Model Based Human Reliability Analysis in a Dynamic PRA Environment

- *The ADS-IDAC Approach*

Overview of ADS-IDAC

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Presentation Outline

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- Model-Based Human Reliability Analysis in a Dynamic Environment
- General Overview of ADS-IDAC
  - Branching Rules
  - Dynamic Performance Influencing Factors
- The IDA Cognitive Model
  - **I**nformation Processing
  - **D**ecision-Making
  - **A**ction Execution
- Verification & Validation Activities

Dynamic Risk Assessment

Dynamic simulation techniques can address several risk assessment challenges:

- Significant influence from sequencing and/or timing of events
- Component failure rates dependent on system process variables
- Time and/or system-state dependent success criteria
- Strong dependencies between human actions and system feedback

Model Based Human Reliability Analysis

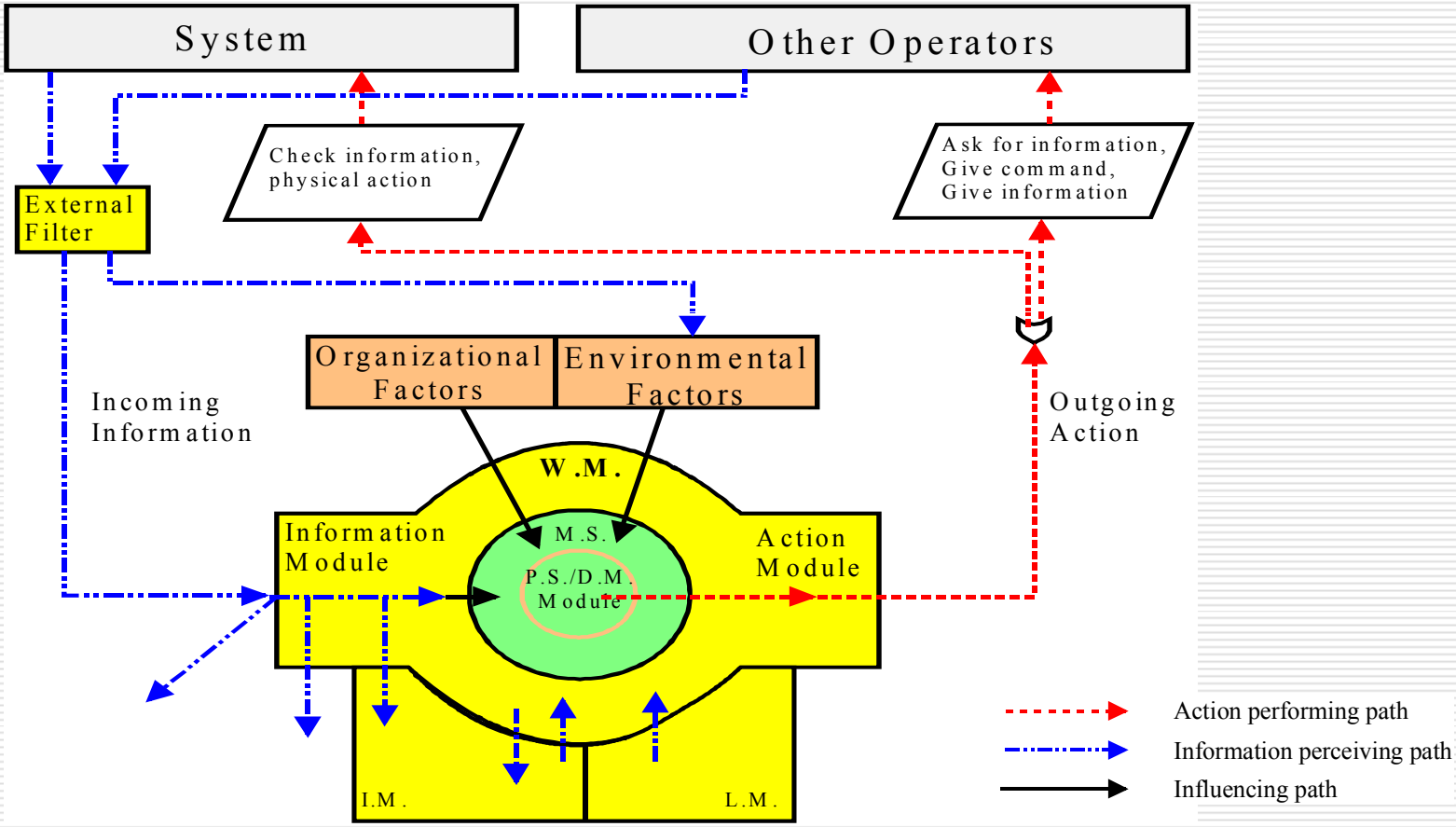
- An operator cognitive model explicitly links contexts and operator actions
- IDAC model includes elements such as perception, memory, operator knowledge base, decision-making processes
- Performance Influencing Factors (PIFs) bias operator behavior by establishing preferences/tendencies.
  - However, the underlying cognitive model, not PIFs, is responsible for determining operator behavior

The ADS-IDAC Simulation Model

ADS-IDAC - **A**ccident **D**ynamics **S**imulator with the **I**nformation **D**ecision and **A**ction in a **C**rew Context operator model

- Discrete Dynamic Event Tree (DDET) Simulation Method
- Model-based HRA approach
  - Integrates a thermal hydraulic nuclear plant model with a control room crew human performance model
  - Provides rich situational context for evaluating factors that may influence decision-making performance (e.g., identifying error forcing contexts)

IDAC Operator Cognitive Modeling Framework



Human Error in ADS-IDAC

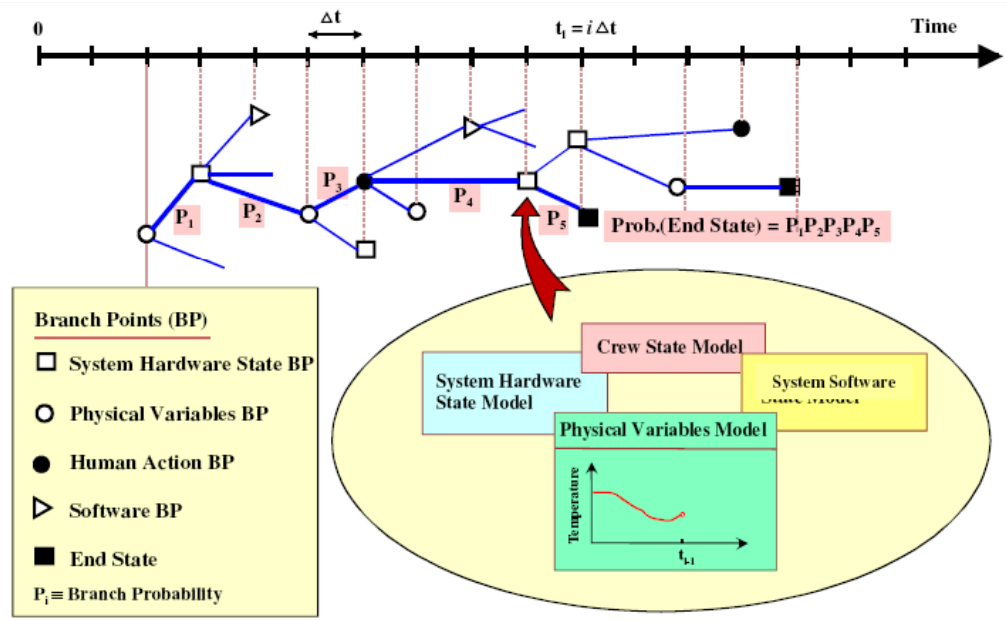
- Error defined in terms of the operator failing to meet a plant need - focuses on safety impact of operator actions
- Error categories based on mismatches between the operators and the plant system with reference to the IDAC cognitive processes
  - information gathering and perception
  - information assessment, diagnosis, and problem definition
  - decision making processes (e.g., selection of inappropriate alternative or use of incorrect decision criteria)
  - action execution

Key Features of ADS-IDAC

- Operator actions (and errors) driven by information processing and decision-making
  - Places emphasis on contextual factors and cognitive processes rather than performance shaping factors
- Model-based approach provides better framework for data collection and analysis
- Crew model allows each operator to possess unique skills & abilities
- Operator cognitive model resides in a rich contextual environment
  - Improves realism of HRA analysis

ADS-IDAC Simulation Approach - Discrete Dynamic Event Tree

- ADS-IDAC generates a discrete dynamic event tree (DDET) based on the application of simple branching rules
- Both the branching rules and the timing of branch events influence the scenario trajectory
- The DDET structure links dynamic system behavior with hardware reliability models and operator actions to provide a more complete risk assessment



Branching rules reflect variations in plant hardware and crew responses to plant events

ADS-IDAC Branching Rules

ADS-IDAC can generate branching points for the following attributes

- Procedure execution
  - Timing
  - Control input variations
  - Step skipping
- Operator knowledge & experience
  - Activation of mental beliefs
  - Activation of rule- and knowledge-based actions
- Equipment Performance
  - Conditional failures
  - Initiating events

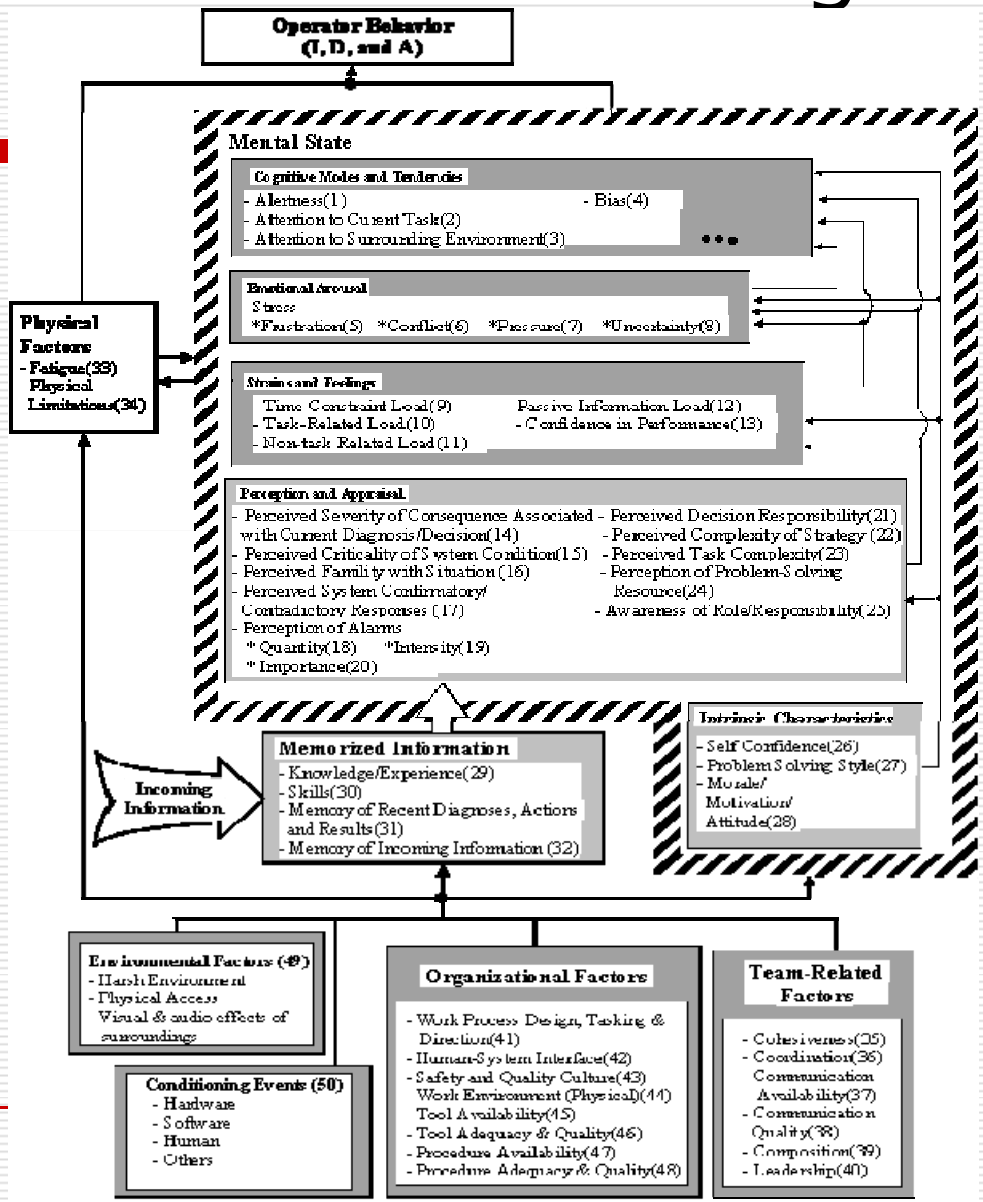
Dynamic Performance Influencing Factors (PIFs)

- Dependencies between human actions carried by static and dynamic PIFs
- Three dynamic PIF factors have been implemented in ADS-IDAC:
  - Information Loading
    - related to operator workload
  - Time Constraint Loading
    - related to plant dynamics
  - Criticality of System Condition
- Dynamic PIFs currently support:
  - Procedure step skipping module
  - Information gathering process

Dynamic Performance Influencing Factors (PIFs)

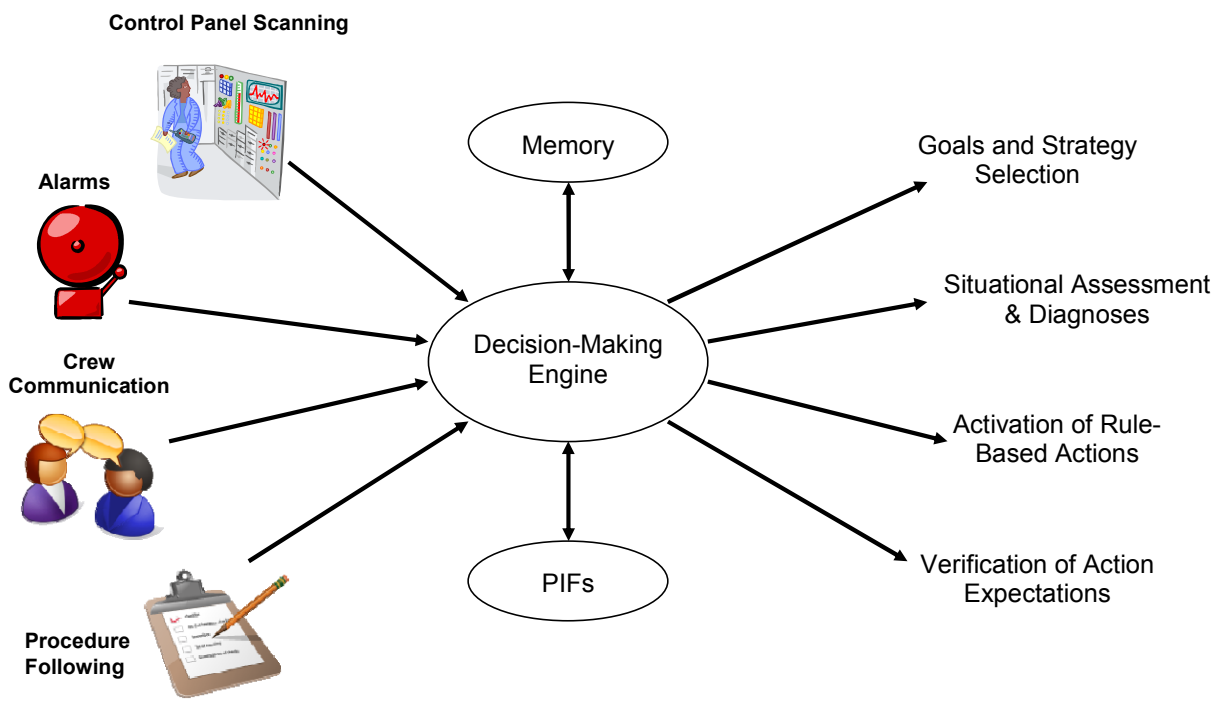
PIFs are grouped into two broad categories:

- Internal
  - Cognitive Modes
  - Emotional
  - Strains & Feelings
  - Perception
  - Memory
  - Intrinsic characteristics
- External
  - Environment
  - Conditioning Events
  - Organizational Factors
  - Team Related Factors



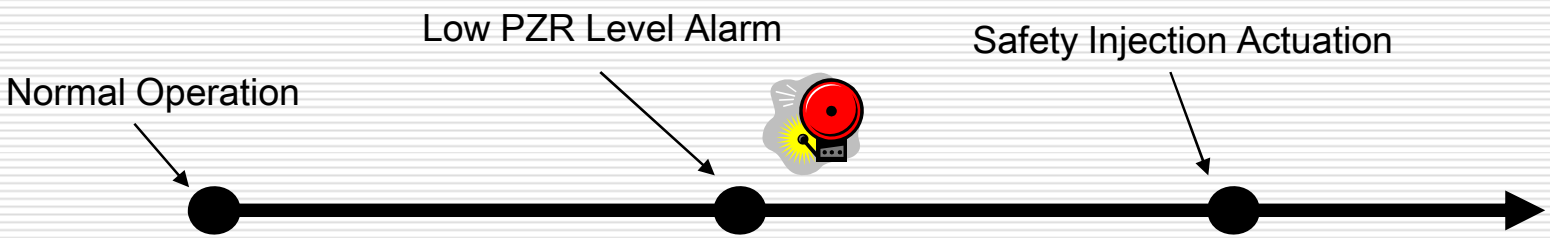
The IDAC Cognitive Model - Information Processing

- The quality of operator decision-making is directly influenced by the quantity and accuracy of perceived information
- Information gathering can be either passive or active
- Perceived information can be biased or filtered



Decision-Making Engine Links Information with Actions

Information Processing - Control Panel Scanning



Control Panel Scan Queue			
	Reactor Power	Reactor Power	~~Reactor Power~~
	Tave	Tave	Tave
	RCS Pressure	RCS Pressure	RCS Pressure
	SG Level	~~SG Level~~	~~SG Level~~
		PZR Level	PZR Level
		CVCS Makeup Flow	~~CVCS Makeup Flow~~
			ECCS Flow
			AFW Flow

The control panel scanning model allows operator information gathering to dynamically evolve as information is perceived

The IDAC Cognitive Model - **D**ecision-Making

- Decision-making engine guides:
  - Goal and strategy selection
  - Procedure following
  - Situational assessment and event diagnosis
  - Knowledge-based activities
  - Mental belief activation
- Based on the recognition primed decision-making model

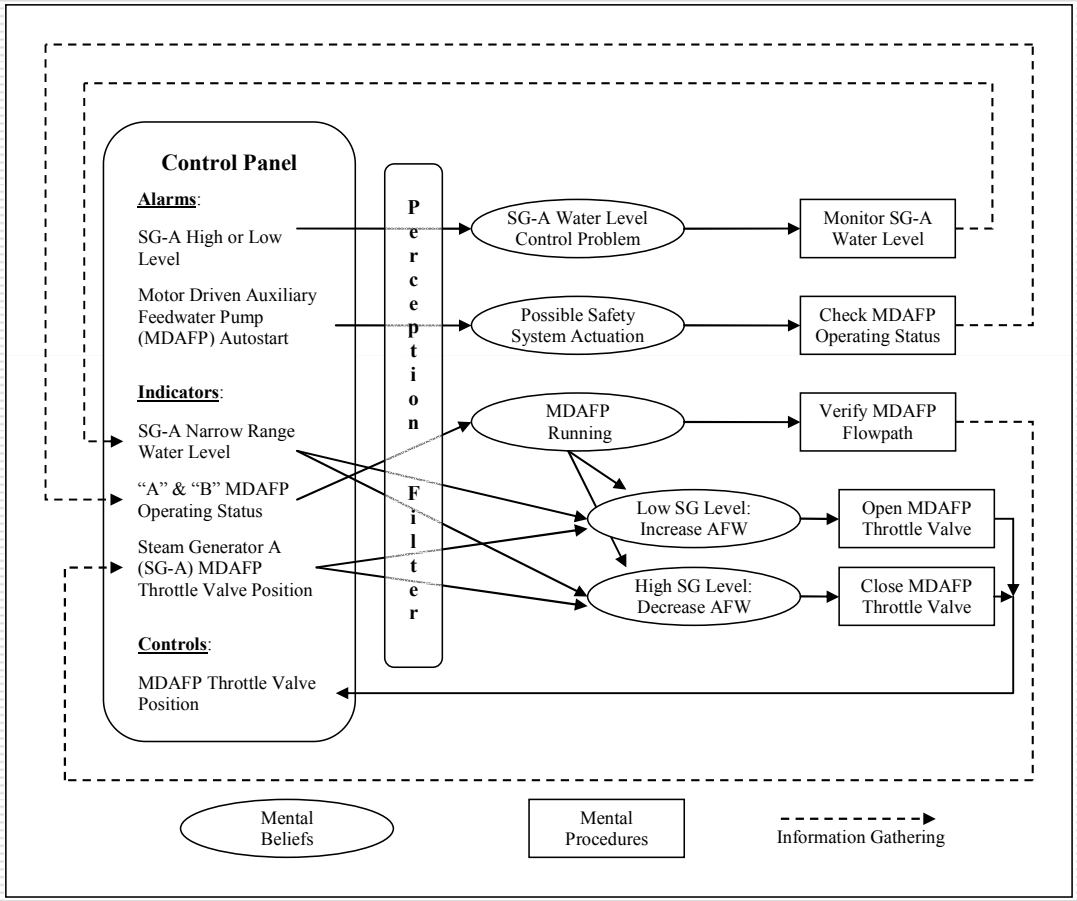
Decision-Making
- Representing Knowledge with Mental Beliefs

- Mental beliefs link perceived information to the operator's situational assessment, decisions, and actions
- Each mental belief has the following properties:
  - prerequisite conditions
  - timing parameters
  - follow-on actions
- Mental beliefs used to model:
  - Non-proceduralized skill- and rule-based actions
  - EOP continuous action steps
  - Diagnostic processes and directed information gathering

Decision-Making
- Representing Knowledge with Mental Beliefs

Auxiliary Feedwater Flow Control

- **Mental model links: (1) indicators & alarms; (2) beliefs; and (3) actions.**
- **Actions include control manipulations and active information gathering**



The IDAC Cognitive Model - **A**ction Execution

- Several categories of human actions are modeled:
  - Procedure directed actions
  - Knowledge-based actions
  - Memorized skill- and rule- based actions
- An error of omission may occur when a procedure step is skipped
- An error of commission may occur when information and decision-making processes lead to inappropriate actions

Action Execution - Procedure Step Skipping

Skip probability based on static and dynamic factors

Static Factors

Type of Step	• Verification Steps • Prerequisite Steps • Decision Steps • Objective-Related Action Steps • Monitoring Steps
Type of Procedure	• EOP/FRG • Normal/Abnormal • Alarm Response • Memorized
Complexity of Actions	• Location of actions • Step structure • Familiarity with action

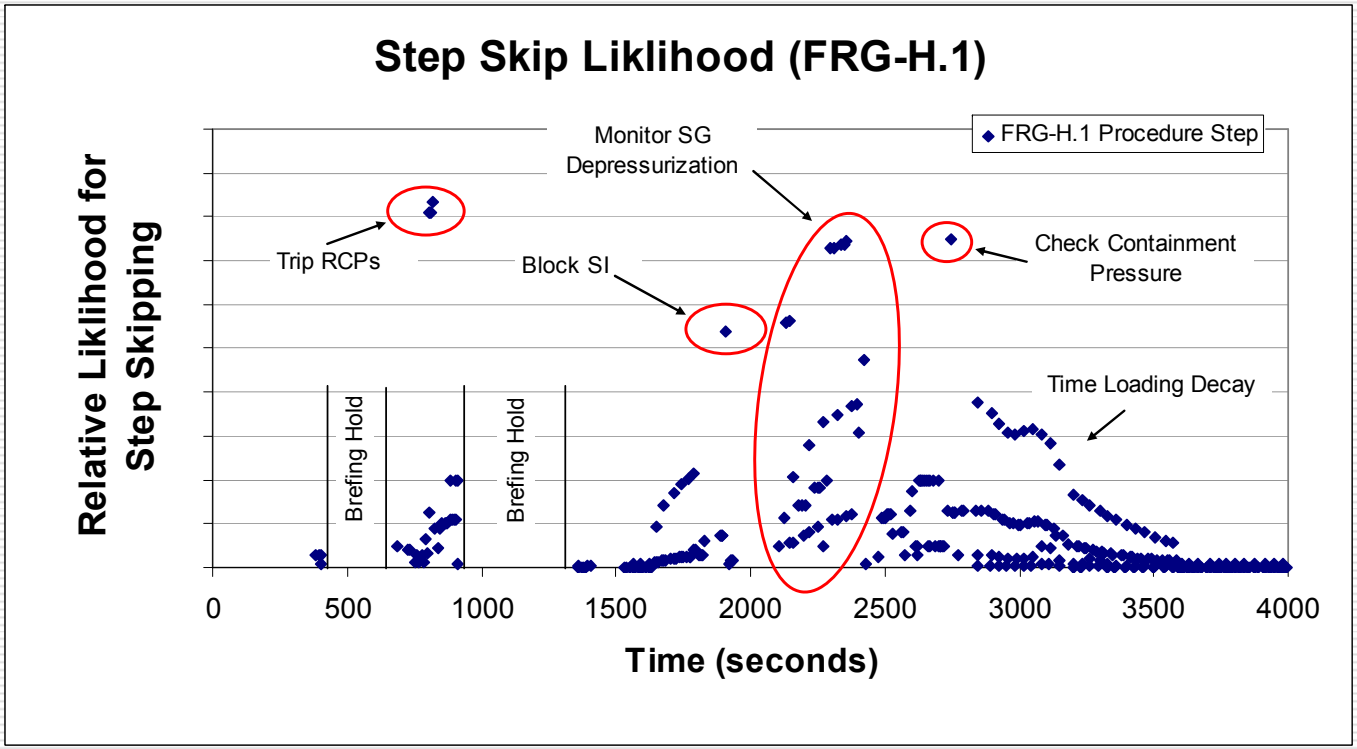
Dynamic Factors

Time Constraint Loading	• Based on time until a critical parameter exceeds a specific threshold • Represents plant dynamics
Action Relevance	• Measures the relevance of the step action to the operator's situational assessment • If the action is closely associated with an identified plant need, the relevance is high

Action Execution
- Procedure Step Skipping

- Likelihood of skipping a procedure step dynamically determined

- Reflects PIFs, information perception, operator knowledge, and procedure characteristics



Verification and Validation

- Data from first international HRA comparison study used to calibrate ADS-IDAC model (SGTR scenario)
- ADS-IDAC can capture a wide range of crew variability with relatively simple behavior rules

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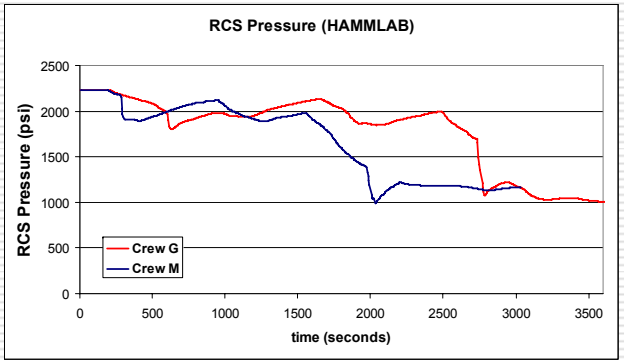
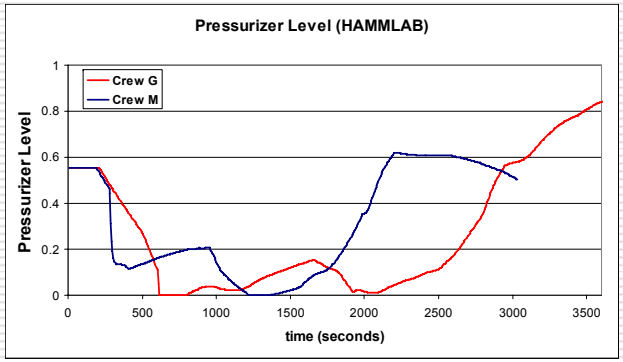
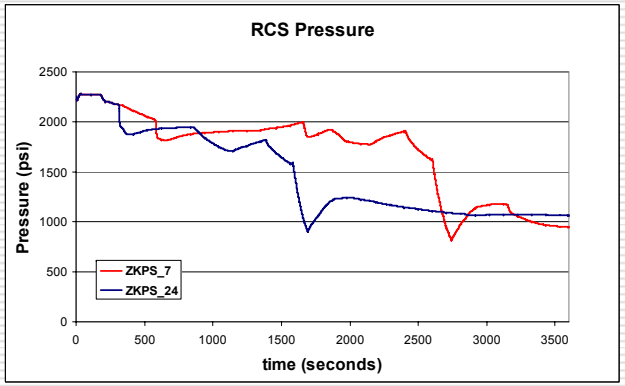
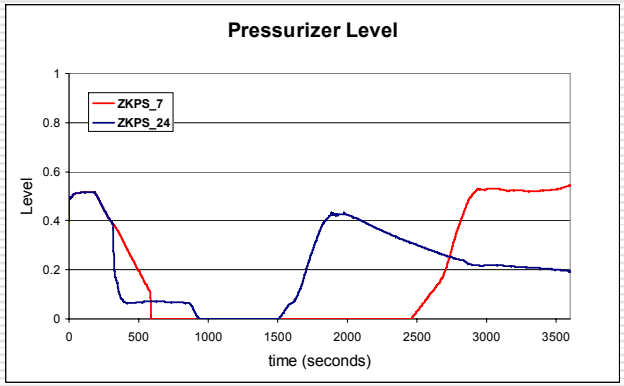




ADS-IDAC





Conclusions

- Recent improvements to the ADS-IDAC code have dramatically improved the realism of plant and operator models.
  - ADS-IDAC is capable of capturing a wide range of crew behaviors within a structured environment
  - The ADS-IDAC knowledge base framework can represent the complex operator mental models of plant behavior that guide crew actions.
  - Calibration process generalizes observed data within the IDAC framework to preserve the predictive capabilities

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