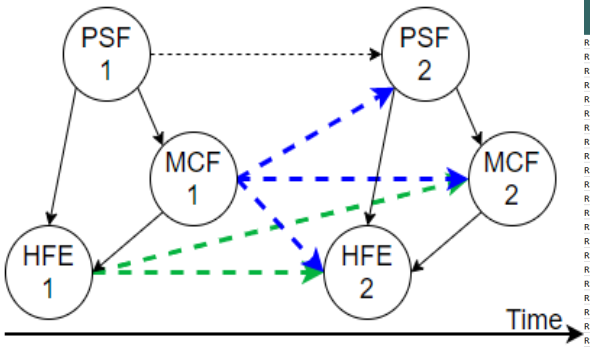
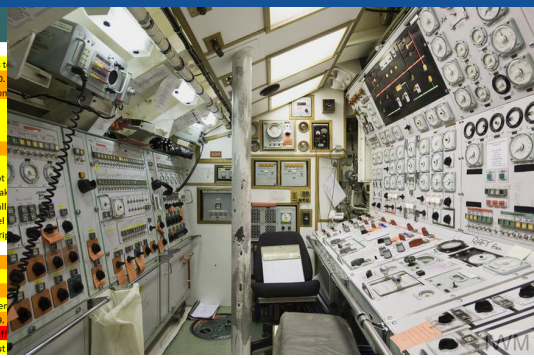


Scenario	Desc.	Year	Cycle	Malf. Order	Malfunction	TOE Order	TOE (training objective element)
RST211.02	Loss Of Heat Sink /Post Trip Steam Gene	2014	1	1	Loss of all SGFPs	1	TRIGGER step 1, Loss of Feedwater.
RST211.02	Loss Of Heat Sink /Post Trip Steam Gene	2014	1	1	Loss of all SGFPs	2	Acknowledges annunciators using directed communications t
RST211.02	Loss Of Heat Sink /Post Trip Steam Gene	2014	1	1	Loss of all SGFPs	3	Directs a manual reactor trip and entry into 0POP05-EO-E000.
RST211.02	Loss Of Heat Sink /Post Trip Steam Gene	2014	1	1	Loss of all SGFPs	4	Perform Immediate 0POP05-EO-EO00 Immediate Actions fro
RST211.02	Loss Of Heat Sink /Post Trip Steam Gene	2014	1	1	Loss of all SGFPs	5	Reports Lockout on E1C
RST211.02	Loss Of Heat Sink /Post Trip Steam Gene	2014	1	1	Loss of all SGFPs	6	Stops SDG 13
RST211.02	Loss Of Heat Sink /Post Trip Steam Gene	2014	1	1	Loss of all SGFPs	7	Takes SG C PORV, to manual.
RST211.02	Loss Of Heat Sink /Post Trip Steam Gene	2014	1	2	Loss of All AFW Flow Rec	1	Transition to 0POP05-EO-ES01
RST211.02	Loss Of Heat Sink /Post Trip Steam Gene	2014	1	2	Loss of All AFW Flow Rec	2	Crew begins monitoring Critical Safety Functions.
RST211.02	Loss Of Heat Sink /Post Trip Steam Gene	2014	1	2	Loss of All AFW Flow Rec	3	At ES-0.1 step 3, crew recognizes that 'A' and 'C' MDFP are not
RST211.02	Loss Of Heat Sink /Post Trip Steam Gene	2014	1	2	Loss of All AFW Flow Rec	4	(Prior to ES-0.1, step 8) Notices and reports NO AFW Flow ma
RST211.02	Loss Of Heat Sink /Post Trip Steam Gene	2014	1	2	Loss of All AFW Flow Rec	5	At ES-0.1 step 8, crew recognizes that SG levels have been fall
RST211.02	Loss Of Heat Sink /Post Trip Steam Gene	2014	1	2	Loss of All AFW Flow Rec	6	(After ES-0.1, step 8) Notices and reports decreasing SG Level
RST211.02	Loss Of Heat Sink /Post Trip Steam Gene	2014	1	2	Loss of All AFW Flow Rec	7	Notifies Owners of the Rx. Trip within 15 minutes of a unit tri
RST211.02	Loss Of Heat Sink /Post Trip Steam Gene	2014	1	2	Loss of All AFW Flow Rec	8	Dispatches PO to check valve line up on B SG
RST211.02	Loss Of Heat Sink /Post Trip Steam Gene	2014	1	2	Loss of All AFW Flow Rec	9	Reports criteria to enter FRH1 is met.
RST211.02	Loss Of Heat Sink /Post Trip Steam Gene	2014	1	2	Loss of All AFW Flow Rec	10	Determines FRH1 is required.
RST211.02	Loss Of Heat Sink /Post Trip Steam Gene	2014	1	2	Loss of All AFW Flow Rec	11	ENTERS and Directs FRH1
RST211.02	Loss Of Heat Sink /Post Trip Steam Gene	2014	1	2	Loss of All AFW Flow Rec	12	Determines Bleed and Feed is Required based on requiremer
RST211.02	Loss Of Heat Sink /Post Trip Steam Gene	2014	1	2	Loss of All AFW Flow Rec	13	Determines Feed & Bleed is required based on FR-H.1 step 9,
RST211.02	Loss Of Heat Sink /Post Trip Steam Gene	2014	1	2	Loss of All AFW Flow Rec	14	Initiate RCS bleed and feed so that the RCS depressurizes suff
RST211.02	Loss Of Heat Sink /Post Trip Steam Gene	2014	1	3	Commences FEED and BL	1	Determines Recirc valve is open and orders AF-009 to be shut



Can HRA Data Address HFE Dependency?

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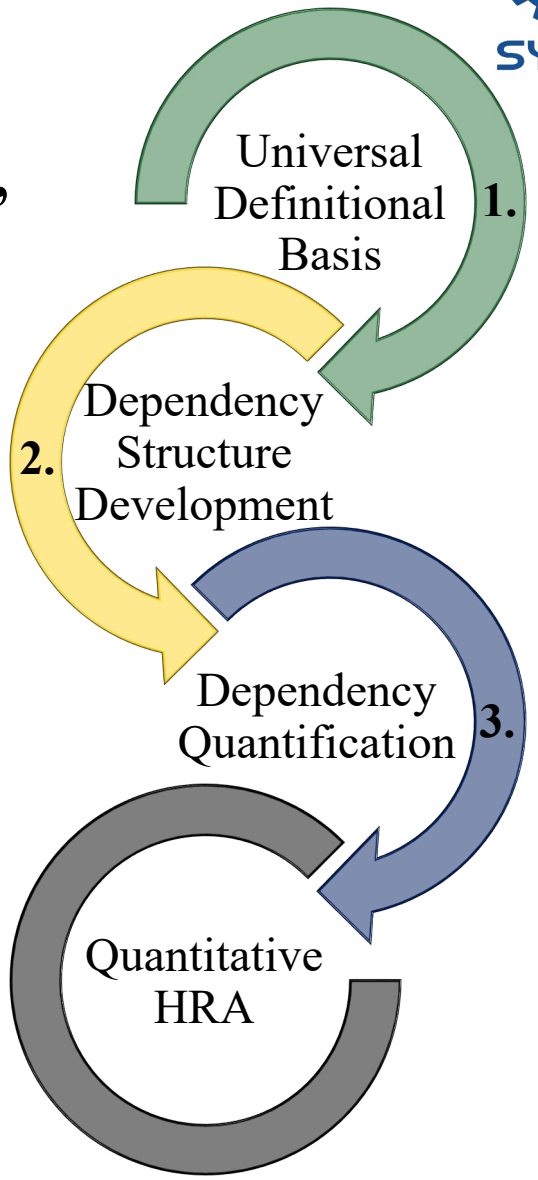
Center for Risk and Reliability

NRC HRA Data Workshop, 2020 March 13

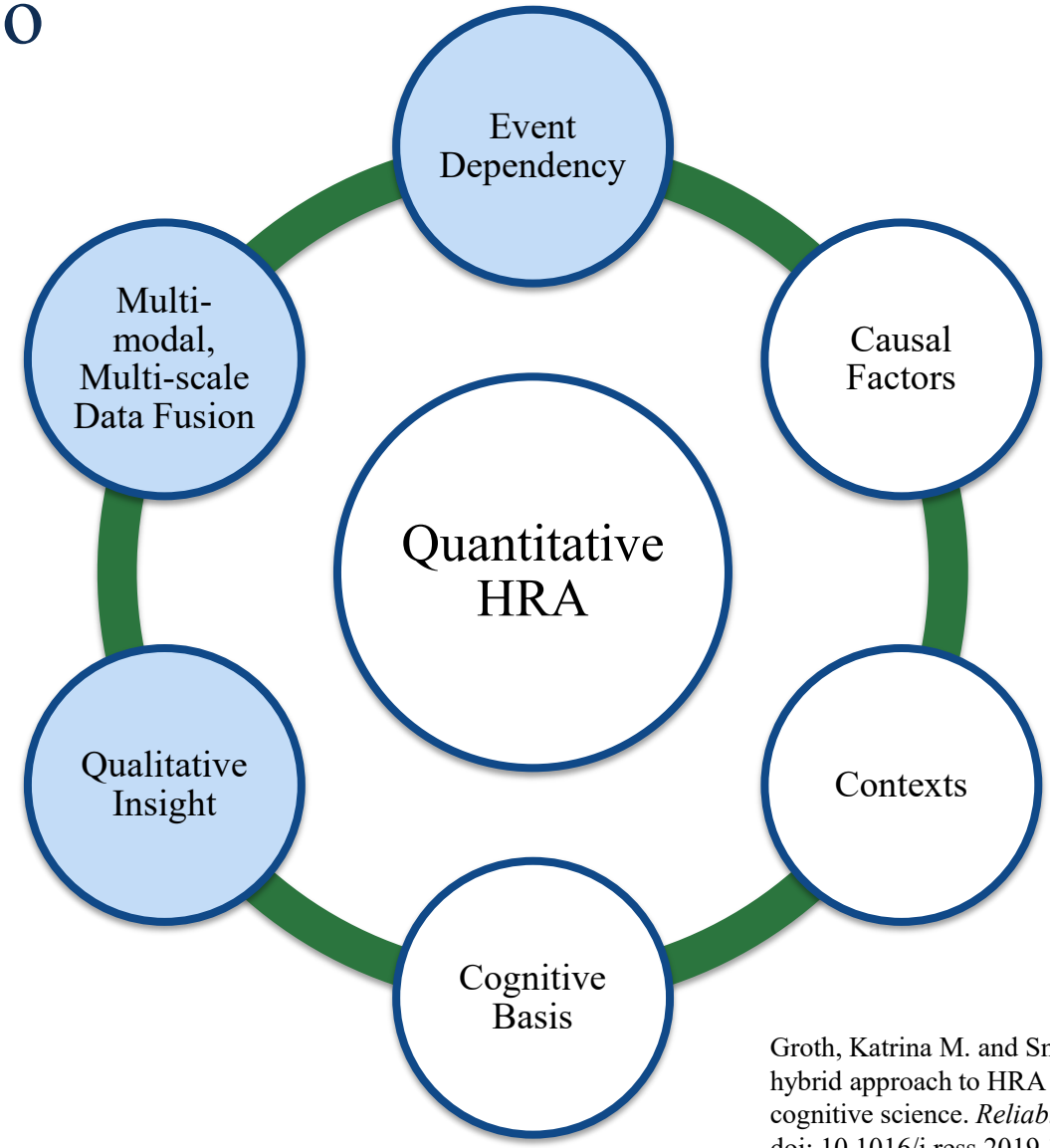
Research Objectives and Tasks

Develop the theoretical & mathematical foundations to model "HRA dependency" and enable parameterization using multiple HRA data sources

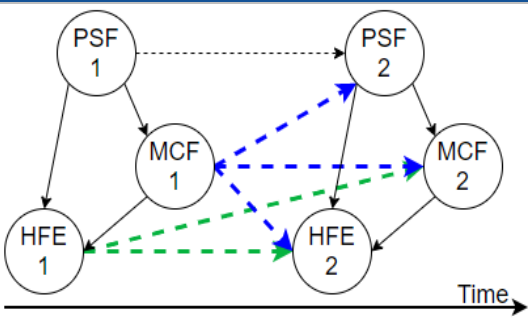
- **Task 1:** Define key terminology (both words and equations).
- **Task 2:** Develop the mathematical framework for modeling HRA dependency.
- **Task 3:** Mathematical framework for quantifying dependency using HRA data.

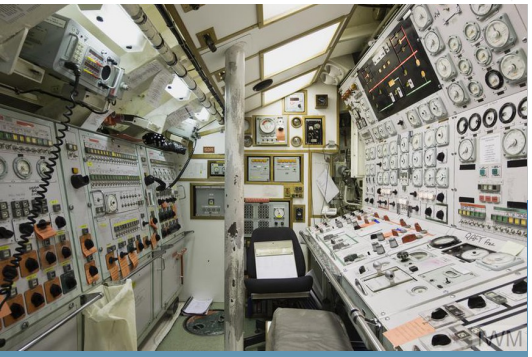


Context for this research within UMD HRA portfolio



Groth, Katrina M. and Smith, Reuel and Moradi, Ramin. (2019). A hybrid approach to HRA using simulator data, causal models, and cognitive science. *Reliability Engineering and System Safety*, 191. doi: 10.1016/j.ress.2019.106507





Outline

1. Motivation for studying (HFE) dependency in HRA
   - Current Treatment
   - Complications
   - Opportunities
2. Progress on definitions
3. Plans for addressing dependency with HRA data

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Current Treatment of Dependency in HRA is based on THERP

- The need to consider the effects of dependent events was identified in THERP
  - Expert elicitation used to assess the dependency level between two events, limited to a 5-point scale from Complete (CD) to Zero Dependence (ZD), $k \in \{0, 1, 6, 19, \infty\}$:

$$\text{cHEP} = \frac{1 + k \cdot n\text{HEP}}{k + 1}$$

- Most current HRA methods employing dependency rely on THERP-derived approach

Gaps and limitations of current treatment

- Weak technical basis for HFE dependency assessments, need for more:
  - **Traceability:** no consistent scientific basis for assigning dependence level
  - **Realism**: dependency is more nuanced than a simple 5-point scale
  - **Consistency**: assigned dependence level heavily influenced by the expert
- Need to define appropriate methods for capturing & modeling dependency between HFEs
  - Consistent with modern, data-driven, cognitively-based causal approaches to HRA.

Literature demonstrates a long-term need for clarity around the concept of dependency

Authors	Year	Findings
Blackman & Boring	2017	• Dependency assessment in SPAR-H. • Dependency treatment can cause spurious quantification of errors if applied frequently.
Herberger & Boring	2016	• THERP dependence approximates dependencies between two HFEs. • Dependency terminology partially defined: intersection, union, independence, disjoint and dependence.
Bao et al.	2013	• PSF-HFE dependency. • A dependency treatment method based on fuzzy theory and BN combined with CREAM method.
Čepin	2008	• Comparison between SPAR-H and IJS-HRA. • Subjectivism impacts the HRA results. • There is need for detailed guidelines on HRA dependency.
Čepin	2008	• There is a gap between the theory of HRA methods and their use in PRA. • A method for dependency treatment between HFEs in PRA, including pre-initiators, post-initiators, and initiators.
Whaley et al.	2007	• A dependency treatment guideline for THERP-based dependency models.
Barriere et al.	1995	• Dependencies between HFEs.

Opportunity for improvement via deeper research

- Current industry efforts focus on developing better guidance for using the dependency equations in existing HRA methods
- Research efforts need to go beyond near-term industry concerns.

HRA requires:
1. Clarification about the meaning of dependency
2. New, data-informed models
…and more urgently than it needs prescriptive guidance for use of existing models

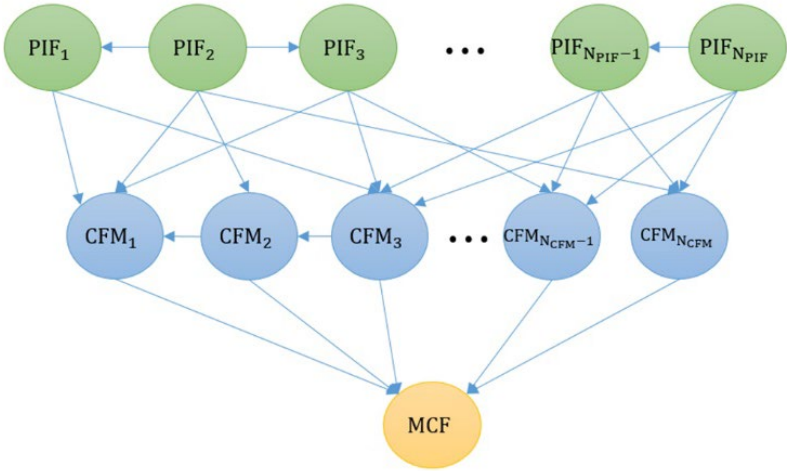
Task 1: Define clear terminology & definitions

- **What does dependency actually mean in the context of HRA?**
- Resolve significant conceptual problems & misuse of mathematical terminology within HRA:
  - "HRA dependency"
  - Crew failure mode / HFE / Major crew function / PIF
  - Probability of [multiple HRA concepts] & uncertainty
  - Conditional vs. joint vs. marginal probability $\Pr(A|B)$, $\Pr(A \cap B)$, ...

Overheard at PSAM "Probability of human error is just number of failures out of number of opportunities. We just need to count things."

Recent work at UMD defined a generalized set of HRA quantification elements – these can all be "dependent"

- 3 Core types of variables:
  - Performance influencing factors (PIFs)
  - Crew failure modes (CFM)
  - Major Crew Functions (MCFs)



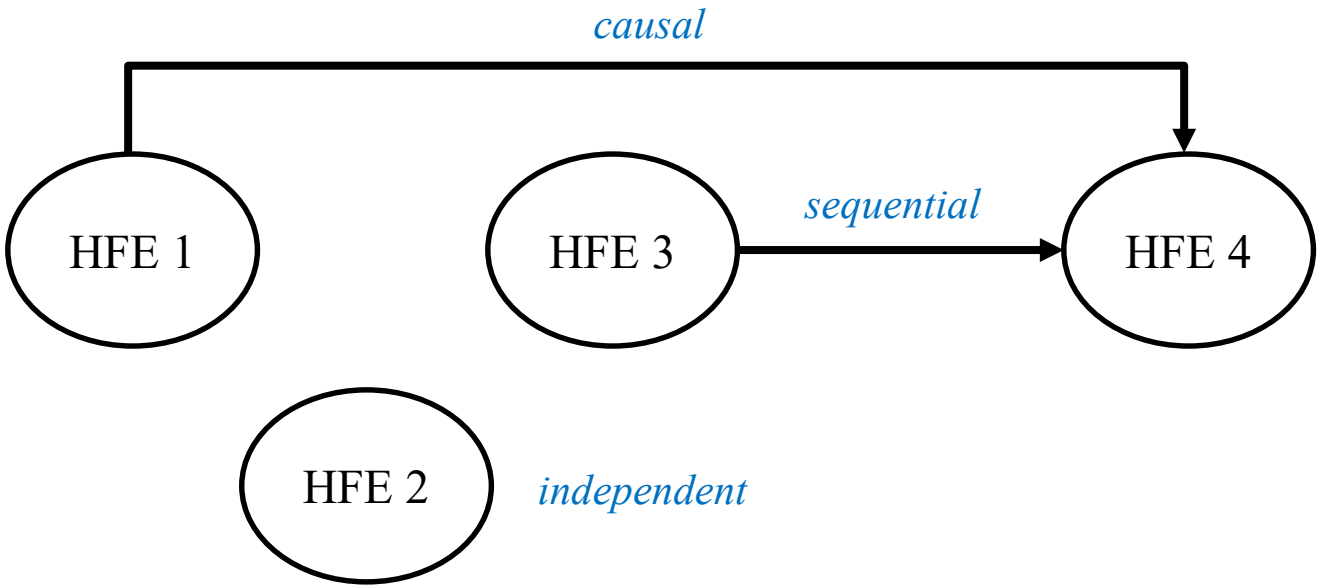
- 5 core types of probabilistic relationships need to be quantified (4 of which involve dependency):

$$\Pr(PIF_x)$$
$$\Pr(PIF_x|pa(PIF_x))$$
$$\Pr(CFM_k|pa(CFM_k))$$
$$\Pr(MCF_i|pa(MCF_i))$$
$$\Pr(HFE|MCFs))$$

Groth, Katrina M. and Smith, Reuel and Moradi, Ramin. (2019). A hybrid approach to HRA using simulator data, causal models, and cognitive science. *Reliability Engineering and System Safety*, 191. doi: 10.1016/j.ress.2019.106507

Event relationships

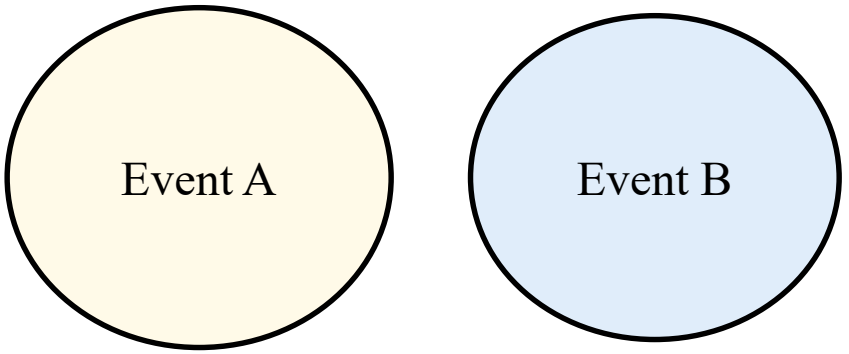
- Events can be:
  - Independent
  - Mutually exclusive
  - Dependent
- Dependency can come from:
  - Sequential relationships
  - Multiple types of causal relationships



Definition of mutually exclusive (disjoint)

- Two events are *mutually exclusive* if they cannot both happen at the same time
  - $Pr(A|B) = Pr(B|A)=0$
  - $Pr(A \cap B) = 0$
  - E.g.: A = HFE occurs, B = HFE does not occur

- Mutually exclusive = Maximum negative dependence



Venn diagram for two mutually exclusive events.

Herberger, S. M. and R. L. Boring (2016, 10). Human failure event dependence: What are the limits. In PSAM 2016 - 13th International Conference on Probabilistic Safety Assessment and Management.

Definition of independent events and dependent events

- **Independent events**:

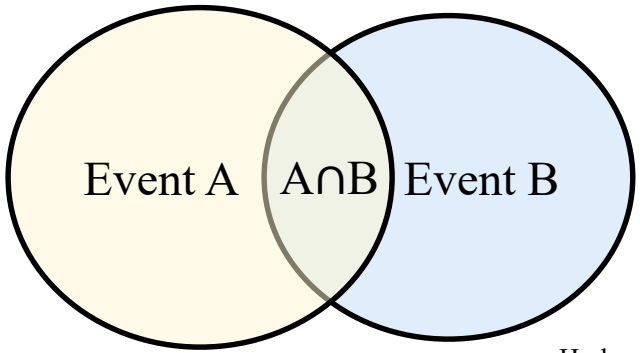
the occurrence of one does not depend on or change the probability of the occurrence of the other:

  - $Pr(A|B) = Pr(A)$
  - $Pr(A \cap B) = Pr(A)Pr(B)$

- **Dependent events**:

the occurrence of one event *changes* the probability of the occurrence of the other:

  - $Pr(A|B) \neq Pr(A)$
  - $Pr(A \cap B) = Pr(A|B)Pr(B)$

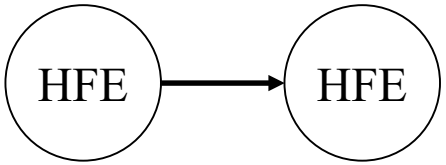


Venn diagrams for both cases is the same – cannot distinguish independence from dependence.

Herberger, S. M. and R. L. Boring (2016, 10). Human failure event dependence: What are the limits. In PSAM 2016 - 13th International Conference on Probabilistic Safety Assessment and Management.

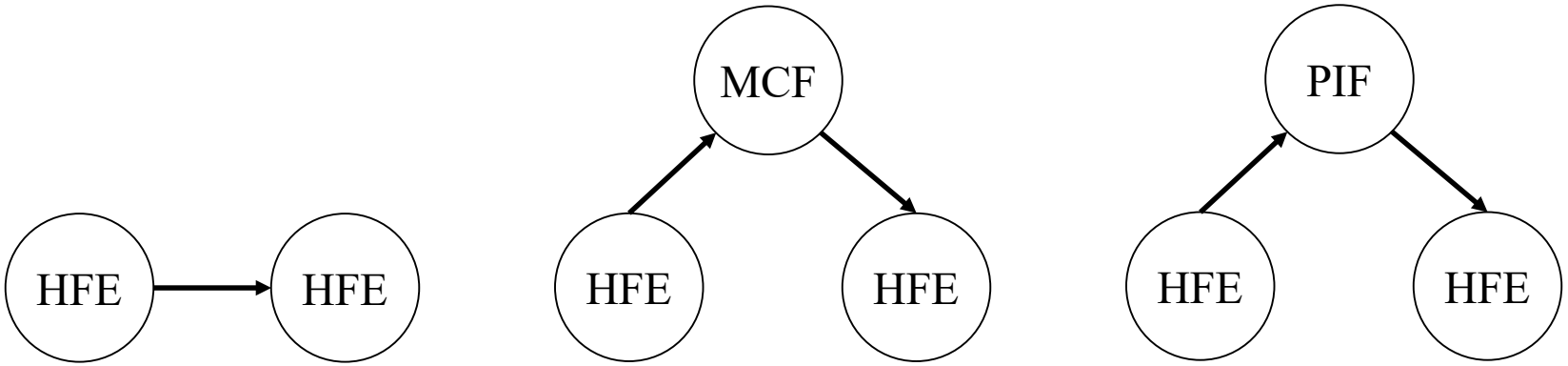
Working results: Dependency definition

- Classically: dependency as "error begets error" paradigm
  - Occurrence of a failure increases the probability of a subsequent failure
  - Direct, causal dependency



- Proposal: nuanced conception of dependency

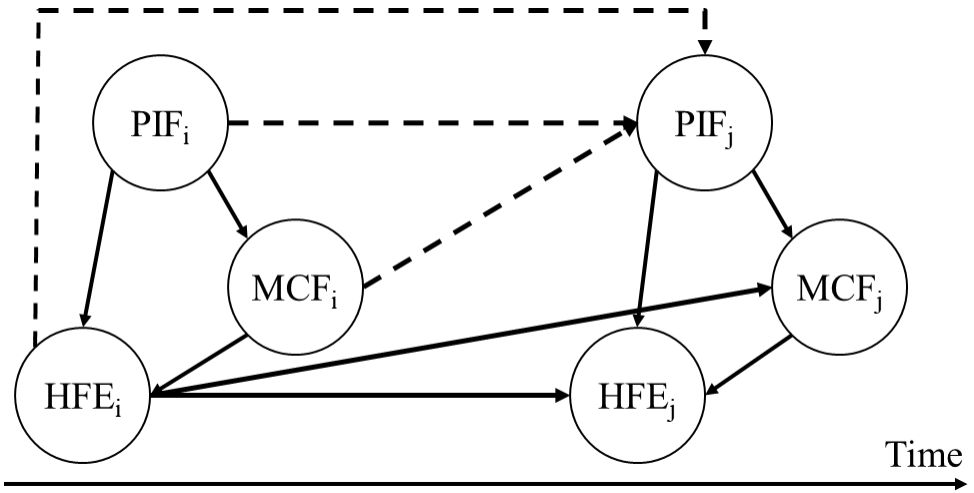
$$\Pr(\text{HFE}|\text{HFE}), \Pr(\text{HFE}|\text{MCF}), \Pr(\text{HFE}|\text{PIF})$$
$$\Pr(\text{MCF}|\text{MCF}), \Pr(\text{MCF}|\text{PIF})$$



Working results: Dependency structures

- Two broad categories of dependency relationships:
  - Direct
  - Indirect

- Three identified relationship types, based on De Ambroggi & Trucco, Fenton & Neil, Boring et al., Groth et al.
  - State dependence
  - Situational dependence (dash)
  - Effect-modulating dependence



Next steps: HRA data brings opportunities for being rigorous about the concept of dependency

- It's easy to theorize about possible dependency relationships, **but data is needed to determine realistic relationship structures & quantification**
- HRA data offers a thorough and useful source of scientific information which can inform dependency
  - Qualitative
  - Structural (logic)
  - Quantitative

Next steps: Exploring HRA Data connection to dependency models

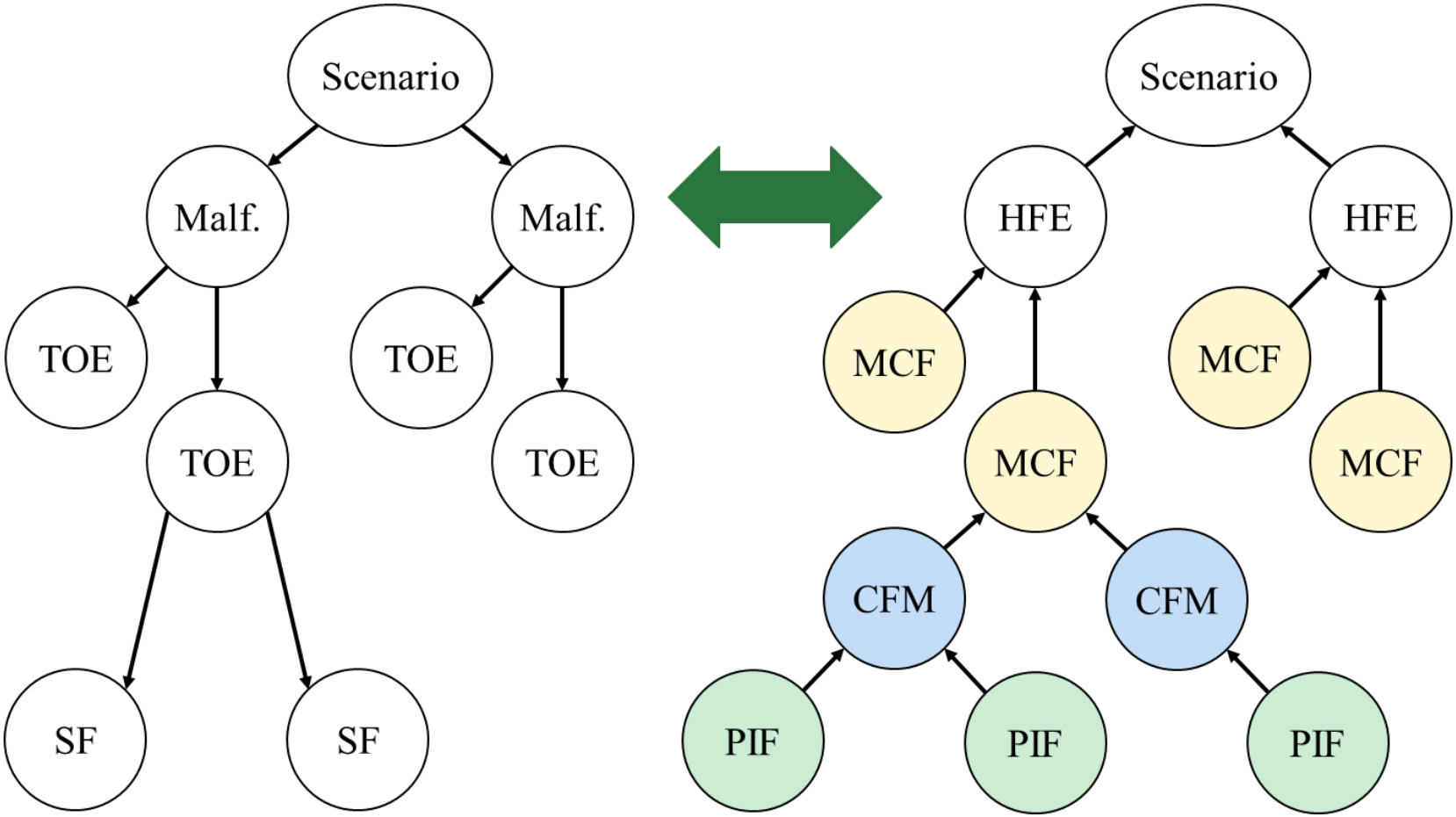
1. Mapping specific HRA data variables (e.g., SACADA) onto the generalized HRA quantification elements (MCF, PIF, HFE) from Groth 2019
    1. Within SACADA data structure: UNSAT Training Objective Elements (TOEs) ⟺ HFE level
2. Multiple UNSAT TOEs by the same Crew in a single 'Malfunction' ⟹ High value data for thinking about HFE dependency

Level	Total (Unique)	UNSAT/SATΔ (Unique)
Scenarios	21 (7)	14 (6)
Malfunctions	49 (14)	19 (10)
Training Objective Elements (TOEs)	369	27
Situational Factors (SFs)	29	22

Mapping SACADA elements onto generalized HRA quantification elements

SACADA Variables
(Chang et al. 2014)

HRA Quantification Elements
(Groth et al. 2019)



Next steps

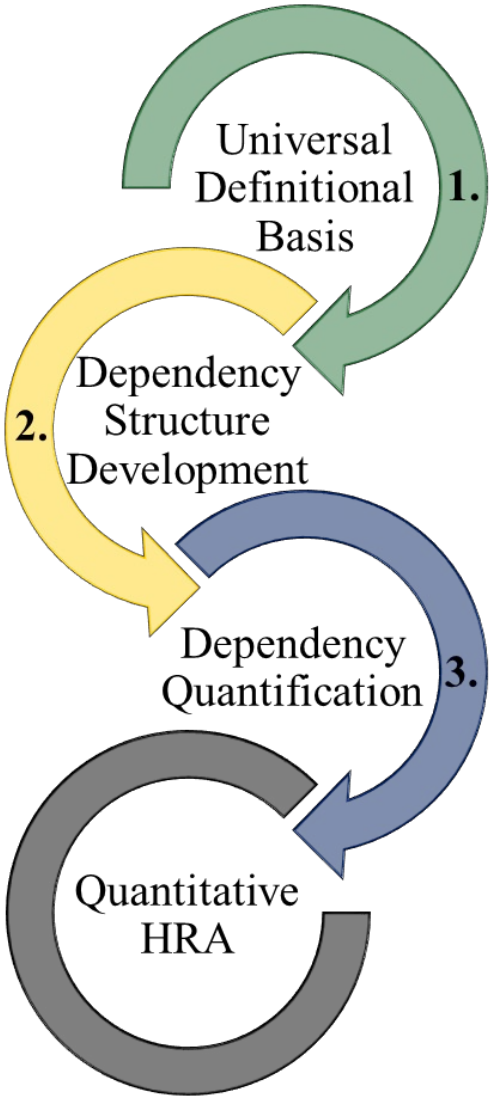
- ESREL 2020: Paglioni, Vincent P. and Groth, Katrina M., "Unified Definitions for Dependency in Quantitative Human Reliability Analysis"
- Spring & Summer 2020: Further refinement of dependency types and definitions for HRA → Journal paper draft

- Dissertation year 3: Use HRA data to identify and quantify dependency relationships in BN models
  - Serial HFE-level failures in publicly-available dataset
  - Pr(HFE|HFE)
  - Pr(HFE|PIF)

Conclusions: HRA Data & HFE Dependency

- Dependency can be defined more rigorously in HRA
  - Doing so entails mathematics & words
  - Modeling dependency entails considering HFEs and other constructs (PIF, MCF, CFMs) and using causal models
- HRA data sources offer a useful avenue for investigating dependency structures between HFEs and high-level tasks:

  $\Pr(\mathrm{HFE}|\mathrm{HFE})$, $\Pr(\mathrm{HFE}|\mathrm{MCF})$



Thank you!

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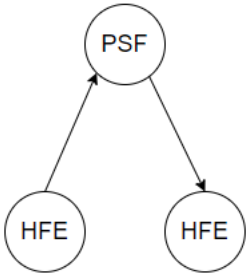

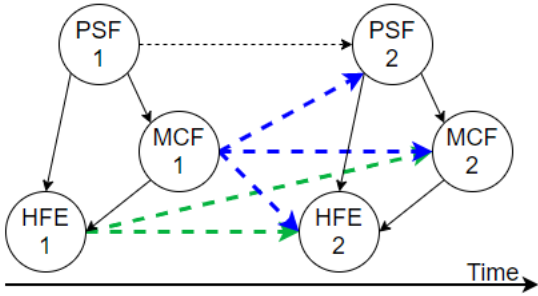

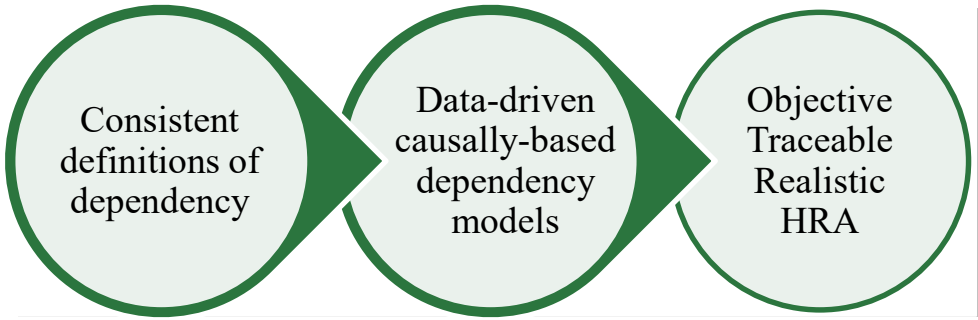

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