Modeling Nuclear Power Plant Operator Knowledge and Procedural Adherence in the ADS-IDAC Simulation Model

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Presentation Outline

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- Introduction
  - General Overview of ADS-IDAC
  - The IDA Cognitive Model
- Diagnostic Engine
- Plant Functional Decomposition
- Applications
  - Information Gathering
  - Knowledge-Based Actions
  - Procedure Step Skipping

Introduction
- ADS-IDAC Simulation Approach

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)

Introduction
- IDA Cognitive Model

- IDA cognitive model provides framework for information processing, decision-making, and actions
- Operator mental state influences each cognitive process
- Error defined as a failure to meet a plant/system need

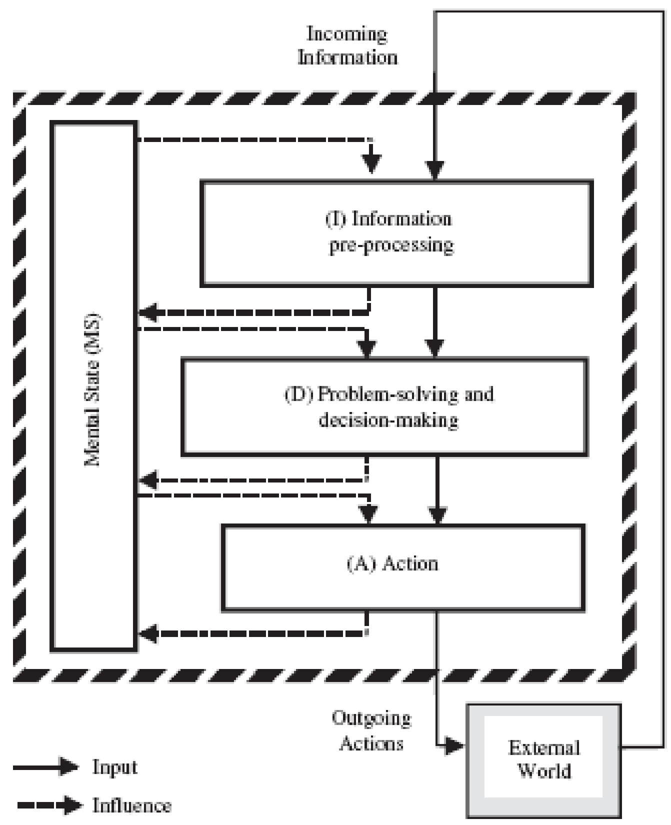
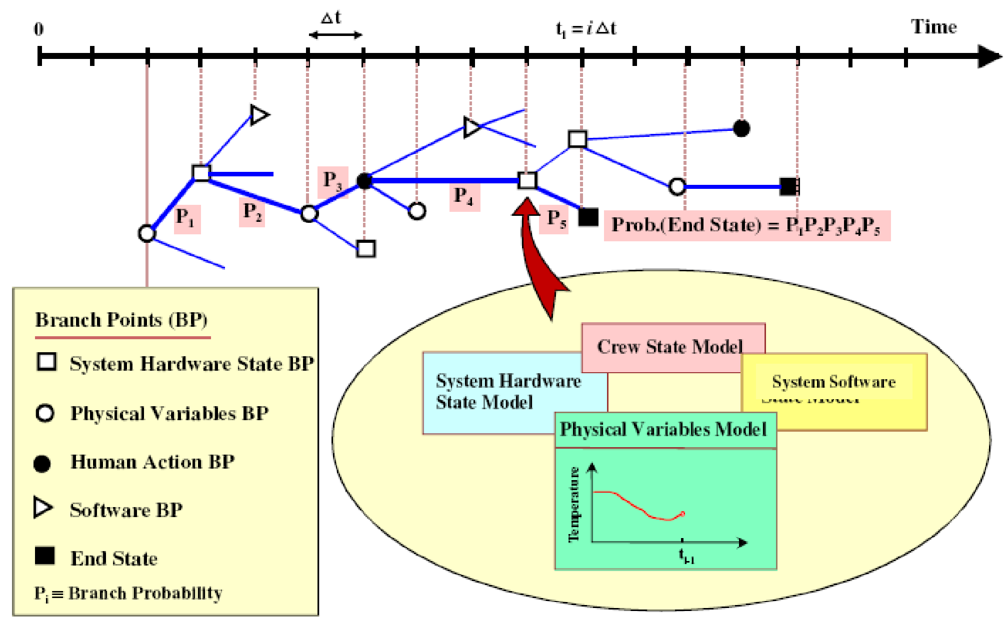


Fig. 2. Operator cognitive flow model.

Introduction
- 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

Diagnostic Engine

- Inference Method Used to Identify Possible Event Diagnoses
  - Diagnosis will influence follow-up actions such as goal and strategy selection, identification of appropriate procedures, or additional troubleshooting
- Two Event Types Are Considered
  - Initiating Events (e.g., LOCA, SGTR) - Classified based on their relative frequency and consequences
  - Imbalance Events. Used to Identify Mass or Energy Imbalances in Major Plant Systems
- Fuzzy Logic Technique Used to Calculate the Likelihood of Possible Events Based on the Operator's Confidence Level in Perceived Plant Symptoms

Diagnostic Engine

- Event-Symptom Relationship Matrix

Initiating Event	Event Category	Associated Parameters									
		Cont. Pressure	Reactor Power	T_{ave}	PZR Water Level	RCS Pressure	RCS Flowrate	MF Flowrate	MS Flowrate	SG Water Level	SG Pressure
Changing Steam Demand	Normal		T	S	T	T		T	P		
Controller Failure - PZR Water Level	Normal				P	T					
Controller Failure - RCS Pressure	Normal					P					
Controller Failure - RCS Temperature	Normal		T	P	S	T					
Controller Failure - SG Water Level	Normal							P		S	
Normal Steady-State Operation	Normal			P		P					
Leak – MF System	AOO							S		P	
Leak – MS System	AOO							T	P		
Leak – RCS	AOO				P	S					
Load Rejection	AOO		T	S	T	T		S	P		S
Loss of Feedwater Flow	AOO			T				P		P	
Loss of RCS Flow	AOO						P				
MS Isolation Valve Closure	AOO		T	S	T	T		S	P		S
RCS Overfill	AOO				P	S					
Reactor Trip	AOO		P	P	S	T		T	T		
ATWS - Loss of Load	Accident		T	S	T	T			P		S
Loss of Coolant Accident	Accident	P			P	P					
MF System Line Break	Accident	P		S				P		P	
MS System Line Break	Accident	P	T	S	T	T		T	P		P
Steam Generator Tube Rupture	Accident				P	S		T		P	
Energy Imbalance - PZR	Imbalance					P					
Energy Imbalance - RCS	Imbalance			P							
Energy Imbalance - SG	Imbalance										P
Mass Imbalance - RCS	Imbalance				P						
Mass Imbalance - SG	Imbalance									P	

P: Primary effects; S: Secondary effects; T: Tertiary effects.

Parameter states based on trends (increasing, decreasing, steady)

Relationship matrix compact method for capturing operator knowledge

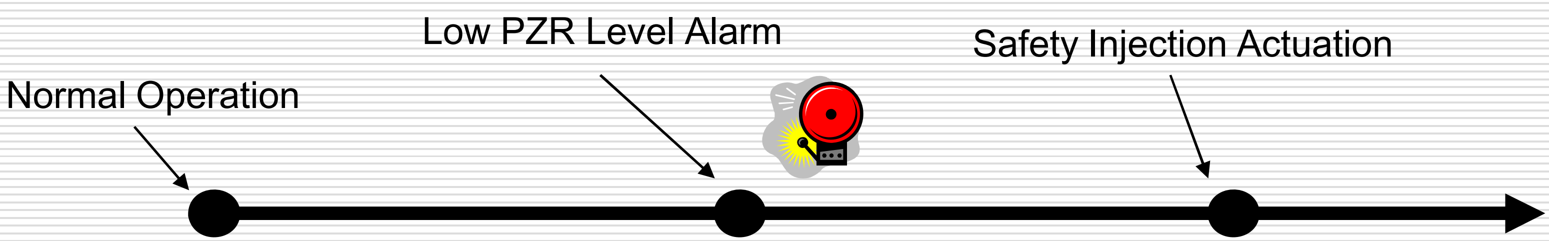
Plant Functional Decomposition

- The ADS-IDAC operator knowledge base links components to functions and functions to diagnostic events
  - All plant components are categorized by the high-level plant functions they support
  - Plant functions are based on controlling mass, energy, and momentum at a system level (e.g., reactor coolant, pressurizer, steam generator, etc.)
  - The diagnosis module used to identify deficiencies in maintaining plant functions

Plant Functional Decomposition

- Model allows operator to identify the relevance of each component to the current plant state
  - For example, a high pressure injection pump has high salience when a deficiency in pressurizer mass control is perceived
- The plant functional decomposition supports key features in the IDA cognitive model:
  - Information Processing – Control Panel Scanning
  - Decision-Making – Knowledge Based Response
  - Action – Procedure Step Skipping

Applications
- Information Processing



Information Collection Priorities (Scan Queue)	Normal Operation	Low PZR Level Alarm	Safety Injection Actuation
	Reactor Power	Reactor Power	Reactor Power (greyed)
	Tave	Tave	Tave
	RCS Pressure	RCS Pressure	RCS Pressure
	SG Level	SG Level (greyed)	SG Level (greyed)
		PZR Level	PZR Level
		CVCS Makeup Flow	CVCS Makeup Flow (greyed)
			ECCS Flow
			AFW Flow

Operator's Information Gathering Focus Shifts as Plant Functional Needs are Identified

Applications
- Knowledge-Based Actions

- Applies the functional decomposition framework and the diagnosis module to support a “reasoning” based approach to problem solving
  - Focuses on restoration of safety functions
  - Each function is associated with specific components (e.g., AFW throttle valves linked to mass balance in SGs)
  - When the operator diagnoses a functional problem, specific actions can be activated
  - This mode of plant interaction is completely independent of the procedure following approach

Applications
- Knowledge-Based Actions

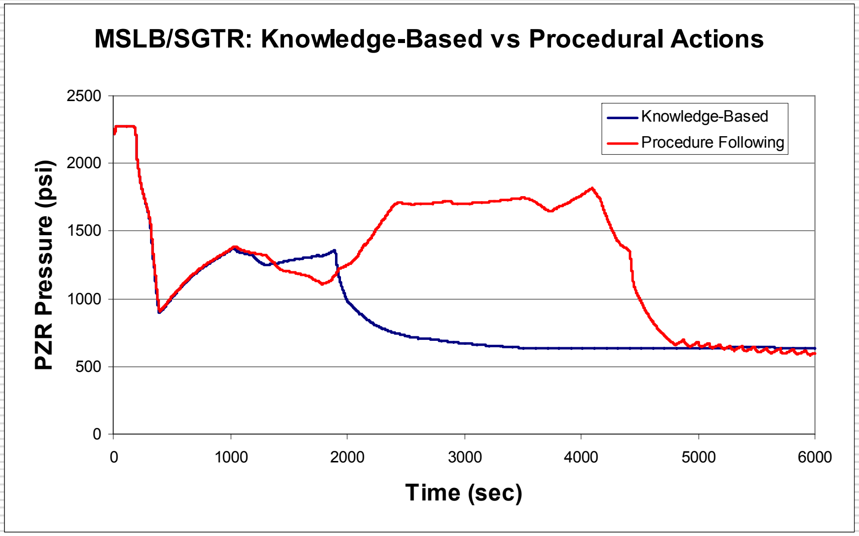
Example Knowledge-Based Actions for a Steam Generator Tube Rupture

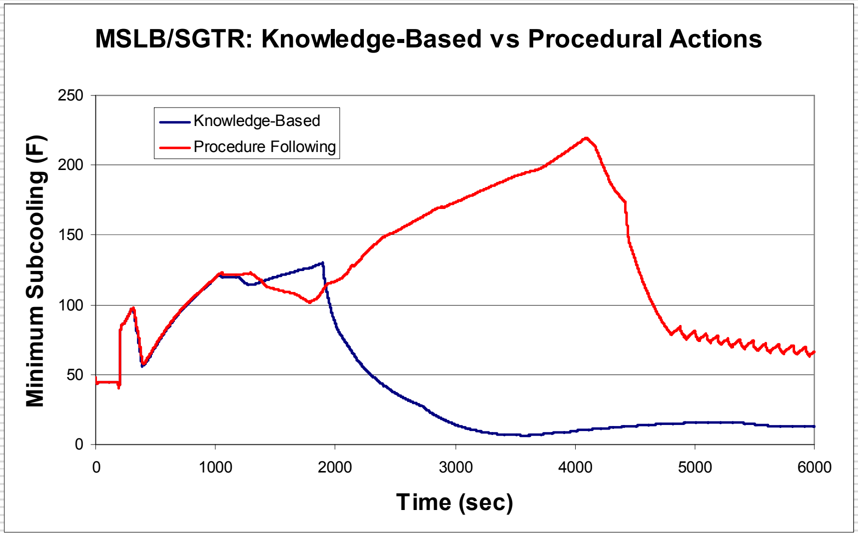
A relatively small number of rules can drive complex plant interactions

Imbalance Diagnosis	Actions	Prerequisites
Low mass in the reactor coolant system	Isolate chemical and volume control system letdown	•Low pressurizer water level
	Actuate emergency core cooling systems	•Low pressurizer water level
High mass in the reactor coolant system	**Stop emergency core cooling injection flow**	**•Adequate sub-cooling margin and pressuizer water level**
Low energy in the pressurizer	Reduce setpoint of SG atmospheric steam dump valves	•Goal to cooldown reactor coolant system activated •Sub-cooling margin less than 10F
High mass in a steam generator	Isolate steam generator (e.g., shut main steam, main feedwater, and auxiliary feedwater isolation valves	•Mental belief that reactor is shut down and a steam generator tube rupture has occurred.
	Open pressurizer spray valve	**•Mental belief that reactor is shut down and a steam generator tube rupture has occurred. •RCS pressure *greater* than ruptured SG pressure**
	Close pressurizer spray valve	•Mental belief that reactor is shut down and a steam generator tube rupture has occurred. •RCS pressure *less* than ruptured SG pressure

Applications
- Knowledge-Based Actions

- Knowledge-based and procedure-based operator response follow different trajectories to achieve similar end states
  - May be useful for potential errors of commission or "jumping" sections within a procedure





Applications
- 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

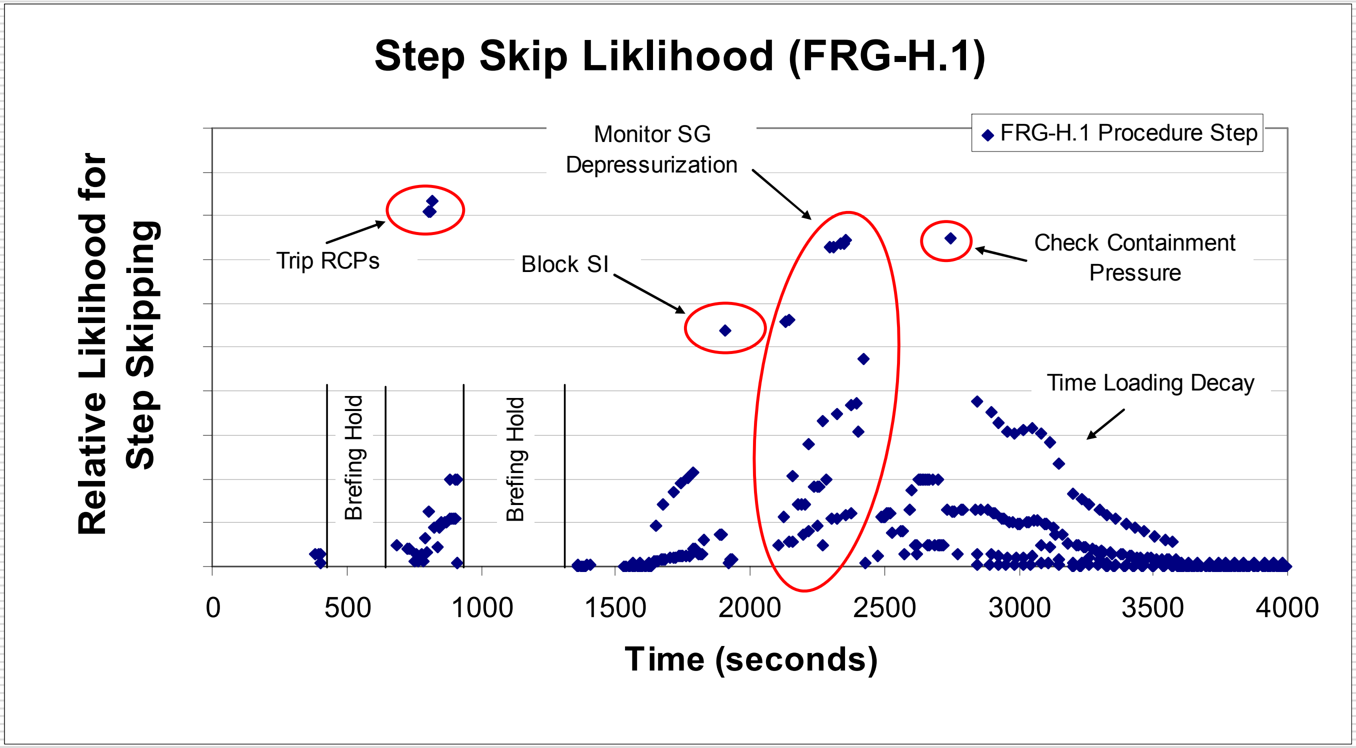
Dynamic Factors

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

Applications
- Procedure Step Skipping

- Likelihood of skipping a procedure step dynamically determined

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



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.

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