A process to assess infrastructure related risks due to natural hazards with stress tests – Part 2

Infrarisk Consortium

PSCT – Pieter van Gelder, Noel van Erp

ETHZ – Bryan T. Adey, Jürgen Hackl, Juan Carlos Lam and Magnus Heitzler

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Stress Testing Concept

- Stress tests refer to the analysis of a particular system or subsystem under a specific set of adverse conditions to determine the potential losses.
- The outcome of stress tests can be used to inform decisions regarding the protection of existing or future-planned infrastructure, which can contribute to the resilience of critical transport networks.

Stress Test Definition

In a stress test we just construct the one outcome probability distribution for some given adverse scenario S, say, $p\left(O_{i(s)} \mid S, A^{(0)}\right)$ where the $O_i^{(s)}$ are the outcomes, for $i^{(S)} = 1,\ldots, n^{(S)}$ and $A^{(0)}$ is the action to keep the status quo.

Stress Test Definition

- The stress output consists of, in probability theoretical terms, an outcome probability distribution which is conditional to the proposed stress scenario; i.e. a conditional outcome distribution.
- Typical stress outcome metrics are the costs of physical repairs to the network, delay times for network users, loss of connectivity etc.

Missed stress test opportunity

Stress test framework follows the risk framework of WP4

We zoom in on the following steps:

- Generate a natural hazard stress scenario → Spatial hazard map
- Spatial hazard map → Probability map via conditional fragility curves
- Probability Map → Damage state scenario selection via smart algorithms (MC, NS, PSA)
- Selected set of damage state scenarios → Estimation of outcome metric → Evaluation of the outcome metric

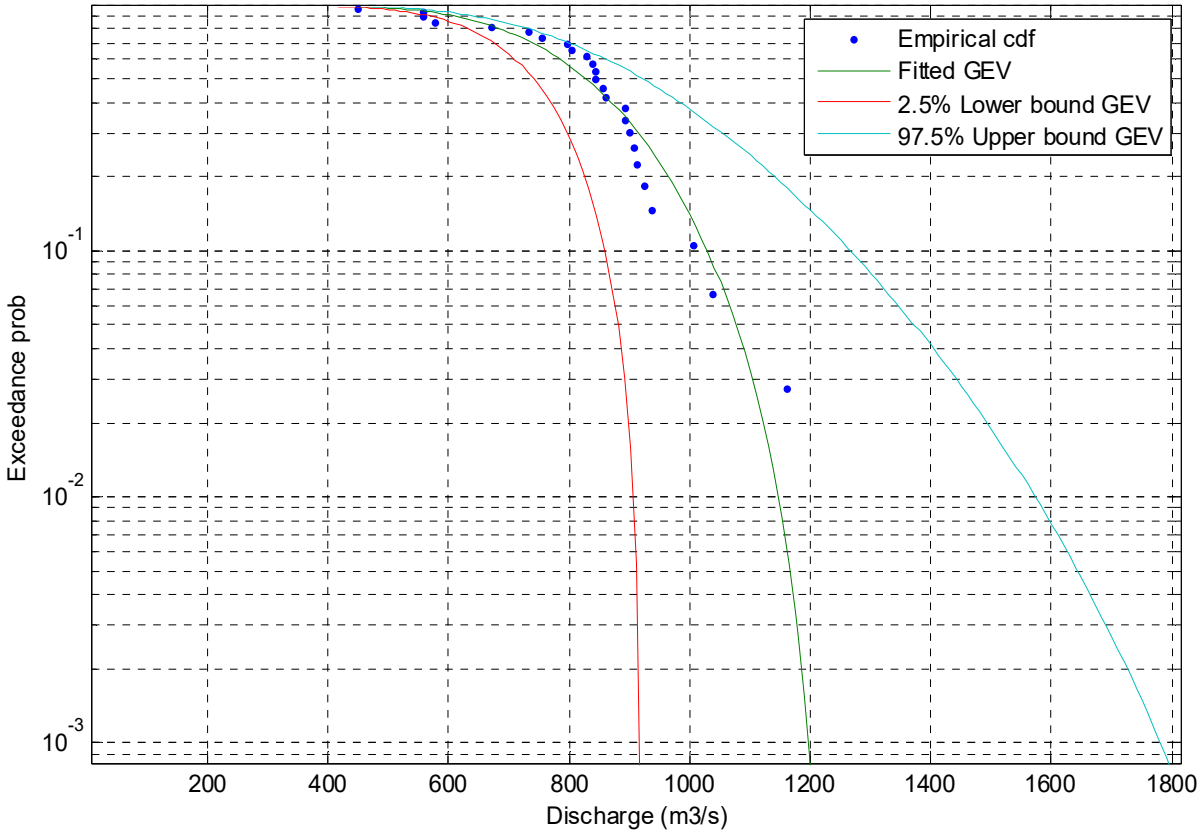
Selecting stress scenario's

- Stress scenarios can be based on
  - historical scenarios, employing shocks that occurred in the past,
  - hypothetical/synthetic scenarios, constructed to take account of plausible changes in circumstances that have no historical precedent.
  - extreme value theory, which applies statistical analysis to the tails of return distributions,
  - maximum loss approach, which estimates the combination of factors that would cause the largest loss to the system under consideration

Selecting stress scenario's

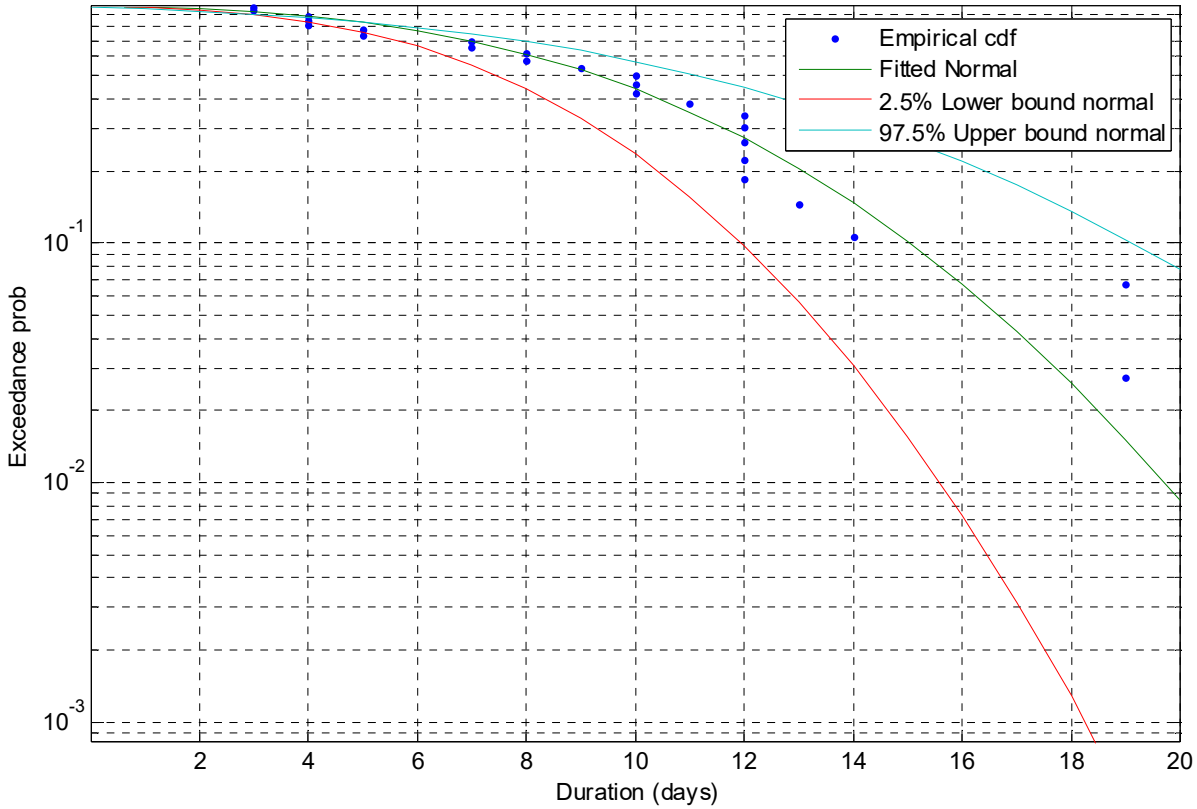
- Structured brainstorming sessions, such as conducted in general morphological analyses (Ritchey, 1998), may be used to elicit stress scenario's
- One possible instrument by which to structure a brainstorming session is the use of Delphi panels and Similarity Judgment (Prak, 2009)

Selecting stress scenario's:
1/T years flood hazard (intensity)

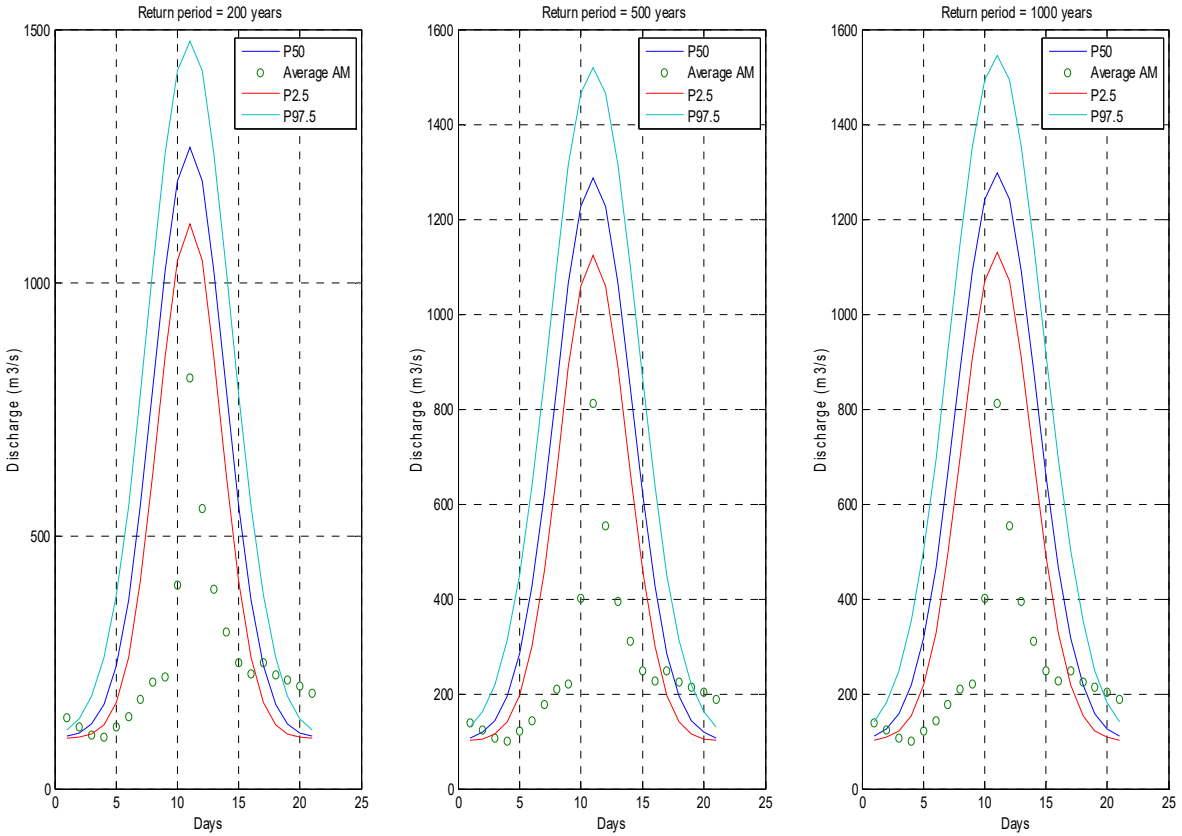


Selecting stress scenario's

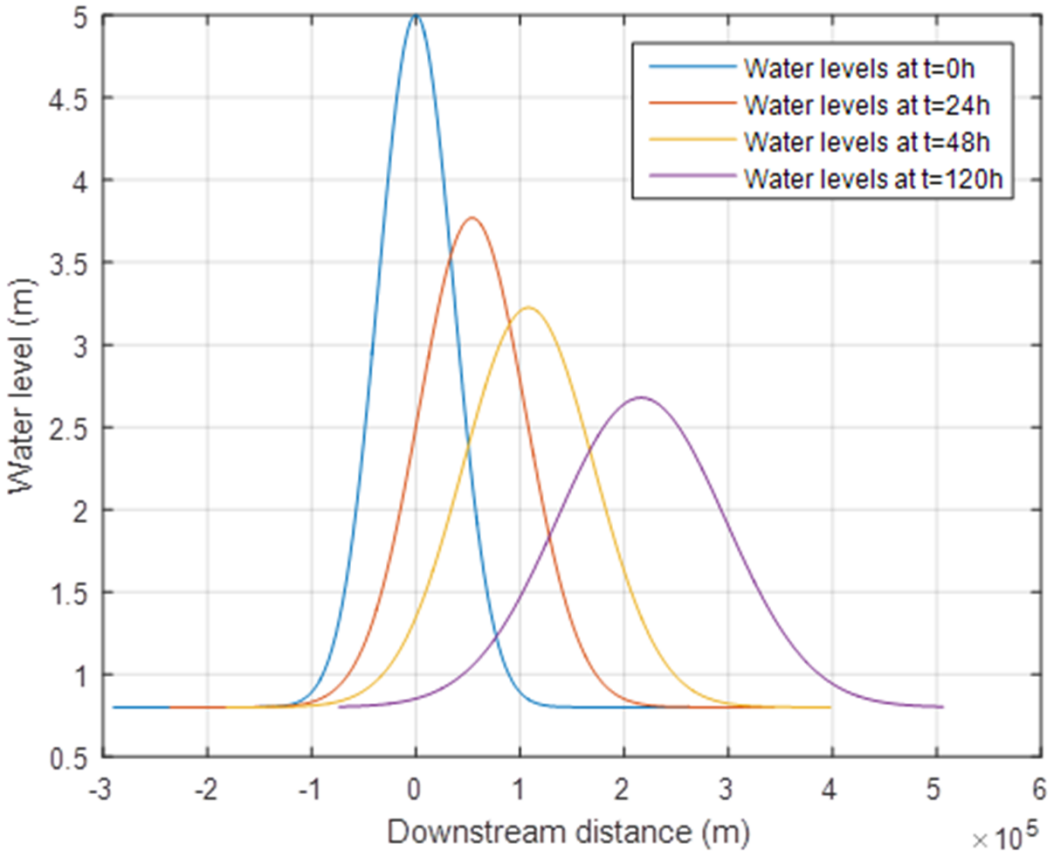
1 / T years flood hazard (duration)



Selecting stress scenario's (hydrographs)

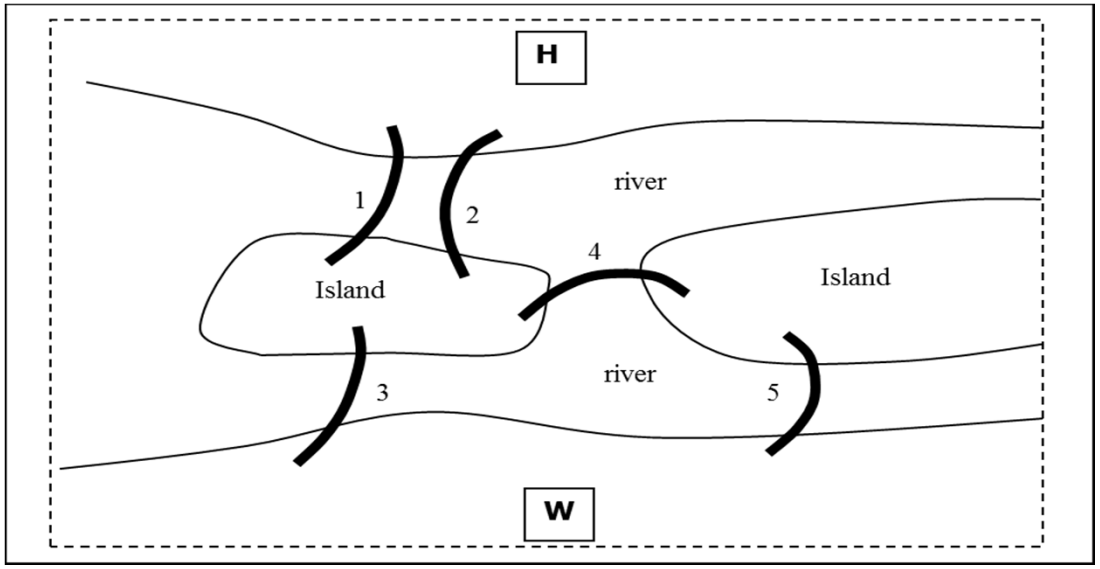


Propagation of flood stress scenario downstream ‘Spatial hazard’



Infrastructural systems

- **Infrastructural systems can be modeled as fault tree systems with a large number of (dependent) components**



Spatial hazard map → Probability map

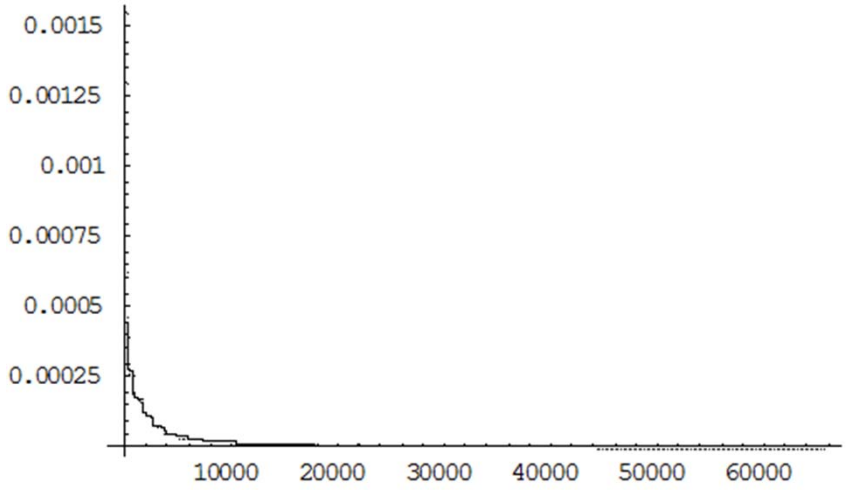
Say we have a probability map for damage states of objects arranged in a 11-by-11 grid, caused by the spatial hazard

0.000420084	0.000707223	0.00118904	0.00188693	0.00261704	0.00294877	0.00261704	0.00188693	0.00118904	0.000707223	0.000420084
0.000707223	0.00141485	0.00294877	0.00591196	0.00995425	0.0121162	0.00995425	0.00591196	0.00294877	0.00141485	0.000707223
0.00118904	0.00294877	0.00827847	0.0238561	0.0557883	0.0777806	0.0557883	0.0238561	0.00827847	0.00294877	0.00118904
0.00188693	0.00591196	0.0238561	0.111633	0.389245	0.597382	0.389245	0.111633	0.0238561	0.00591196	0.00188693
0.00261704	0.00995425	0.0557883	0.389245	0.989766	1.	0.989766	0.389245	0.0557883	0.00995425	0.00261704
0.00294877	0.0121162	0.0777806	0.597382	1.	1	1.	0.597382	0.0777806	0.0121162	0.00294877
0.00261704	0.00995425	0.0557883	0.389245	0.989766	1.	0.989766	0.389245	0.0557883	0.00995425	0.00261704
0.00188693	0.00591196	0.0238561	0.111633	0.389245	0.597382	0.389245	0.111633	0.0238561	0.00591196	0.00188693
0.00118904	0.00294877	0.00827847	0.0238561	0.0557883	0.0777806	0.0557883	0.0238561	0.00827847	0.00294877	0.00118904
0.000707223	0.00141485	0.00294877	0.00591196	0.00995425	0.0121162	0.00995425	0.00591196	0.00294877	0.00141485	0.000707223
0.000420084	0.000707223	0.00118904	0.00188693	0.00261704	0.00294877	0.00261704	0.00188693	0.00118904	0.000707223	0.000420084

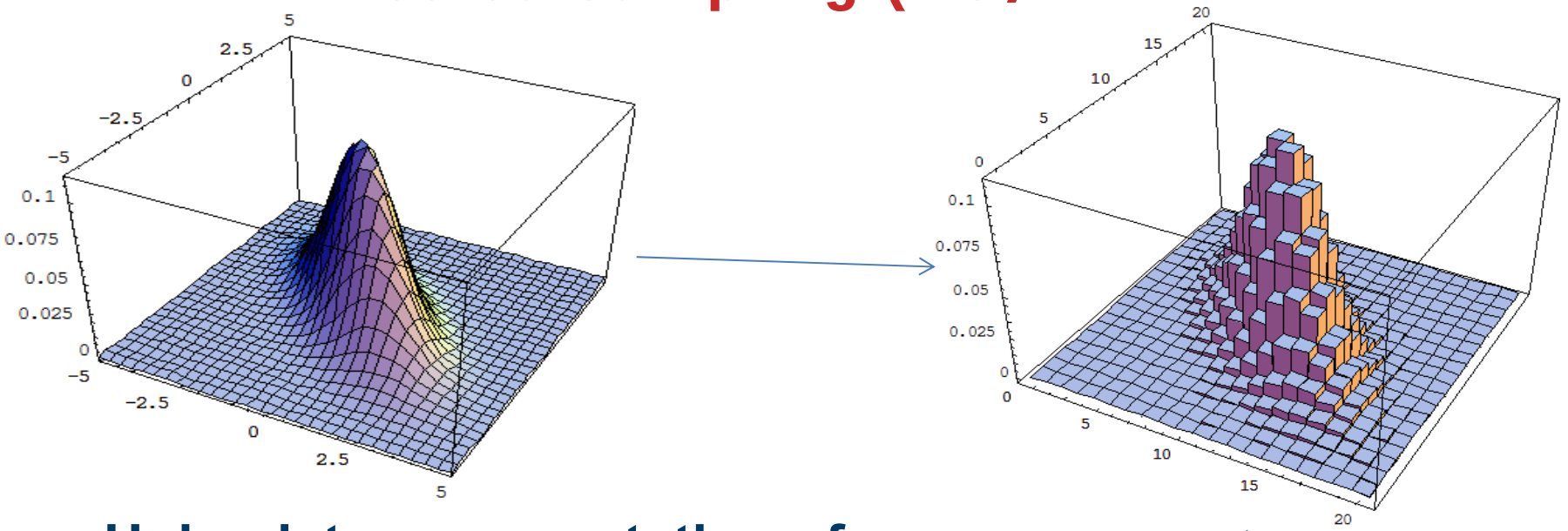
The damage state space which corresponds with this probability map is $2^{121} = 2.66 \acute{} 10^{36}$.

Probability Map → Damage state scenario selection via smart algorithms (MC, NS, PSA)

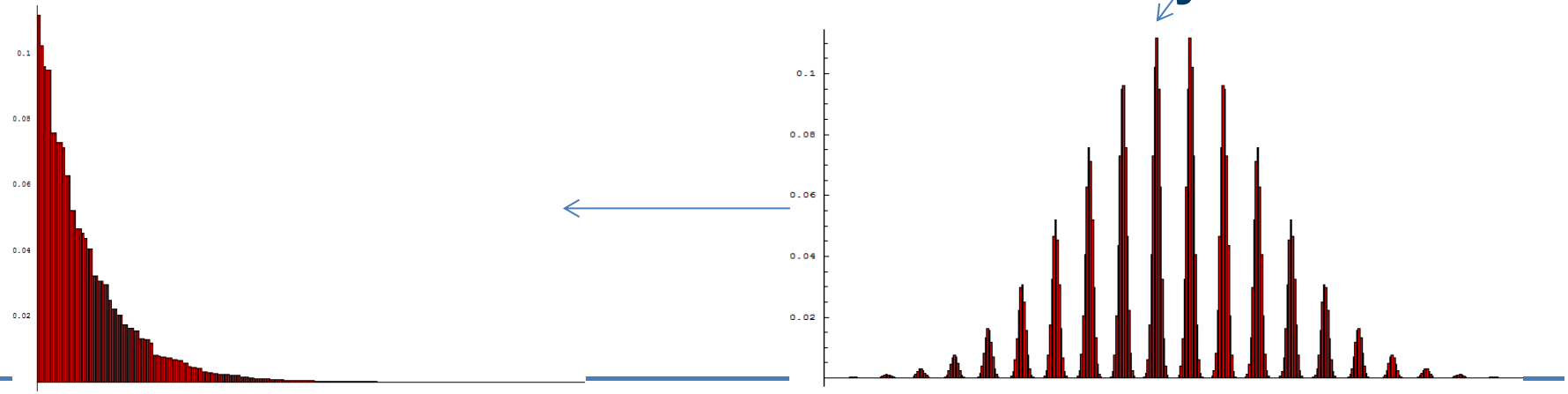
- The 2.66 10^36 damage state vectors can be reduced to 65536 damage state vectors with a probability coverage of 1.0



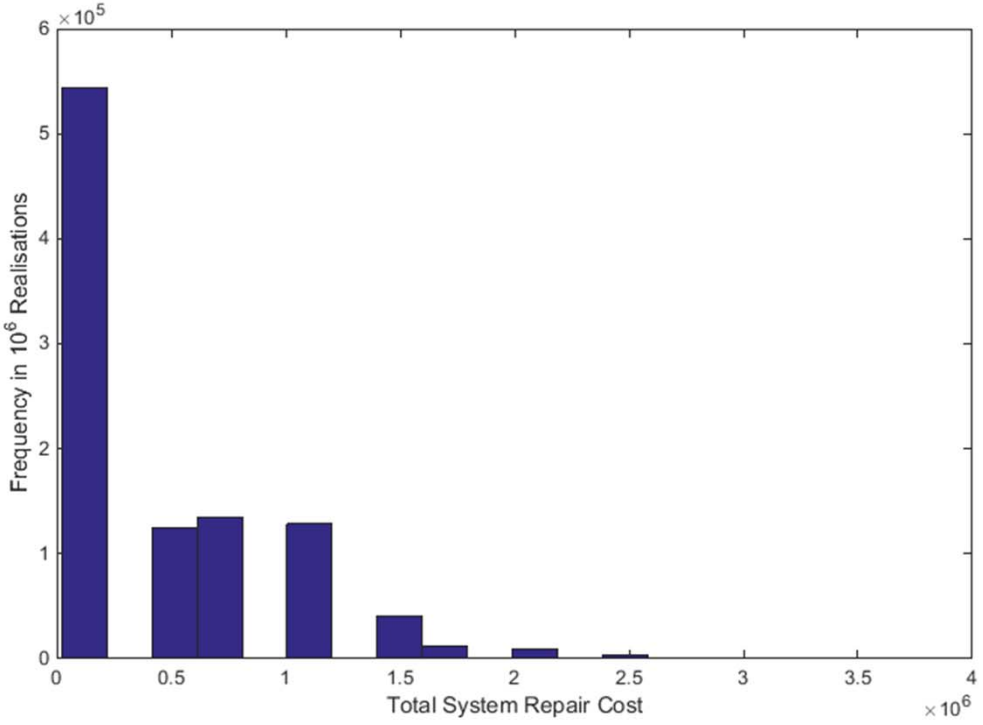
Nested Sampling (NS)



- **Univariate representation of multivariate systems**



Selected set of damage state scenarios → Estimation of outcome metric



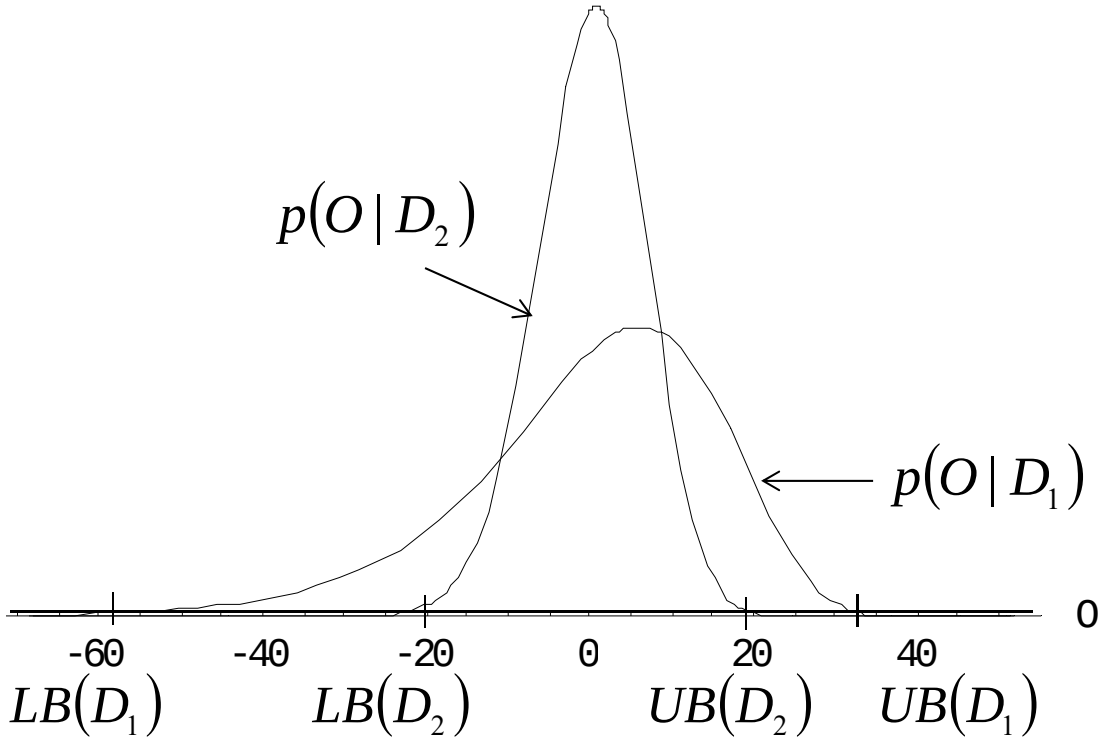
Decision making phase of a stress test outcome

- The level of risk that is considered acceptable will typically vary from situation to situation
- Stress test outcome distributions can be compared to eachother, following a Bayesian decision-theoretical framework

Evaluation of the outcome metric

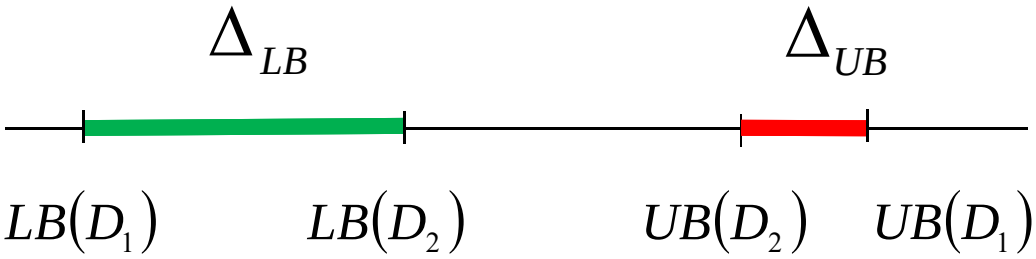
- **Comparison of two conditionalized outcome probability distributions**

Decision making phase of a stress test outcome



Decision making phase of a stress test outcome

- Trade-off lower and upper bound 'gains':
  - Δ_{LB} dominates Δ_{UB}.
  - Δ_{LB} favours D_2 over D_1.
  - Choose D_2.



Decision making phase of a stress test outcome

- Or, equivalently, choose D_2 because:

$$LB(D_2) - LB(D_1) > UB(D_1) - UB(D_2)$$

- Or, equivalently, choose D_2 because:

$$LB(D_2) + UB(D_2) > LB(D_1) + UB(D_1)$$

- The comparison of bounds may be simplified into comparison of a single measure:

Decision making phase of a stress test outcome

- Choose the decision D_i which maximizes the sum of bounds:

$$LB(D_i) + E(D_i) + UB(D_i)\ .$$

- As opposed to choosing the decision D_i which maximizes the expectation values:

$$E(D_i).$$

Concluding remarks

- General stress test framework is presented in which stress tests are just a special instance of a risk assessment, where instead of marginalizing over all the possible stress scenarios one specific stress scenario is chosen instead for which to gauge its potential effects.
- This stress test framework is simple enough on the conceptual side. On the practical side, however, when one wishes to implement this framework, things can quickly become non-trivial, for which 3 sampling algorithms have been developed.

Novel Indicators for identifying critical **INFRA**structure at **RISK** from Natural Hazards

Website

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