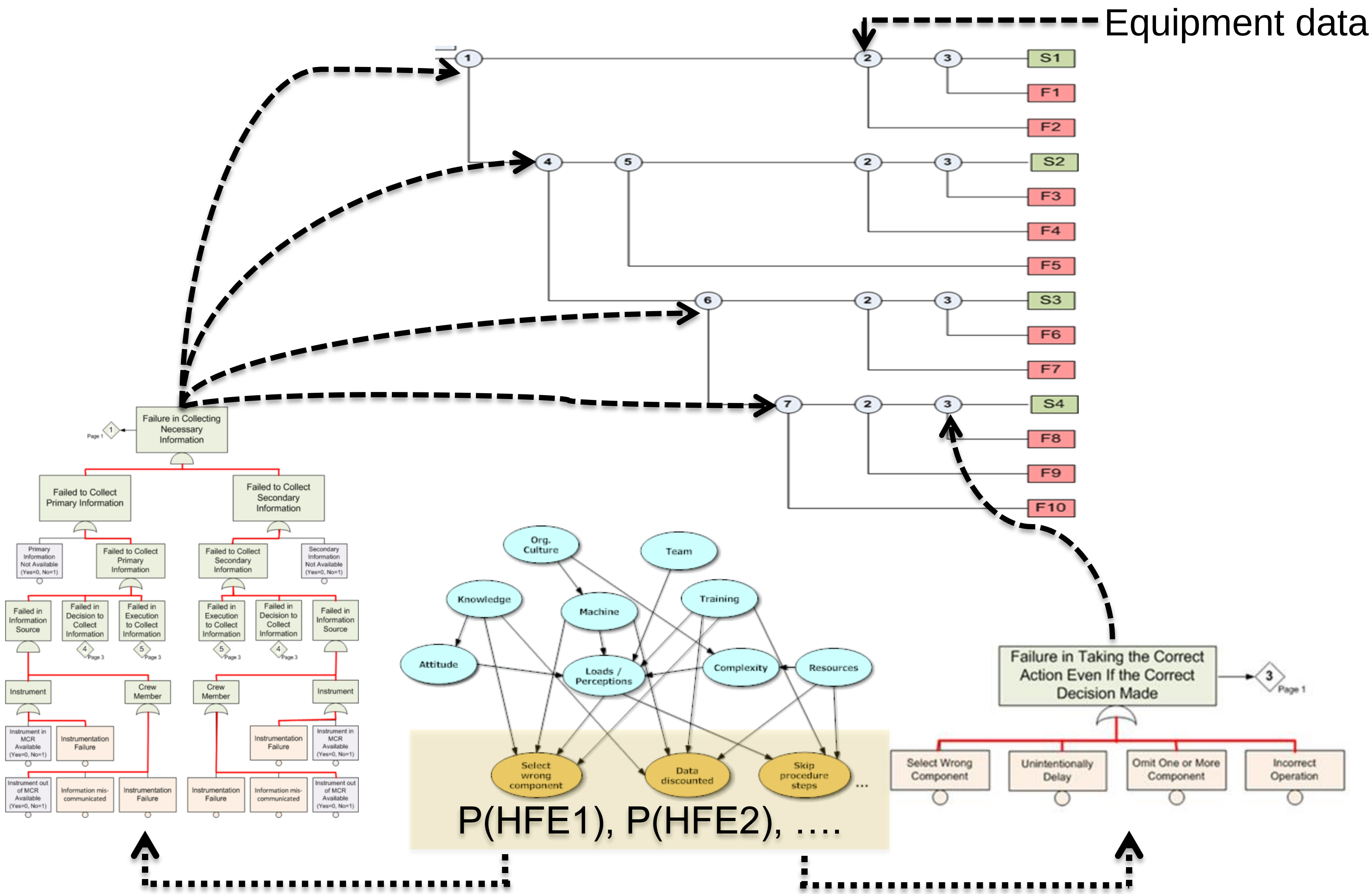

Basic Process

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- HRA Objectives:
  - **Identify**: Define human failure events (HFEs) for inclusion in PRA;
  - **Represent**: Model the factors that contribute to HFEs;
  - **Quantify**: Assign human error probability (HEP) values ;

HFE Identification Process

- *Ask: What human actions (or inactions) could contribute the loss of a critical function in given scenario?*
  - Errors of omission (EOO): No action
  - Errors of commission (EOC): Wrong action

- Resources to use:
  - Diverse team: HRA experience, PRA experience, Human factors/psychology background, workers/trainers,
  - Review of plant procedures, training manuals
  - Review existing PRA models and results
  - Worker interviews; work observations
  - Conduct formal task analysis

Human Error ≠ Human Failure

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- HRA is actually interested in the probability of occurrence **Human Failure Events (HFEs),** not generic human errors.
  - HFE: “the human response to event X will not satisfy system requirement Y.”
- Example HFEs:
  - Failure to initiate manual actions
    - (e.g. Feed & Bleed after a Steam Generator Tube Rupture)
  - Failure to properly restore valve lineup after system testing
  - Prematurely terminating Safety Injection

Model performance context

- Ask: What factors and circumstances can enhance or degrade performance (and thus change the likelihood of error)?
  - Usually called: Performance Shaping Factors (PSFs), Performance Influencing Factors (PIFs), or Context
- Each HRA method uses a different set of PSFs; number of PSFs used in any method can range from 3 – 50+
  - May (or may not) include: plant/scenario factors, cognitive factors, organizational factors

Taxonomy of PSFs

- Each HRA method uses a different set of PSFs
  - Impact: Used by NRC for HRA data collection & future model development

Organization

Organization-based

- Training Program
  - Availability
  - Quality
- Corrective Action Program
  - Availability
  - Quality
- Other Programs
  - Availability
  - Quality
- Safety Culture
- Management Activities
  - Staffing
    - Number
    - Qualifications
    - Team composition
  - Scheduling
    - Prioritization
    - Frequency
- Workplace adequacy
- Resources
  - Procedures
    - Availability
    - Quality
  - Tools
    - Availability
    - Quality
  - Necessary Information
    - Availability
    - Quality

Team

Team-based

- Communication
  - Availability
  - Quality
- Direct Supervision
  - Leadership
  - Team member
- Team Coordination
- Team Cohesion
- Role Awareness

Person

Person-based

- Attention
  - To Task
  - To Surroundings
- Physical & Psychological Abilities
  - Alertness
  - Fatigue
  - Impairment
  - Sensory Limits
  - Physical attributes
  - Other
- Bias
- Morale/Attitude
  - Problem Solving Style
  - Information Use
  - Prioritization
    - Conflicting Goals
    - Task Order
  - Compliance
- Knowledge/Experience
- Skills
- Familiarity with Situation

Machine

Machine-based

- HSI
  - Input
  - Output
- System Responses
  - Ambiguity

Situation

Situation-based

- External Environment
- Hardware & Software Conditions
- Task Load
- Time Load
- Other Loads
  - Non-task
  - Passive Information
- Task Complexity
  - Cognitive
  - Task Execution

Stressors

Stressor-based

- Perceived Situation:
  - Severity
  - Urgency
- Perceived Decision:
  - Responsibility
  - Impact
    - Personal
    - Plant
    - Society

Groth & Mosleh (2012). A data-informed PIF hierarchy for model-based Human Reliability Analysis *Reliability Engineering and System Safety, 108*, 154-174.

Assign an HEP

- Elicit information about PSFs/context for a particular HFE
- Pass that information through a model to get an HEP (Human Error Probability)

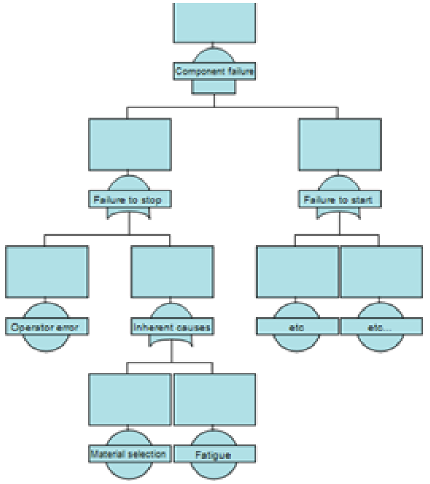
Analyst observations

Complexity	Highly complex	5	☐
	Moderately complex	2	☐
	Nominal	1	☐
	Obvious diagnosis	0.1	☐
	Insufficient Information	1	☐
Experience/ Training	Low	10	☐
	Nominal	1	☐
	High	0.5	☐
	Insufficient Information	1	☐
Procedures	Not available	50	☐
	Incomplete	20	☐
	Available, but poor	5	☐
	Nominal	1	☐
	Diagnostic/symptom oriented	0.5	☐
	Insufficient Information	1	☐

Model

(Experts, THERP, SPAR-H, ATHEANA, CBDT, etc)

HEP



SPAR-H method

1. Assess context in terms of PSFs (Performance Shaping Factors)

- Available time
- Stress/stressors
- Complexity
- Experience/training
- Procedures
- Ergonomics/HMI
- Fitness for duty
- Work processes

2. Calculate HEP (Human Error Probability)

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

Where BHEP = 0.01 for diagnosis tasks and 0.001 for action tasks

PSFs	PSF Levels	Multiplier for Action
Available Time	Inadequate time	P(failure) = 1.0 ☐
	Time available is ≈ the time required	10 ☐
	Nominal time	1 ☐
	Time available ≥ 5x the time required	0.1 ☑
	Time available is ≥ 50x the time required	0.01 ☐
	Insufficient Information	1 ☐
Stress/ Stressors	Extreme	5 ☐
	High	2 ☐
	Nominal	1 ☐
	Insufficient Information	1 ☑
Complexity	Highly complex	5 ☐
	Moderately complex	2 ☑
	Nominal	1 ☐
	Insufficient Information	1 ☐
Experience/ Training	Low	3 ☐
	Nominal	1 ☑
	High	0.5 ☐
	Insufficient Information	1 ☐
Procedures	Not available	50 ☐
	Incomplete	20 ☐
	Available, but poor	5 ☐
	Nominal	1 ☑
	Insufficient Information	1 ☐
Ergonomics/ HMI	Missing/Misleading	50 ☐
	Poor	10 ☐
	Nominal	1 ☐
	Good	0.5 ☐
	Insufficient Information	1 ☑
Fitness for Duty	Unfit	P(failure) = 1.0 ☐
	Degraded Fitness	5 ☐
	Nominal	1 ☐
	Insufficient Information	1 ☑
Work Processes	Poor	5 ☐
	Nominal	1 ☐
	Good	0.5 ☑
	Insufficient Information	1 ☐

HRA Methods

- Over 50 HRA methods available
  - THERP, ASEP, SPAR-H, ATHEANA, CREAM, SLIM-MAUD, CBDT, IDA, HCR-ORE, IDHEAS, CESA, PHOENIX….
- Level of task decomposition varies widely between methods
  - "Turn a dial" vs. "Adjust pump charging flow" vs. "Initiate Feed & Bleed"
- No two methods use the same set of PSFs
  - Methods range from 3 to 50+ PSFs
- Quantitative results can vary widely (several orders of magnitude)

Challenges: Credibility & validity

- Existing HRA methods are heavily reliant on expert judgment
- In PRA, data is used to build confidence; HRA is seen as subjective
    - Different method => different results
    - And often: Same method & different team => different results
- Tradeoff between: qualitative insight, technical basis, and ease-of-quantification

HRA R&D directions

- Several international data collection projects
  - Halden Reactor Project
  - KAERI
  - US NRC
- New modeling efforts focusing on:
  - Creating methods will strong technical basis (combining psychological research, operating experience, simulator data)
  - Adding underlying causal model to answer “why”, not just “how often”

Recent Sandia R&D: SPAR-H BN

Goal:

- Starting with a widely used HRA method:
  - Encode causal understanding of the drivers for human error
  - Inform the model using multiple sources of data/information
    - Cognitive literature, current HRA methods, simulator data

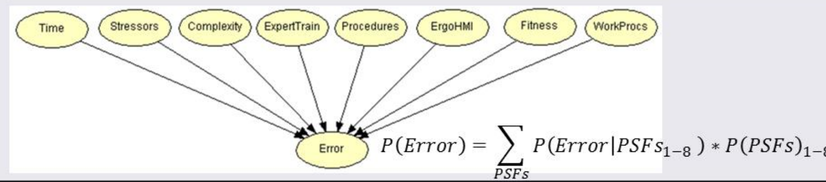
Approach:

- Bayesian Networks: offer a way to reason about uncertain events, using uncertain information
  - Allow assembly of diverse types of information
  - Built-in causal framework
  - Ability to incorporate sparse data

Updating SPAR-H with data

- Developed method to use simulator data to refine HRA models (incl. BNs)
  - Impact: Credibility for HRA industry

Model structure: Built from existing HRA method (SPAR-H)



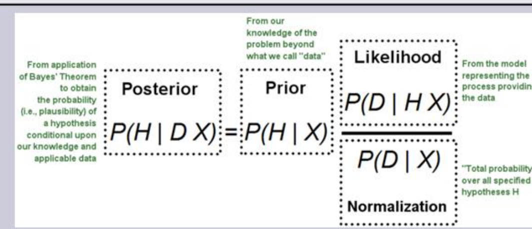
Prior probabilities: Use existing HRA method & expert elicitation

$$P(Error) = NHEP \cdot \prod_{i=1}^{8} PSF_i$$

Data: Extract from simulator data from nuclear power research

Time	Stressors	Complexity	ExpertTrain	Procedures	ErgoHMI	Fitness	WorkProcs	Error?
Extra	Nom.	Moderate	Nom.	Avail., but poor	Nom.	Nom.	Nom.	No
Extra	Nom.	Moderate	Nom.	Avail., but poor	Nom.	Nom.	Nom.	No
Extra	Nom.	Moderate	Nom.	Avail., but poor	Nom.	Nom.	Nom.	No
Extra	Nom.	Moderate	Nom.	Avail., but poor	Nom.	Nom.	Nom.	No
Barely adeq.	High	Moderate	Nom.	Avail., but poor	Nom.	Nom.	Nom.	No
Barely adeq.	High	Moderate	Nom.	Avail., but poor	Nom.	Nom.	Nom.	Yes(No)
Barely adeq.	High	Moderate	Nom.	Avail., but poor	Nom.	Nom.	Nom.	Yes(No)
Barely adeq.	High	Moderate	Nom.	Avail., but poor	Nom.	Nom.	Nom.	Yes
Inadequate	High	High	Low	Avail., but poor	Nom.	Nom.	Poor	Yes
Inadequate	High	High	Low	Avail., but poor	Nom.	Nom.	Poor	Yes
Inadequate	High	High	Low	Avail., but poor	Nom.	Nom.	Poor	Yes
Inadequate	High	High	Low	Avail., but poor	Nom.	Nom.	Poor	Yes
Extra	Nom.	Nom.	Nom.	Nom.	Nom.	Nom.	Nom.	No
Extra	Nom.	Nom.	Nom.	Nom.	Nom.	Nom.	Nom.	No
Extra	Nom.	Nom.	Nom.	Nom.	Nom.	Nom.	Nom.	No

Method: Implement Bayes' Theorem to update probabilities in model



Groth & Swiler (2013). *Bridging the gap between HRA research and HRA practice: A Bayesian Network version of SPAR-H.* Reliability Engineering and System Safety, 115, 33-42.

Groth, Smith & Swiler (2014). *A Bayesian method for using simulator data to enhance human error probabilities assigned by existing HRA methods.* Reliability Engineering & System Safety,128, 32-40.

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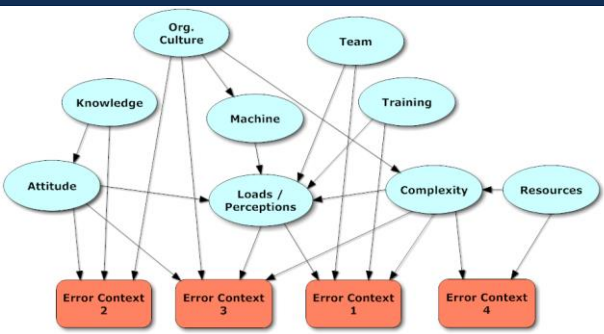

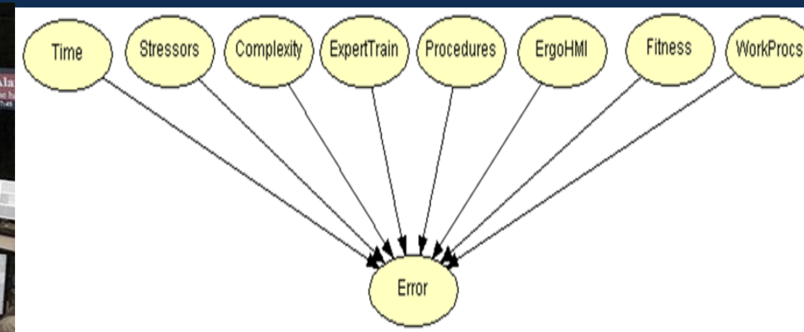

Questions?

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