Dynamic PRA Approach for the Prediction of Operator Errors

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Presentation Outline

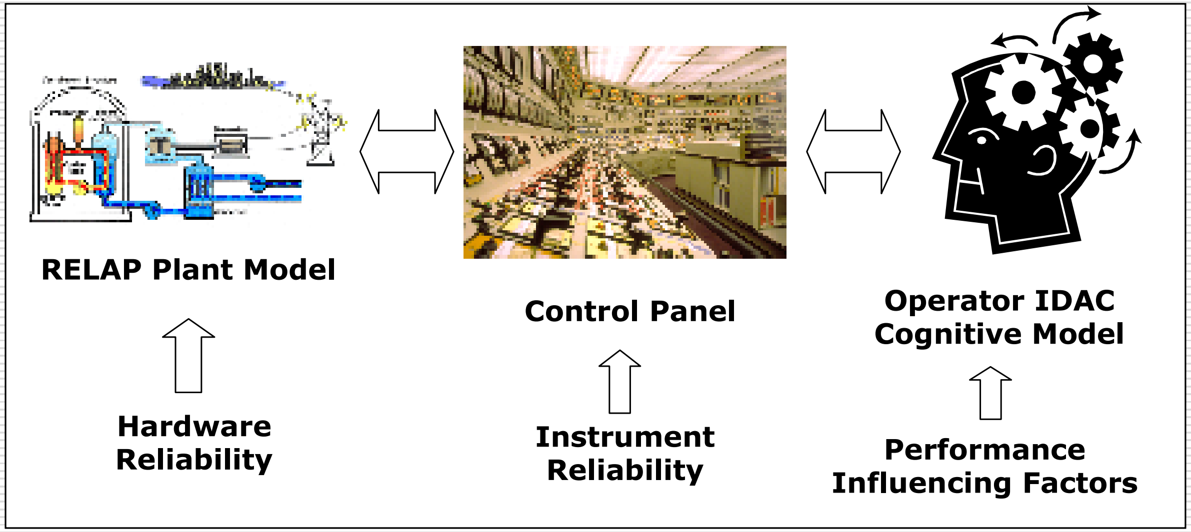
- Presentation Outline
  - Dynamic PRA Methods
  - General Overview of ADS-IDAC
    - Thermal Hydraulic Nuclear Plant Model
    - Operator Model
  - Dynamic Performance Influencing Factors
  - Information Filtering and Perception
  - Future Research Activities

Dynamic PRA

- Compared to conventional human reliability analysis techniques, dynamic simulation methods can improve the modeling of several important factors:
  - Feedback between operator and reactor plant
  - Timing and sequencing of events
  - Success criteria
  - Dependencies arising from situational context
- But, dynamic methods introduce several challenges:
  - Truncation techniques needed to limit sequence explosion
  - Quality of results dependent on realism of the underlying plant and operator models
  - Interpretation of results

ADS-IDAC Overview

- **A**ccident **D**ynamics **S**imulator with the **I**nformation, **D**ecision, and **A**ction in a **C**rew Context Cognitive Model (ADS-IDAC)
  - *UMD has been developing, improving, and refining ADS-IDAC for nearly two decades*



Thermal-Hydraulic Model

- RELAP5 Thermal-Hydraulic Engine
  - Recognized thermal hydraulic analysis tool
  - Existing RELAP plant models can be readily adapted to the ADS-IDAC environment
- Plant models require some modifications
  - Interactive controls and instrumentation
  - Realistic representation of plant systems, protective features, and controls
- The current three-loop PWR plant model includes:
  - 200 indicators
  - 90 controls
  - 80 alarms

Operator Model

- Operator actions guided by high-level goals and problem solving strategies

Goal	Strategies	Comment
Maintain Normal Operation	• Passive Information Gathering • Memorized Rule-Based Actions	
Troubleshoot Abnormal Conditions	• Active & Passive Information Gathering • Memorized Rule-Based Actions • **Knowledge-Based Actions**	Actions driven by operator's situational assessment
Monitoring	• Active & Passive Information Gathering • Memorized Rule-Based Actions	
Maintain Safety Margin	• Active & Passive Information Gathering • Memorized Rule-Based Actions • **Follow Written Procedures**	Implements EOPs

Operator Model

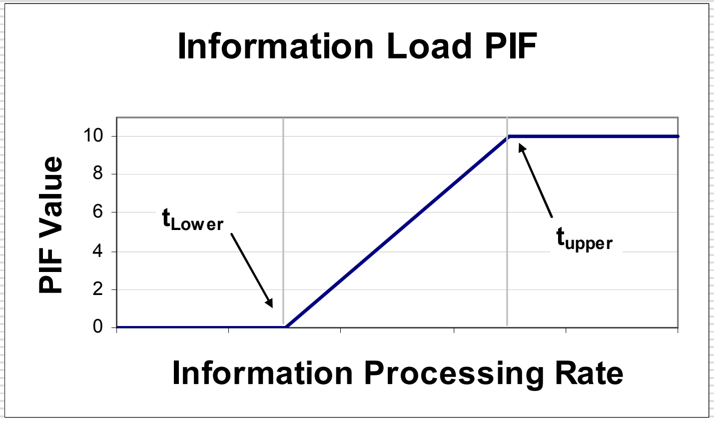
- Operator profile specifies tendencies, preferences, and capabilities
  - PIF profiling factors
  - Utilization of memorized information
  - Problem solving preferences
  - Threshold for diagnosing an accident condition
  - Procedure pacing and adherence
  - Information handling capabilities
- Operator knowledge base defines procedures, mental models, and heuristic rules

Dynamic Performance Influencing Factors (PIFs)

- Three dynamic PIF factors have been implemented in ADS-IDAC:
  - Information Loading
  - Time Constraint Loading
  - Criticality of System Condition
- Dynamic PIFs currently support:
  - Procedure step skipping module
  - Information gathering process

Dynamic PIFs: Information Load

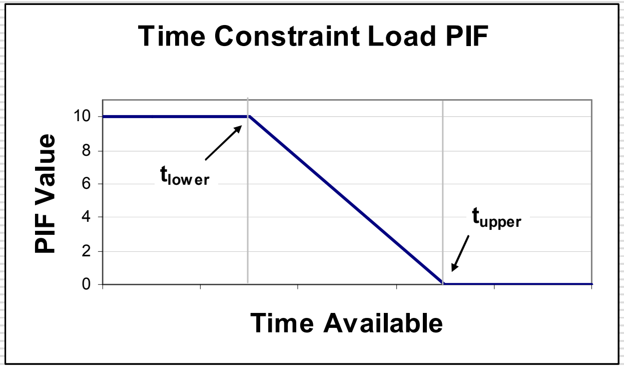
- Information Load PIF based on average information processing rate for each operator
  - "Information" includes alarms, control panel interactions, and crew communication
  - Includes both passive and active information load
- Related to operator task load



$$PIF_{Info\,Load} = 10\left[\frac{\dot{I}_{Perception\,Rate} - \dot{I}_{Lower\,Threshold}}{\dot{I}_{Upper\,Threshold} - \dot{I}_{Lower\,Threshold}}\right]$$

Dynamic PIFs: Time Constraint Load

- Measures amount of time available until a process parameter passes a critical threshold
  - Parameters and thresholds can be uniquely defined for each operator
  - PIF value depends on amount of time available and operator’s high level goal (e.g., normal operation vs. accident mitigation)
- Related to time pressure perceived by the operator

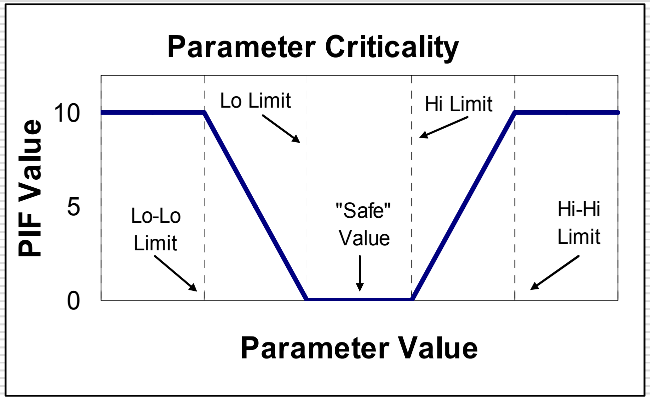


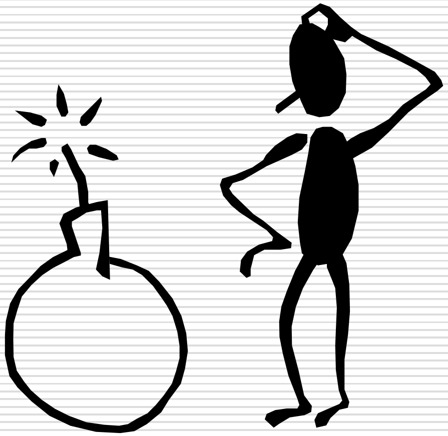
$$t_{i,available} = \frac{P_i - P_{i,Threshold}}{\dot{P}_i}$$

$$PIF_{i,TimeConstrain} = 10\left[1 - \frac{(t_{i,available} - t_{lower})}{(t_{upper} - t_{lower})}\right]$$

Dynamic PIFs: Criticality of System Condition

- Criticality of System Condition modeled after the Safety Parameter Display System (SPDS)
  - Measures plant deviation from nominal (safe) conditions
  - Each operator can use a unique combination of parameters, thresholds, and weighting factors
- Related to the operator's perception of the severity of the plant state

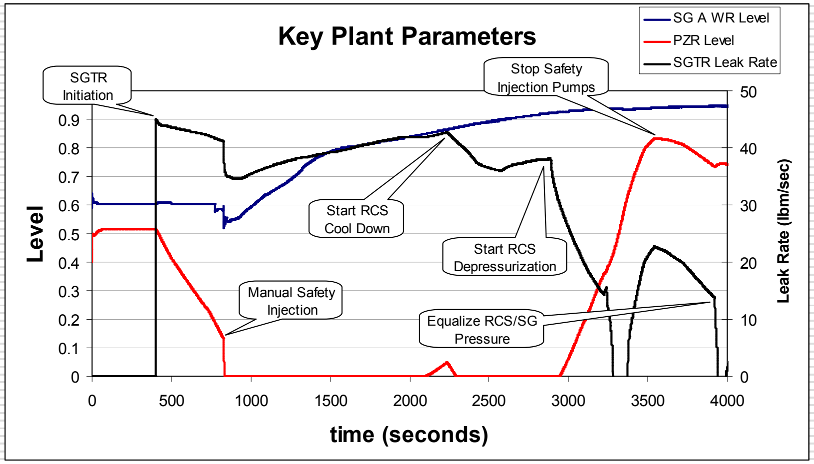


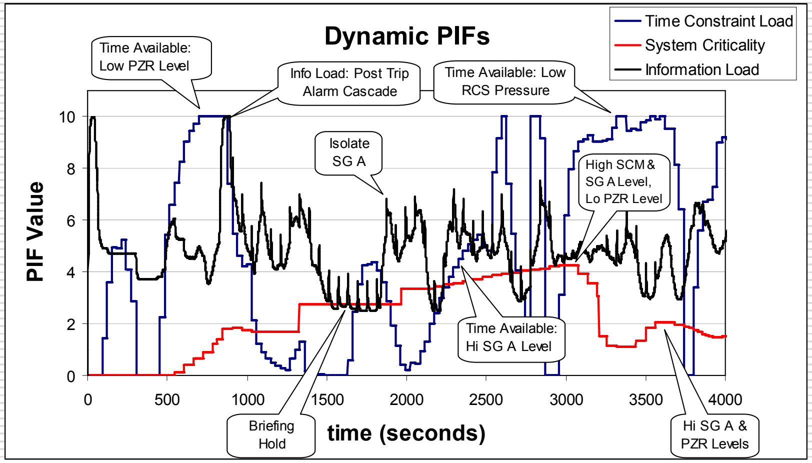


$$PIF_{System\,Criticality} = \frac{\sum_i \omega_i \, PIF_{Parameter\,Criticality\ i}}{\sum_i \omega_i}$$

Dynamic PIFs: Example

- Example Application – Steam Generator Tube Rupture
  - Operators utilize procedure following strategy
- Dynamic PIFs reflect both plant dynamics and operator activities
  - Briefings and delays
  - Degrading and improving plant status
  - Periods of high task loads



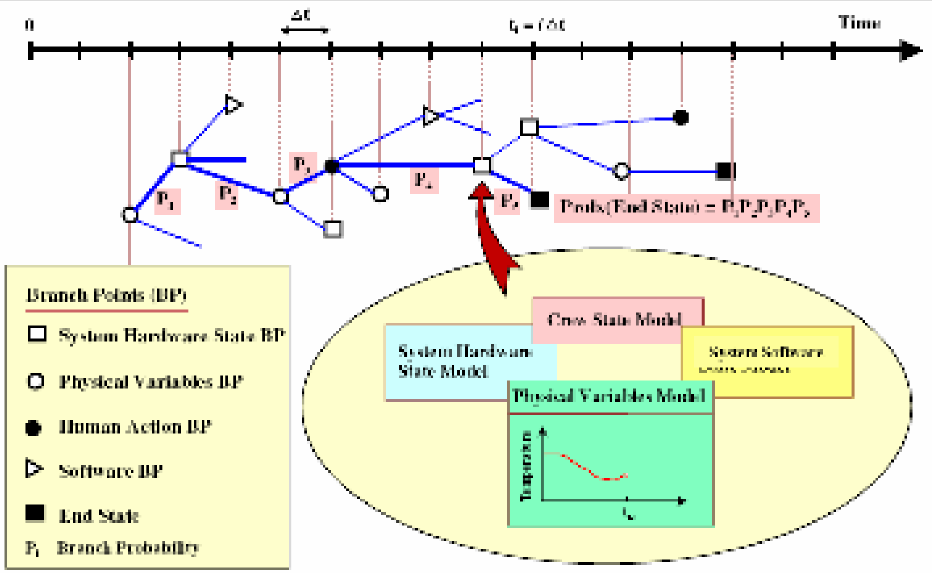


Information Perception & Filtering

- All operator decisions and actions are based on perceived information
  - Raw data from the thermal-hydraulic model subject to filtering process
    - Operator must gather information
    - Biasing filter can distort information
- Differences between perceived and actual plant data can drive the operator toward error forcing situations
  - Incorrect situational assessment leads to inappropriate action-rule activation
  - Information distortion adversely impacts assessment of component, system, or plant state

Modeling Potential Error Events: Branching Rules

- ADS-IDAC generates a discrete dynamic event tree (DDET) based on the application of simple branching rules
- Feedback from the plant model, information perception, and PIFs all influence the activation of branching rules
- The branching path from the initiating event to a final end state define the scenario trajectory



Error events occur when the sequence of branching events result in the failure to meet a plant need...

Conclusions

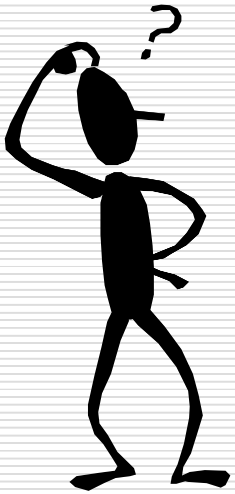
- Recent improvements to the ADS-IDAC code have dramatically improved the realism of plant and operator models.
  - RELAP5 Plant Model
  - Operator Goals and Problem Solving Strategies
  - Dynamic PIFs
  - Information Processing

Taken together, these factors reinforce the man-machine feedback loop and improve the ability of ADS-IDAC to model crew-to-crew variabilities and dependencies

Future Work

- Knowledge base expansion
- Model calibration
  - Heuristic rules
  - Pace and timing of operator actions
  - Operator preferences/tendencies
- Validation
  - Halden HRA Comparison Study
- User interface
  - Facilitate ADS-IDAC model development, revisions, and simulation execution
- Post processing tools
  - Sequence grouping and visualization
  - Importance measures and metrics

UMD ADS-IDAC Project



Questions....