Probabilistic Risk Assessment: Strengths and Weaknesses

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American Society of Mechanical Engineers
Verification and Validation Symposium
Las Vegas, Nevada
May 15 – 17, 2019
Outline of the Presentation

• Use of probabilistic risk assessment
• Framework for PRA
• Addressing the three questions of PRA
• Lessons learned from past failures of PRA
• Closing remarks
How Widely Used is PRA?

• Nuclear power industry; Nuclear Regulatory Commission

• Underground storage of nuclear and toxic wastes; Environmental Protection Agency

• NASA; particularly manned space flight

• DoD; flight test range safety analyses

• Damage due to hurricane, tornado and flooding; National Flood Insurance Program and private insurance companies

• Corporate and business insurance of all type; private insurance companies

• After high consequence system failures during the last two decades, weaknesses in PRA have been examined (NASA, 2010; Dubois, 2010; Huber, 2010; Aven, 2010; Elele, 2010)
Framework for Probabilistic Risk Assessment

• Steps in PRA are usually associated with answering three questions (Kaplan and Garrick, 1981):
  1) What can go wrong?
  2) How likely is it to go wrong?
  3) What are the consequences of going wrong?

• Risk is usually quantified as:

\[ Risk = p_i \cdot c_i \quad i = 1, 2, \ldots n \]

• where
  − \( p_i \) is the probability of occurrence of the event occurring
  − \( c_i \) is the consequence of the event
  − \( n \) is the number of events considered

• PRA can is also referred to as quantitative risk assessment (QRA)
How Do We Answer These Questions?

1. What can go wrong?
   - Identify initiating events (abnormal and hostile environments)
   - Construct plausible event and/or fault trees (scenarios)

2. How likely is it?
   - Use experimental and operational data to characterize probabilities
   - Use expert-opinion to characterize probabilities
   - Assume independence/dependence between events/subsystems
   - Use M&S to predict outcomes of each scenario
   - Compute probabilities of each event and/or fault to estimate the probability of the final adverse result

3. What are the adverse consequences?
   - Consequences are usually measured in terms of financial impact
   - Consequences can be extremely diverse and not easily quantified in terms of financial impact
Quantification of Probabilities and Consequences

• Probabilities of rare events are hard to quantify:
  – There are few, if any, previous events to estimate a distribution
  – Expert opinion is heavily relied on, which can be unreliable

• Consequences are difficult to quantify for certain applications:
  – Nuclear power industry; Nuclear Regulatory Commission
  – Underground storage of nuclear and toxic wastes; Environmental Protection Agency
  – NASA, particularly manned space flight
  – DoD; flight test range safety analyses

• For certain applications, consequences are specified:
  – Hurricane, tornado and flood damage; National Flood Insurance Program and private insurance companies
  – Corporate and business insurance of all type; private insurance companies
What Can Be Learned From Past Failures of PRAs?

• Three Mile Island Event (1979)
• Loss of Space Shuttle Challenger (1986)
• Chernobyl Disaster (1986)
• Loss of Space Shuttle Columbia (2003)
• Fukushima Disaster (2011)
What Can Go Wrong?

• (Challenger) Failure of management to accept strong evidence of increasing O-ring leakage for cold launch temperatures

• (Chernobyl) Failure of the plant manager to seek advice concerning the extreme danger of a reactor safety test

• (TMI) Failure to recognize what the plant operators might do when there is conflicting reactor sensor data during a minor abnormal event

• (Columbia) Failure of program management to accept that serious damage could result from impact of ice and foam on the wing
What is the Probability of the Scenario?

• (Challenger) Failure to recognize how difficult it is to convince management of the validity of a simulation result, i.e., O-ring leakage

• (Fukushima) Gross underestimation of the probability of a large earthquake and tsunami

• (Fukushima) Assumed independence of cooling-water-pump failures

• (Columbia) Failure of modeling and simulation to predict major damage due to foam impact
What Are The Consequences of the Scenario?

• (TMI) Gross underestimation of the consequences of the modest failure

• (Columbia) NASA management unwilling to take prudent action while Columbia was in orbit

• (Fukushima) Japanese Nuclear and Industrial Safety Agency did not act on warnings of the risk of loss of electrical power by the U. S. Nuclear Regulatory Commission in 1990.

• (Fukushima) Gross underestimation of the consequences of major failure
Lesson Learned 1

• Lack of an external, independent, rigorous review of a PRA can lead to misinformation and poor decision making
  – Recent PRA found that the probability of loss of crew during the early flights of the Space Shuttle was 1:10, whereas the initial estimate was 1:10,000 (Hamlin, 2011)
  – “The [NASA] safety organization sits right beside the person making the decisions, but behind the safety organization, there’s nothing back there. There’s no people, money, engineering expertise, analysis.” (Admiral Gehman, 2003)

• Observation:

  Lack of independent review of a PRA, or not conducting a PRA, is a purposeful decision of the controlling authority.
Lesson Learned 2

• Negative consequences of a failure, even a minor failure, can destroy a company and even an industry

• The most difficult negative consequences to estimate are those that impact the confidence of the customer, public, and politicians in your organization

Observation:

Organizations, both private and government, must develop and nurture a culture where questioning the status quo is rewarded
Concluding Remarks

• Estimating the probability of rare events is difficult:
  – Probabilities can be influenced by customers and stakeholders of the PRA

• Estimating consequences is even more difficult:
  – Far reaching consequences can be grossly underestimated
  – Consequences can be influenced by the customers and stakeholders of the PRA

• Attorneys, politicians, and special interest groups have little interest in the “truth”, transparency, or independent-peer-reviewed risk of a PRA.

• For high-consequence systems there must be significant independence between the system designer/operator and the regulatory authority.

• Recommendations for conducting PRAs:
  – Imprecise probabilities can better characterize poorly known probabilities and consequences
  – Sensitivity analyses can greatly assist in reducing risks

“Bureaucracy is a construction by which a person is conveniently separated from the consequences of his or her actions.” – Nassim Taleb
References


• Elele, J. N. and J. Smith (2010), "Risk-Based Verification, Validation, and Accreditation," Modeling and Simulation for Defense Systems and Application V, 7705, SPIE, 77050E-1, 77050E-11,


References (continued)


Representation of Uncertainty

Common Perspectives of Uncertainty Represented as a Probability

Frequentist Perspective (Objective View)
The probability is the value to which the long-run frequency converges as the number of observations becomes large.

Bayesian Perspective (Subjective View)
The probability is the degree of belief that a person has that an event will occur, given all the relevant information currently known to that person.

Information Theory Perspective (Imprecise Probability View)
The probability is an expression of the all of the relevant information currently known, but the probability is not necessarily a single number.
Example Of How Uncertainty Can Be More Clearly Communicated

From Roy and Oberkampf (2011)