Integration of Human and Organizational Factors Into Natural and Technological Hazard Risk Models

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Abstract

Socio-technical organizational factors, such as culture, training and development, leadership, and team dynamics, have been identified as key contributors to the world's most devastating accidents. These factors can affect human activities and organizational decision-making during cascading and compounding hazards, affecting the ultimate consequence of such events. Previous research by the author focused on explicit incorporation of human and organizational factors into probabilistic risk analysis (PRA) models for high-consequence technological systems, including nuclear power plants. Ongoing research by the author focuses on human performance modeling, including occupant response and first responder activities during one type of cascading hazard (i.e., fire following earthquakes), as well as its integration with risk models. Such integration allows for more accurate estimation of human contributions to risk, supporting decision making processes by identifying short- and long-term impacts of decisions on event consequences.

Fukushima Nuclear Disaster
Retrieved from: https://www.bbc.com/news/world-asia-56252695

Deepwater Horizon Disaster
Retrieved from: https://darrp.noaa.gov/oil-spills/deepwater-horizon

Space Shuttle Columbia Disaster
Retrieved from: https://www.bbc.com/future/article/20150130-what-caused-the-columbia-disaster

Modeling Human Performance in Support of Diverse and Flexible Coping Strategies (FLEX)

FLEX Background

March 11, 2011: Tohoku Earthquake and Tsunami

- ❑ Loss of emergency generators at Fukushima Dai-ichi nuclear power plant (NPP), leading to hydrogen explosions, core meltdown, loss of containment, and radioactive release [1]

March 30, 2011: NRC Near-Term Task Force Established

- ❑ Task force begins review of NRC regulatory requirements programs, and processes

July 12, 2011: NRC Near-Term Task Force Published Recommendations Based on Review

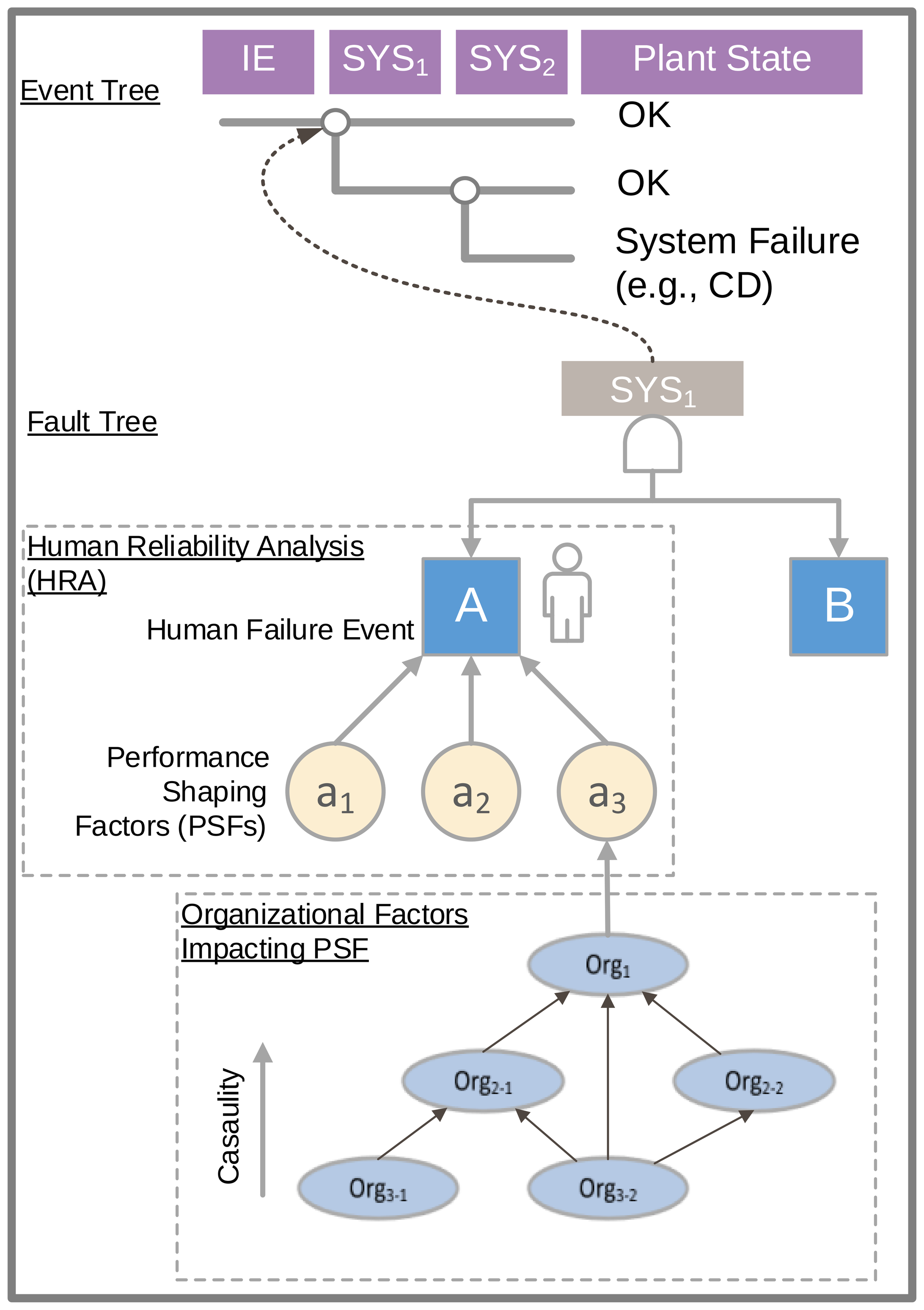
- ❑ Recommendations included formalizing regulatory requirements for beyond design basis events to ensure safety and health of public

September-October 2011: NRC Issues Response to Near-Term Task Force Recommendations

- ❑ NRC Issues Recommendations and Staff Requirements Based on Near-Term Task Force Recommendations

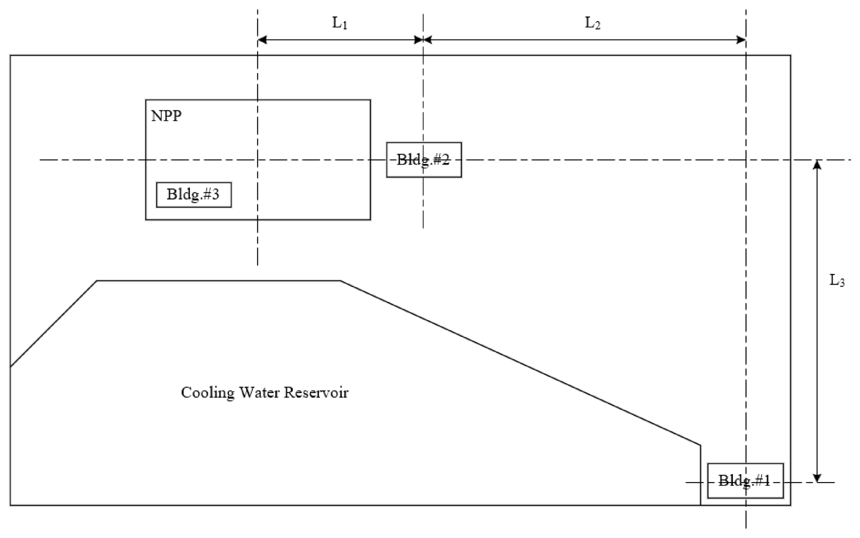
August 2012: U.S. Nuclear Industry Proposes FLEX Strategy

- ❑ Proposed the implementation of FLEX strategies to create additional layers of defense in depth to reduce the potential risks associated with extended power loss and loss of normal access to the ultimate heat sink (LUHS) during Beyond-Design-Basis External Events (BDBEEs) [2].



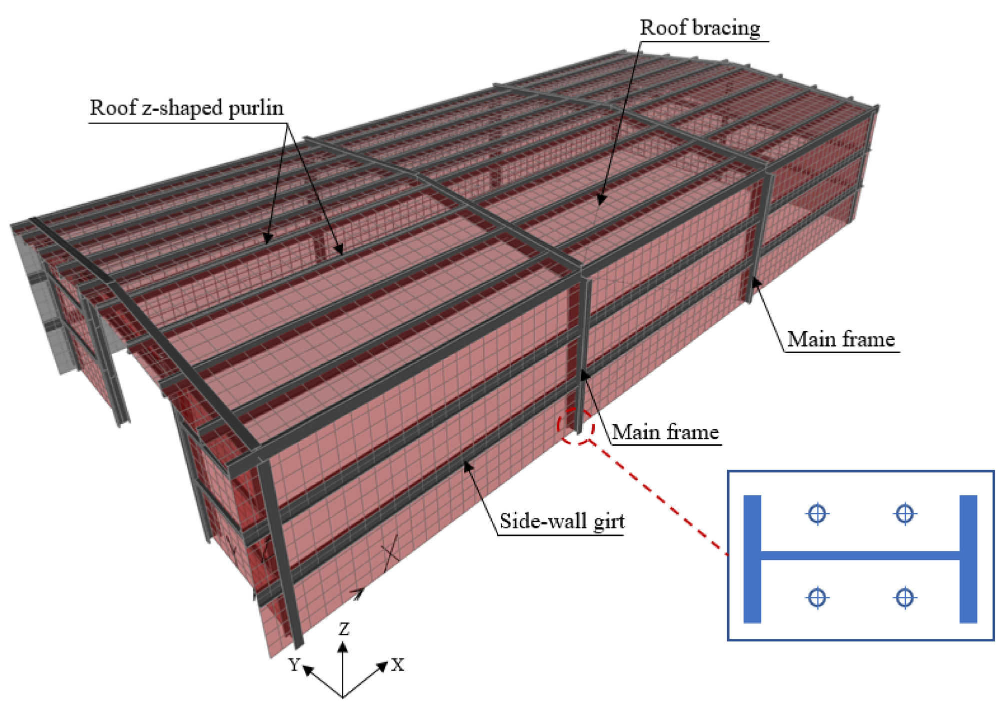
FLEX Case Study

- ❑ Assess impacts of tornados on FLEX equipment storage building of an NPP
- ❑ Utilize one of the second generation HRA techniques (Standardized Plant Analysis Risk HRA [SPAR-H]) to estimate human failure events (HFEs)
- ❑ In SPAR-H, human failure events are classified as diagnosis tasks, action tasks, or a combination of both



SPAR-H Advantages

- ❑ Explicit consideration of both execution and cognitive actions
- ❑ Treatment of Performance Shaping Factors (PSFs) (e.g., external stress from tornado damage) with higher resolution compared to existing methods on human performance
- ❑ Documentation of comprehensive procedure publicly available [3]



FLEX Human Failure Events (HFEs)

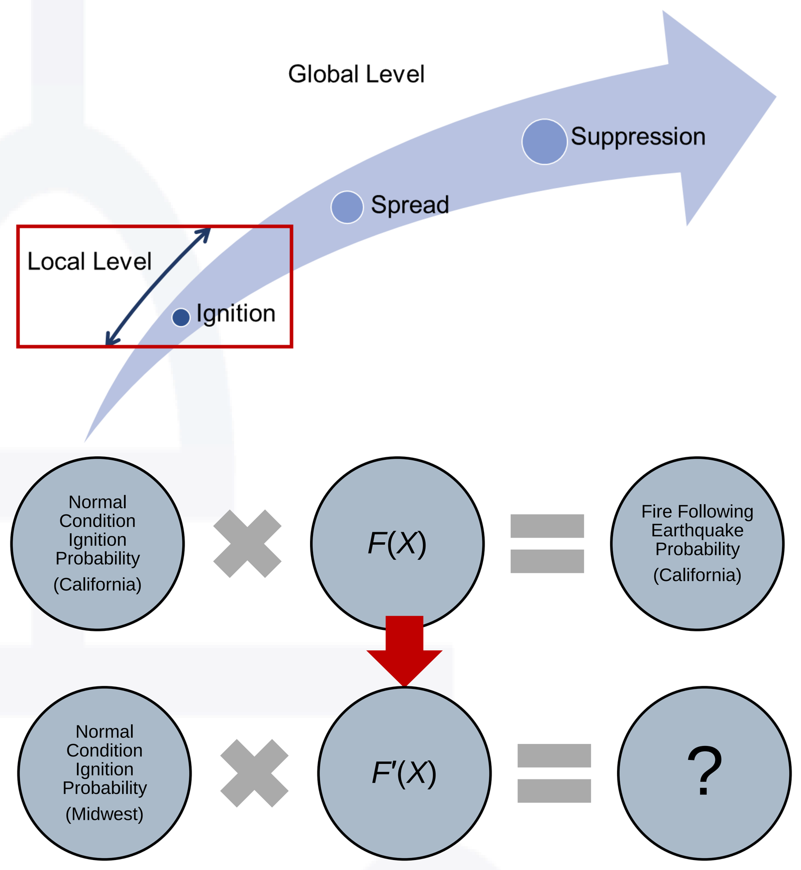
- ❑ HFEs associated with the failure of the Main Control Room (MCR) operator's actions inside the MCR
- ❑ HFEs associated with the failure of the local operators to drive a tractor from each storage building to the Auxiliary Feedwater (AFW) storage tank
- ❑ HFEs associated with the failure of the local operators to connect a Trailer-Mounted Diesel-Driven Pump (TMDDP) to AFW storage tank

Interactions of Human Performance and Cascading Hazards

Research Objective

The objective of this study is to develop a model for estimating the likelihood of FFEs for areas of moderate to high seismicity with limited or no historic FFE records, areas for which conventional data-driven approaches do not work.

The developed model utilizes the probability of normal condition ignition as a baseline and then adjusts this probability through consideration of underlying spatiotemporal causal factors that are altered by the occurrence of an earthquake.



Input Variables

NCI

Spatial Characteristics
- Floor Area
- Building Category
- Population

Ignitability Characteristics
- Fire Prevention System
- Appliance Type
- Ignition Source

Temporal Characteristics
- Seasonality

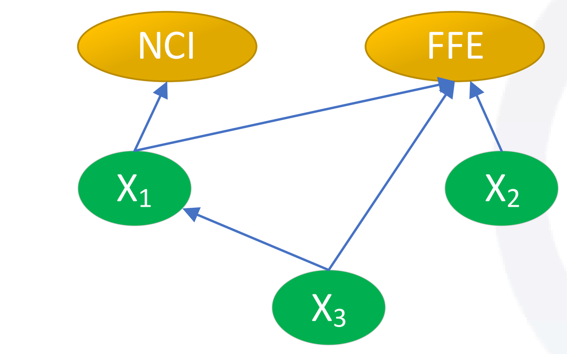
FFE

Spatial Characteristics
- All NC Spatial Characteristics
- Structural and Non-Structural Damage (SD & NSD)
- Structural Type

Ignitability Characteristics
- All NC Ignitability Characteristics

Earthquake Characteristics
- Intensity
- Ground Motion
- Peak Ground Acceleration
- Peak Ground Velocity
- Spectral Acceleration

Temporal Characteristics
- Time of Earthquake
- Seasonality



Developed FFE Model

$$F(x) = P_{FFE_{Mal.}} a_0 + a_1 \quad \begin{cases} a_0 = \frac{1}{X_1} - \alpha \frac{(1-\beta)}{(1-\beta X_1)} \\ a_1 = \alpha\left(\frac{1-\beta}{1-\beta X_1}\right) \end{cases}$$

X_1: Total probability of NCI
α: Relation between human behavior during NCI and an earthquake occurrence
β: Ratio of probability of NCI due to equipment failure to total probability of NCI

References

[1] Nuclear Energy Institute, Diverse and Flexible Coping Strategies (FLEX) Implementation Guide (NEI 12-06, Rev 5). 2018.
[2] U.S. Nuclear Regulatory Commission, Order EA-12-049 - Issuance of Order to Modify Licenses with Regard to Requirements for Mitigation Strategies for Beyond-Design-Basis External Events. 2012.
[3] Schumock, G., S. Zhang, P. Farshadmanesh, J.G. Owens, N. Kasza, J. Stearns, T. Sakurahara, and Z. Mohaghegh, Integrated Risk-Informed Design (I-RID) methodological framework and computational application for FLEX equipment storage buildings of Nuclear Power Plants. Progress in Nuclear Energy, 2020. 120: p. 103186.
[4] Farshadmanesh, P. and J. Mohammadi, A probabilistic methodology for assessing post-earthquake fire ignition vulnerability in residential buildings. Fire technology, 2019. 55(4).

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