Risk analysis in performance-based regulation (PBR) of safety

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Why PBR?

• PBR seeks to improve future outcomes by setting goals rather than by prescribing how to achieve them
  – Emphasizes results rather than compliance
    • Seeks fewer fire fatalities, plane crashes, core breaches, pipeline ruptures, etc., and less damage per event
  – Challenges: What goals to set, how to determine how well they are being met
Why risk analysis in PBR?

1. *Estimate performance* under uncertainty
2. *Predict* performance
3. *Characterize uncertainty* about performance
4. *Detect and quantify changes* in performance
5. *Attribute* safety performance to underlying factors
6. *Quantify effects of changing factors* on performance
7. *Quantify design and performance trade-offs*
8. *Optimize* risk management decisions
9. Support *adaptive learning* and improvement
10. Support social, game-theoretic, and *distributed learning*
11. Support more effective *risk communication* and *participatory risk management*
Roles of risk analysis in PBR: Estimate, predict performance & uncertainties

• *Estimate* performance under uncertainty
  – How are we doing?
  – How do we know?
  – How sure can we be?
  – How much better can we do? (performance gap)

• *Predict* performance using risk models
  – Examples: Fire percolation models (1990s), nuclear, air safety, oil and gas pipelines, etc. probabilistic risk assessment (PRA) models
  – Model verification, validation, and uncertainty quantification (VVUQ) challenges

• *Characterize uncertainties* about performance

http://www.ercim.eu/publication/Ercim_News/enw56/weidl.html
Some risk assessment techniques

- **Fault tree models** decompose risk events into logical combinations of contributing events
- **Bayesian Networks** model probabilistic and causal relations among variables
  - *Influence diagrams* add decisions and evaluations
- **Simulation models** model interacting changes over time

Allan, 2012  Song et al., 2014  Proust et al. 2012
Roles of risk analysis in PBR (Cont.): Detect, quantify, attribute changes

- **Detect and quantify changes** in safety performance under uncertainty quickly and accurately
  - Change-point analysis
  - Earlier, more trustworthy warnings
  - Timely feedback on performance changes

- **Attribute** safety performance and changes in performance to underlying factors
  - Explaining changes
  - Allocating responsibility

Khalil and Mosher, 2016
Roles of risk analysis in PBR: Evaluate risk management programs

- *Evaluate* what is working and what is not (Cary)
  - What factors are having what effects on safety?
- Evaluating compliance is often easier
  - Checklist approach (Brian)
    - Need to produce guidance materials to stabilize understandings (Jeff Wiese)
  - Audit adequacy of programs and operations

*Knox, 2015*
Roles of risk analysis in PBR (Cont.): Quantifying how factors affect risk

• *Quantify effects* of factors on performance
  – Estimate response surfaces
  – Safety performance takes time to observe

• *Quantify design and performance trade-offs*
  – How to aggregate multiple objectives under uncertainty into a “performance” metric?
  – How would changing factors change performance probability distributions?
  – What changes are feasible?
    • What is the design space?


www.research.ed.ac.uk/portal/files/18906329/PEER_EngStructures.pdf
Roles of risk management in PBR: Learning and decision optimization

- **Optimize** risk management decisions
  - Compare and optimize *decision rules* (e.g., testing protocols)
    - A *decision rule* maps data to decisions
    - *Simulation-optimization* algorithms
  - Optimize *decision processes* (e.g., prescriptive, PBR, hybrid) (William Perry)
  - Optimize *allocation* of inspection and enforcement resources
    - Risk-based inspections (Brian)
- **Adaptive learning** & improvement
  - Provide performance feedback
Risk communication and distributed risk management

• Social, distributed, and game-theoretic learning
  – Design incentives to encourage innovation and learning across companies and industries (Don Moynihan, Peter Watson)

• Risk communication and participatory risk management
  – Regulator, regulated, public (Brian Salerno)
  – Incentives design: What data should trigger what penalties or enforcement activity? (Jeff Wiese)

• Learning
  – Detecting weak signals on management systems issues (Peter Watson)
  – How can audit teams learn to look more effectively?
  – How to think about/audit cause-and-effect?
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