Dynamic Modeling of Field Operators in Human Reliability Analysis: An EMRALD and GOMS-HRA Dynamic Model of FLEX Operator Actions

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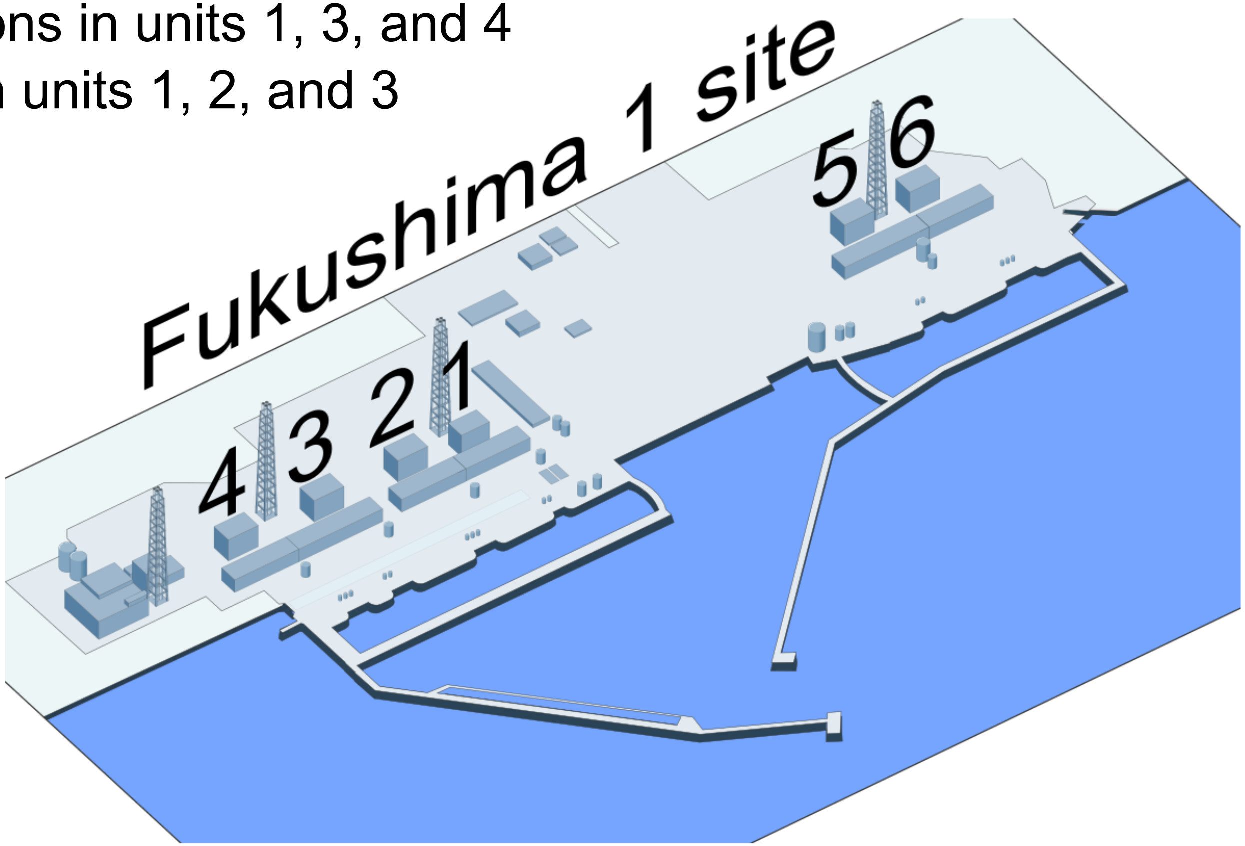
- Beyond-design basis external event (BDBEE), i.e. Tsunami flooded the electrical distribution center and emergency power supplies
  - Extended Loss of Power (ELAP)
  - Loss of core cooling capability
  - Hydrogen explosions in units 1, 3, and 4
  - Core meltdowns in units 1, 2, and 3



FLEX

- Diverse and flexible coping strategies (FLEX) Implementation Guide (NEI 12-06 Rev 4, 2016)
- FLEX consists of the following elements:
  - Both **plant and FLEX equipment** that provide means of obtaining power and water to maintain or restore key safety functions for all reactors at a site
  - Reasonable **staging and protection of FLEX equipment** from BDBEEs applicable to a site
  - **Procedures and guidance** to implement FLEX strategies
  - Programmatic controls that assure the **continued viability and reliability** of the FLEX strategies

GOMS

Way of classifying human actions according to Goals, Operators, Methods, and Selection Rules

- Goals: Tasks to be achieved
- Operators: Elementary perceptual, motor, or cognitive acts
- Methods: Procedure for accomplishing a goal
- Selection rules: Way to chose between competing methods

Developed by Card, Moran, and Newell and considered one of the seminal approaches to human-computer interaction

- Variants like Keystroke Level Model (KLM—*not the airline!*) used extensively to provide timing data to human activities

GOMS-HRA Terminology

Term	Abbreviation	Definition
Task Level Primitive	TLP	A basic human operation occurring at the subtask level. Multiple operations are typically required to achieve specific actions and goals.
Procedure Level Primitive	PLP	A human activity occurring at the procedure step level. Often, multiple task level primitives will be required to achieve a procedure level primitive activity.
Task Level Error	TLE	A nominal human error associated with a task level primitive. Each task level primitives is associated with multiple possible task level errors.

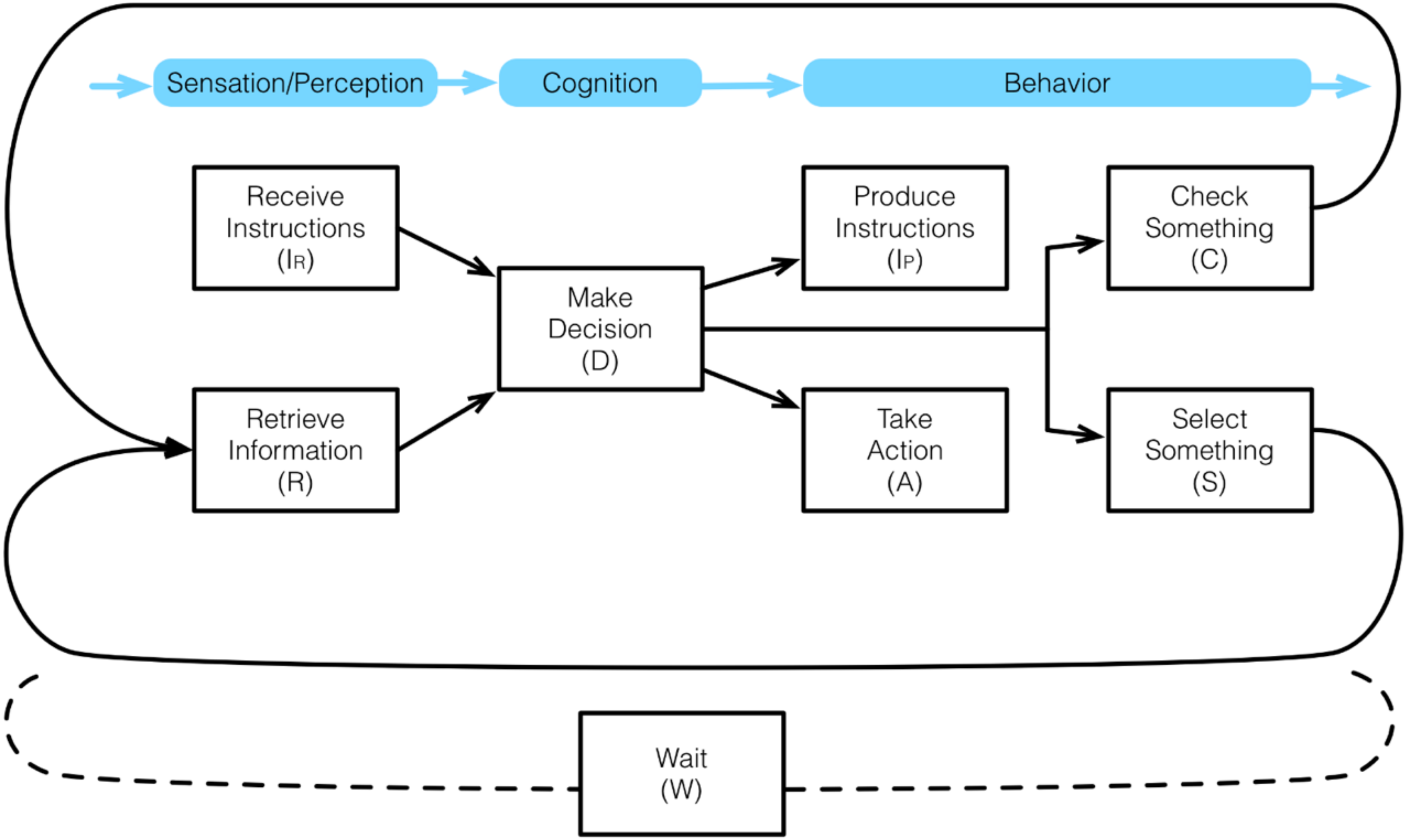
Level of Task Decomposition

GOMS-HRA Task Level Primitives (TLPs)

Each Activity Can Be Decomposed into a Set of Primitives

- *Actions* (A)—Performing required physical actions on the control boards (A_C) or in the field (A_F)
- *Checking* (C)—Looking for required information on the control boards (C_C) or in the field (C_F)
- *Retrieval* (R)—Obtaining required information on the control boards (R_C) or in the field (R_F)
- *Instruction Communication* (I)—Producing verbal or written instructions (I_P) or receiving verbal or written instructions (I_R)
- *Selection* (S)—Selecting or setting a value on the control boards (S_C) or in the field (S_F)
- *Decisions* (D)—Making a decision based on procedures (D_P) or without available procedures (D_W)
- *Waiting* (W)—Period of monitoring until something happens

Task Level Primitive Cognitive Framework



GOMS-HRA Summary Points

GOMS addresses the issue of subtask modeling and lends itself well to adaptation for HRA

- Provides subtasks suitable for dynamic HRA modeling
- Allows ready mapping between procedures and subtasks
  - Operators, of course, do not always follow procedures, but it’s a start
- Provides mapping to HEP values for each subtask
- Provides timing data suitable for dynamic simulation
- Provides likely error types for each task

Does the world need another HRA method?

- Absolutely *not*!
- But, the world needs dynamic HRA, and to that, it needs a better way to handle subtasks in HRA

Dynamic HRA for FLEX

Goal – Use GOMS-HRA with a computation based dynamic simulation tool to model FLEX activities

EMRALD

Event **M**odeling **R**isk **A**ssessment using **L**inked **D**iagrams

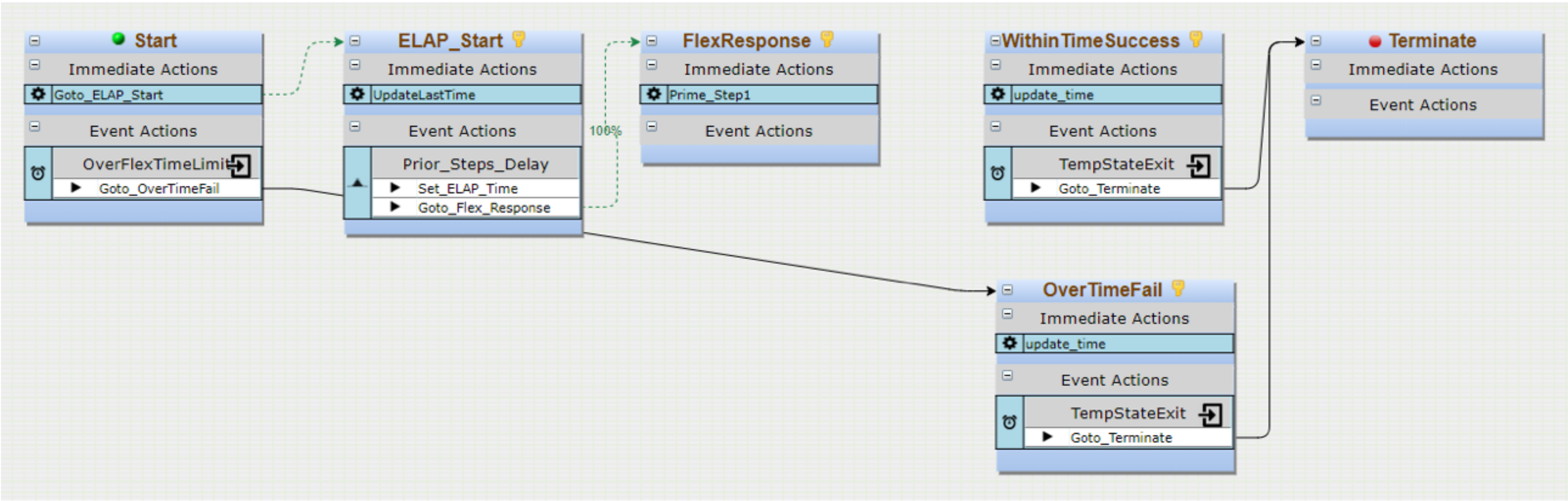
- **Dynamic PRA tool** developed at Idaho National Laboratory
- Discrete Event Simulation (Dynamic modeling)
- Intuitive web-based graphical user interface for modeling
- Basic events, fault trees, event trees
- Open framework for simple coupling with physics codes

GOMS-HRA and EMRALD Modelling Approach

- Proof of concept demonstration and evaluation for FLEX application
  - Limited scope modelling – selected subset of FLEX tasks
  - ELAP Scenario
    - Requires power restoration (assumed and not modelled)
    - Loss of Auxiliary Feed Water (AFW) to the steam generators

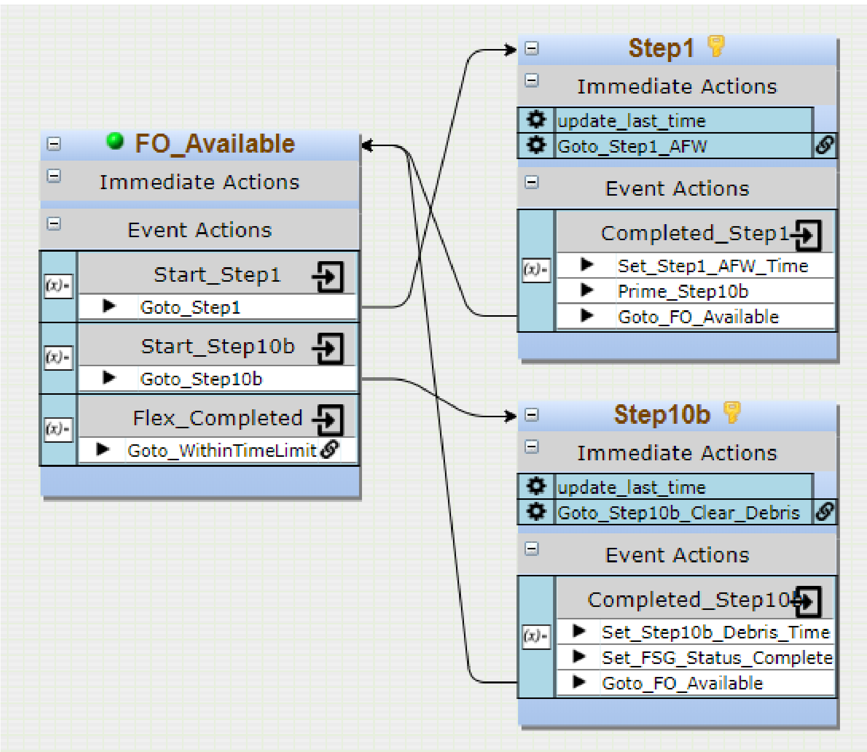
    - Establish makeup flow to steam generators
      - Deploy auxiliary FLEX pump
      - Involves staging process
      - Relies on installation hard cards

Global Model Governing Overall HRA Simulation



- Start Simulation
- Terminate simulation
- Tracks overall time

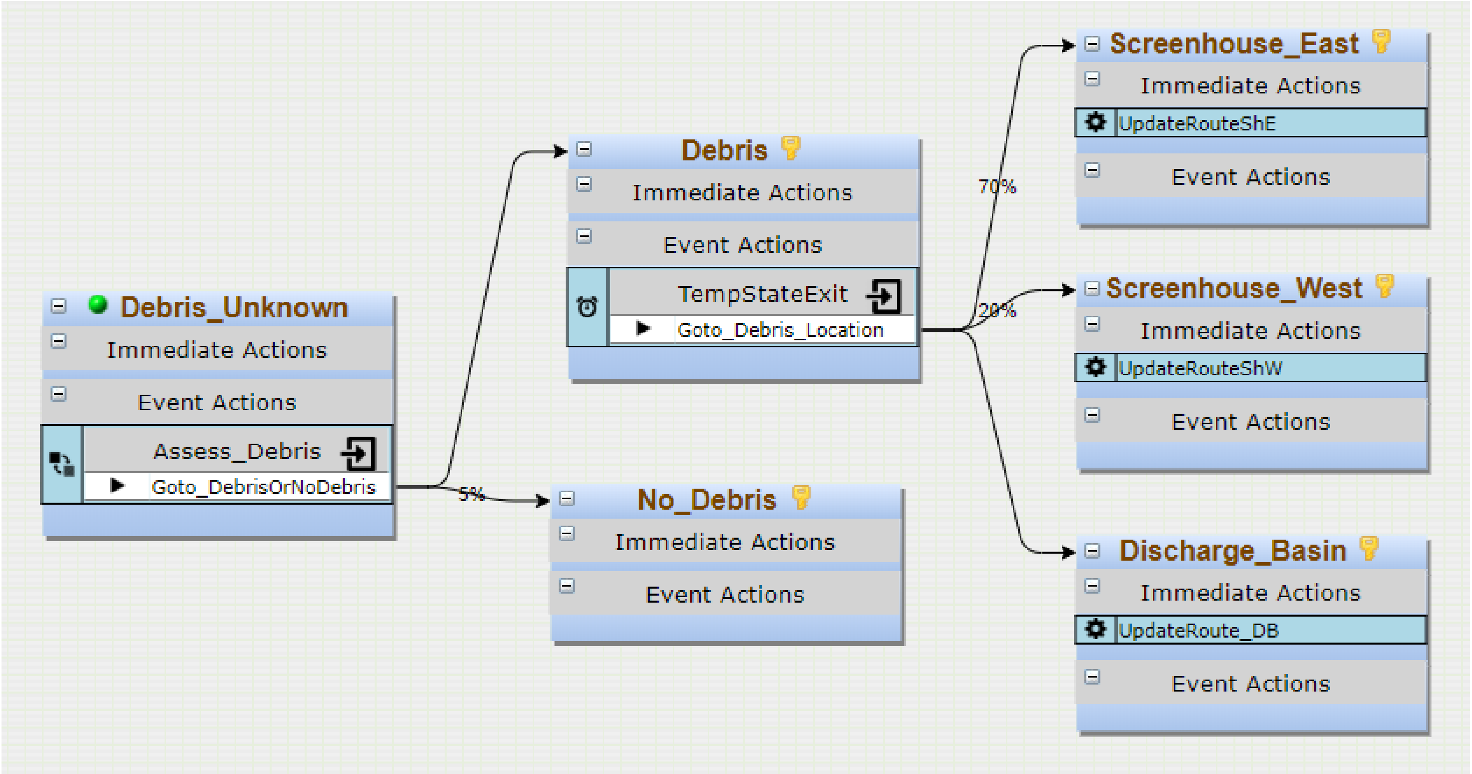
Field Operator Model



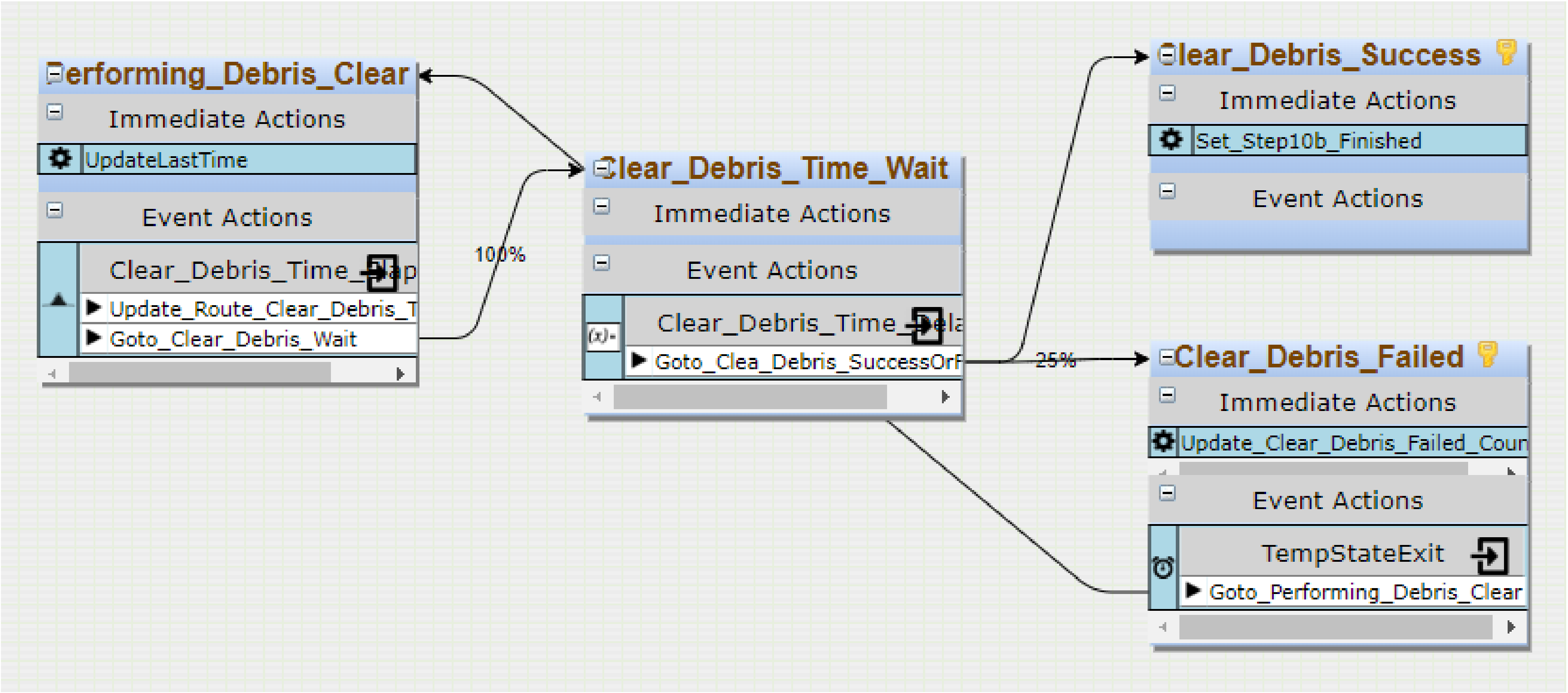
- Operator available or busy
- If busy tracks current activity status
- Container structure for the procedure steps

Staging Procedure Model

- Samples selection of staging location
- Distribution between 3 outcomes
- Tracks time spent clearing debris

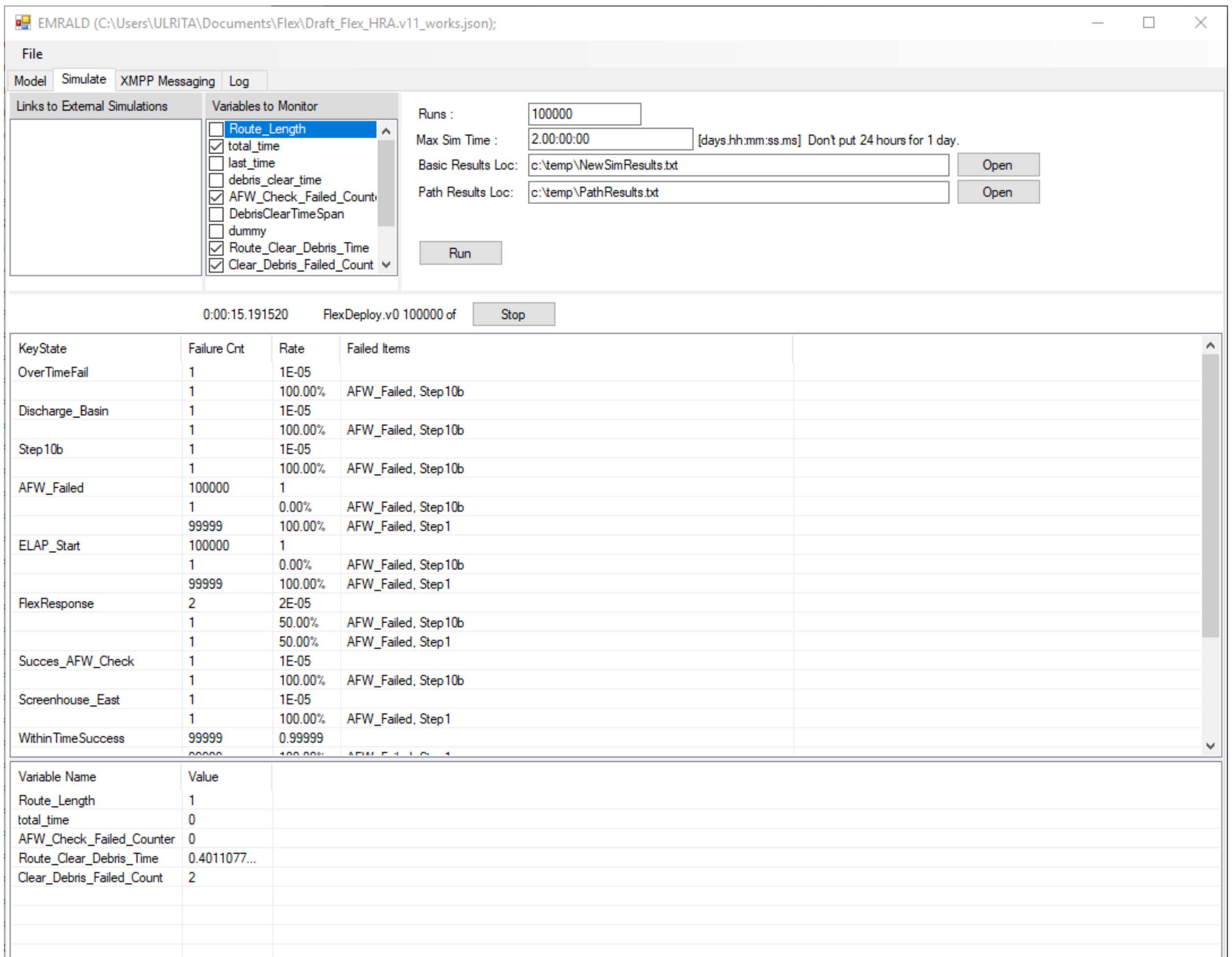


Debris Clearing Activity Model



Results

- Windows based solver engine consumes .json model and outputs Monte Carlo simulation results



GOMS-HRA and EMRALD Modeling Conclusions

Can be used for Dynamic HRA – though a bit cumbersome

1. Linkages between states are tedious
2. Debugging the model is time consuming
3. Updating timing variables requires **manual** variable update
4. Component structure does not align with a human "component"

Future efforts are planned to address these modelling issues

HRA is both modeling *and* data

- Since it's a proof of concept evaluation, PSFs are merely considered and admittedly not implemented well
- We need data on human actions for flex tasks
  - Proves quite challenging

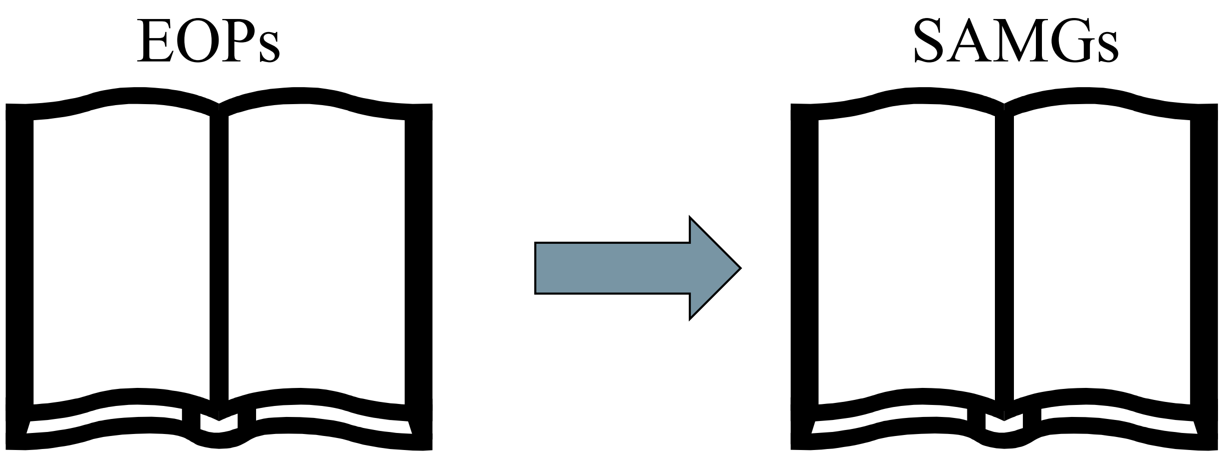
FLEX HRA modeling

Flex is inherently variable

Elevated HEP potential for FLEX Activities

Despite difficulty in data collection it is **crucial** since the conditions may prime **more human errors** than control room operations

FLEX and Severe Accident procedures (SAMGs) may not be written as prescriptive as Emergency Operating Procedures (EOPs)



FLEX Hardcards

SUBMERSIBLE PUMP
HARD CARD

ENSURE the trailer stabilizers are DOWN.

MANEUVER the Boom to the Submersible Pump via the Control Panel <u>OR</u> Remote Controller.

Challenging Context for HRA during severe accidents

- Decision making command control shifts from the control room to the emergency response organization

Challenging Context for HRA during severe accidents

- Information from plant instrumentation required to make decisions is likely less available or less accurate

Challenging Context for HRA during severe accidents

- Critical operator actions that must take place outside the main control room with possible communication issues or environmental issues

Challenging Context for HRA during severe accidents

- Portable temporary equipment may be used that is not as familiar to operators

Shared Equipment – ERO may have to prioritize use for multi-unit accidents

Flex Equipment – ERO may have to prioritize where to deploy for multi-unit accidents

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A Single ERO May Be Responsible for Coordinating Accident Response for Multiple Units in Differing Accident Phases

Quest for Data

HRA is ***both*** the model and the data

- We can build the model but now we need data to validate and refine the model

We **NEED** more data to support modelling with GOMS-HRA

- Timing data
- HEP data for subtask primitives

How do we collect this in such a variable setting?

- Lessons learned from force on force observation data collection
- Specific challenges for FLEX data collection
- Possible solutions to enable more FLEX HRA data collection

Force-on-Force Data Collection Context

- FoF data is highly sensitive
  - Exercise background documents difficult to obtain
  - Eyes only – observer prohibited from timing and note taking
  - Few observers permitted
- Simultaneous activities span entire plant area of control
- SME “Interpreter” required to explain communication and actions

Many of these same challenges map to FLEX activities

Flex Data Collection Challenges

U.S. utilities aren't too keen on sharing their data

- Regulatory and proprietary issues
- Gaining access to data or observation opportunities

Naturalistic Observation Limitations

- Experimental control is nearly non-existent
  - Sample sizes for PSFs under varying conditions are limited
  - Cannot control weather – how do they do this task in 4 feet of water at 2 AM during a hurricane?
- Distributed activities are difficult to capture
  - Requires many more observers than control room
  - Observers may fail to capture key events
- SME interpreter necessary to understand activities

Lessons Learned – Good practices

How to best collect HRA data for severe accidents (FLEX)?

- Identify the best observation location
  - Central Alarm Station for FoF (also most challenging to obtain access)
  - Emergency response command center for FLEX or field or both?

How to enable HRA data collection for severe accidents (FLEX)?

- Could FLEX HRA data be captured with SACADA or HuREX?
  - SACADA concept for researchers?
- Integrate HRA data collection into other experiments
  - Well suited to aid other research collaborations
- Identify analogs – can we collect data from other sources?
  - University partnerships → microworld FLEX?
  - Other industries such as oil and gas

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