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Use of Uncertainty Importance Measures to Complement Risk Importance Measures in PSA

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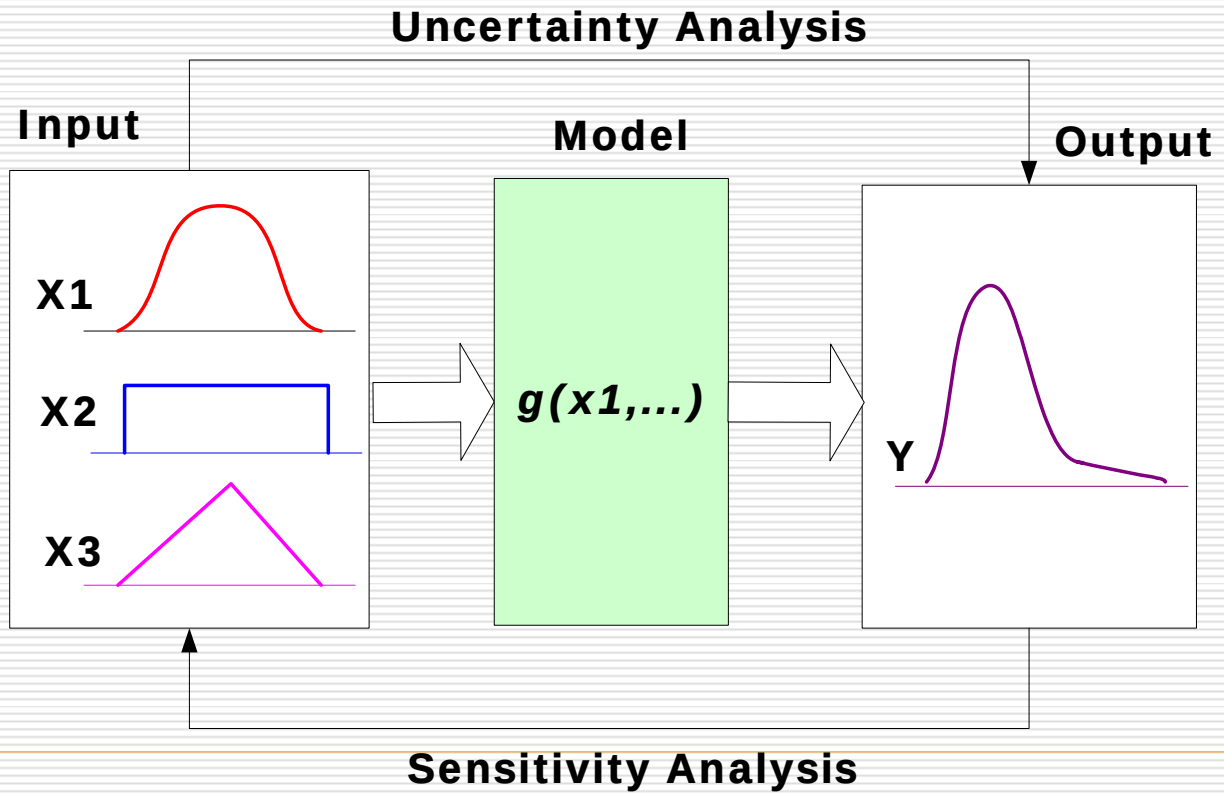
Background

- Uncertainty is an integral part of risk assessment problems.
- Given a Level 1 PSA model *Y=g(X1, X2, ...Xn)*,



Risk Importance Measures (1)

- Fussell-Vesely (FV) measure

$$FV = \frac{Y_{base} - Y(x_i = 0)}{Y_{base}}$$

  - Definition: Fractional contribution of a basic event to the risk when the probability of this event is hypothetically changed from its best estimate value to zero (the event does not occur).

- It measures the maximum reduction in risk if a basic event would never occur.

- It is useful for prioritizing the basic events that can mostly reduce risk.

Risk Importance Measures (2)

- Risk Achievement Worth (RAW)

$$RAW = \frac{Y(x_i = 1)}{Y_{base}}$$

  - Definition: The percentage of the risk increase with the probability of a basic event set to 1 (the event occurs) .

- It measures the increase in risk if a basic event occurred.

- It indicates the importance of maintaining the current level of reliability for the basic event.

Risk Importance Measures (3)

- FV and RAW are commonly used together to identify the role of a basic event in relation to the risk of a NPP.
- FV and RAW are based on best estimate values of the probabilities of basic events and the importance of a basic event to the risk is only evaluated by changing its probability to two extreme values (either 0 or 1).
- Realistic failure probabilities of components are associated with uncertainties, which can be represented by probability distributions.
- The contribution of the uncertainty in a basic event to the uncertainty of the model risk should also be evaluated.

Uncertainty Importance Measures (1)

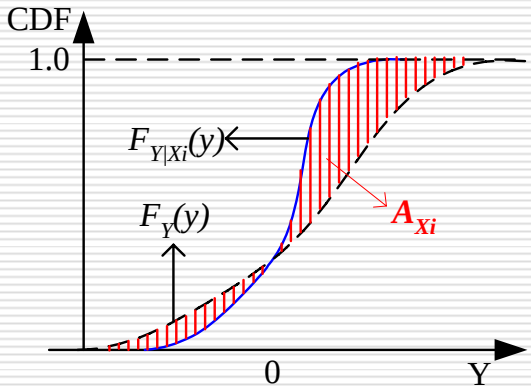
- A variance-based importance measure
  - Total effect importance measure (Homma&Saltelli, 1996)

$$S_{Ti} = \frac{E(V(Y \mid X_{-i}))}{V(Y)}$$

  - $V(Y)$: the variance of Y when all inputs are sampled over their variation range.
  - $V(Y|X_{-i})$: the conditional variance of Y when only the input of interest X_i is allowed to change and all other inputs are fixed.
  - $E(V(Y|X_{-i}))$: the average of $V(Y|X_{-i})$ when all inputs except X_i are allowed to change over in their variation change.

Uncertainty Importance Measures (2)

- An importance measures based on the entire distribution (Liu & Homma, 2007)
  - The difference between $F_Y(y)$ and $F_{Y|Xi}(y)$ is:



$$A_{X_i} = \int \left| F_{Y|X_i}(y) - F_Y(y) \right| dy$$

  - The expected difference between $F_{Y|Xi}(y)$ and $F_Y(y)$ is:

$$E_{X_i}(A_{X_i}) = \int f_{X_i}(x_i)\ A_{X_i}(x_i)\ dx_i$$

  - The measure is defined as: $S_{X_i} = \dfrac{E_{X_i}(A_{X_i})}{|E(Y)|}$

Example 1

- Fault Tree model (Ahmed et al, 1982)

$$Y = X_1 + X_2X_3 + X_4X_5 + X_6$$

Basic Event	Distribution	Mean Value	Error Factor
X_1	Lognormal	0.00125	3
X_2	Lognormal	0.0375	3
X_3	Lognormal	0.0125	3
X_4	Lognormal	0.0375	3
X_5	Lognormal	0.0125	3
X_6	Lognormal	0.00375	3

Results(1)

Basic Event	FV	RAW	S_{Ti}	S_{Xi}
X_1	2 (0.21)	1 (169.23)	2 (0.0884)	2 (0.1133)
X_2	3 (0.08)	5 (3.03)	5 (0.0190)	4 (0.0414)
X_3	3 (0.08)	3 (7.24)	3 (0.0196)	3 (0.0419)
X_4	3 (0.08)	5 (3.03)	4 (0.0192)	5 (0.0414)
X_5	3 (0.08)	3 (7.24)	6 (0.0186)	6 (0.0408)
X_6	1 (0.63)	2 (168.82)	1 (0.8485)	1 (0.4035)

Example 2

- Fault Tree model (Apostolakis & Lee, 1977)

$$Y = X_1 + X_6 + X_7 + X_2X_5 + X_2X_4 + X_3X_4 + X_3X_5$$

Basic Event	Distribution	Mean Value	Error Factor
X_1	Lognormal	0.00125	3
X_2	Lognormal	0.0375	3
X_3	Lognormal	0.0125	3
X_4	Lognormal	0.0375	3
X_5	Lognormal	0.0125	3
X_6	Lognormal	0.00375	3
X_7	Lognormal	0.0000027	10

Results(2)

Basic Event	FV	RAW	S_T	S_{Xi}
X_1	4 (0.17)	2 (134.14)	4 (0.0581)	4 (0.0881)
X_2	2 (0.25)	6 (7.41)	3 (0.1741)	3 (0.1364)
X_3	5 (0.08)	4 (7.58)	5 (0.0204)	5 (0.0437)
X_4	2 (0.25)	6 (7.41)	2 (0.1846)	2 (0.1373)
X_5	5 (0.08)	4 (7.58)	6 (0.0180)	6 (0.0421)
X_6	1 (0.50)	3 (133.81)	1 (0.5577)	1 (0.2988)
X_7	7 (0.0004)	1 (134.31)	7 (1.2 E-6)	7 (0.0004)

Concluding Remarks

- Risk importance measures, such as FV and RAW, are based on best estimate values of the probabilities of basic events. The importance of a basic event is evaluated by changing its probability from the nominal value to the extreme values (0 or 1).

- Realistically, the probabilities of basic events are associated with uncertainties, which propagate through the risk model and leads to the uncertainty in the model output, the risk metric. In order to reduce the output uncertainty, it is necessary to identify the important basic events contributing to the output uncertainty. This can be done by using uncertainty importance measures.

- To set priorities for the allocation of research resources for reducing risk and increasing our confidence in the evaluation result of the risk metric, it is recommended to use them together to identify the dominant basic events.