The added value of information

PROF. DR. SEBASTIAN THÖNS, LUND UNIVERSITY

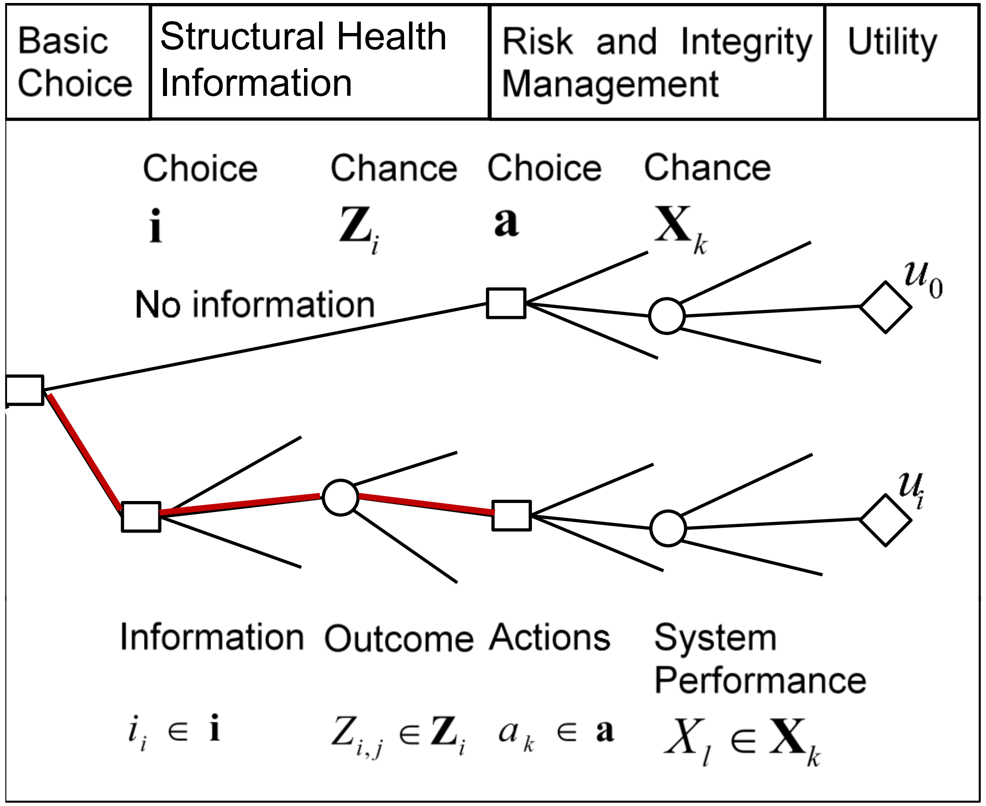
Contents: The added value of information

1) Introduction: Detection theory, Decision theory, Bayes risk and interrelations

2) Value of structural health information

3) Actual research: Decision support for innovation and service life extension

Value of Structural Health Information



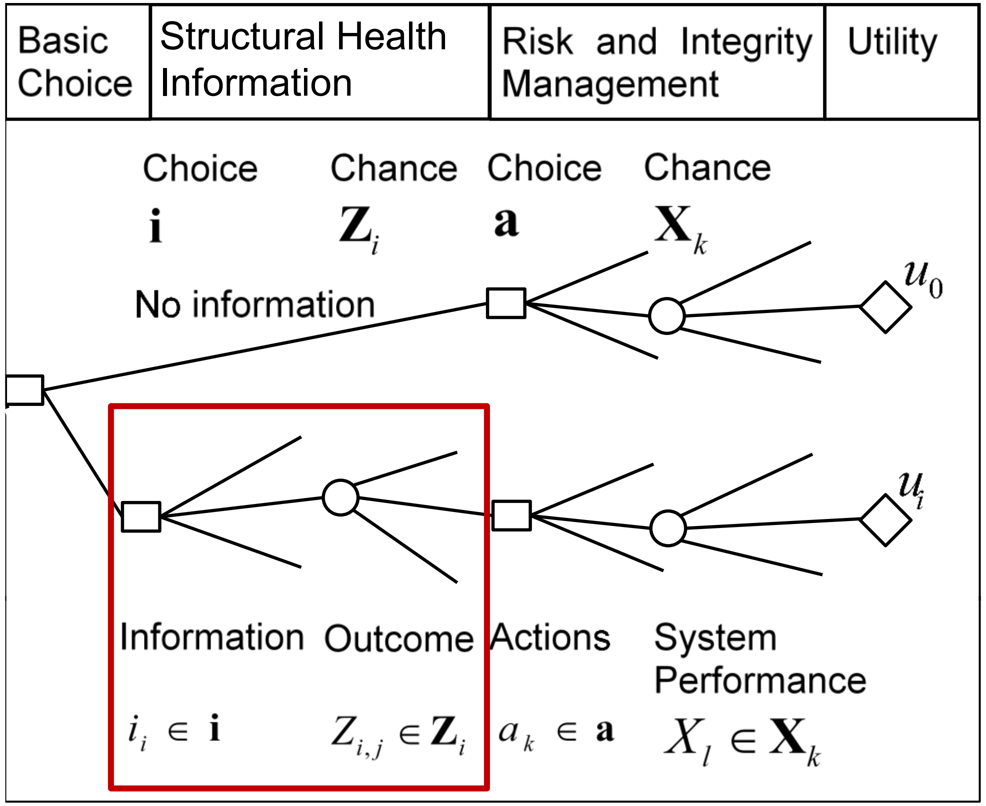
How to calculate? Quantification of the maximum expected value of utility with and without SHI.

$$V_{PI} = U_{PIPA} - U_{PA}$$

- Objective function
  - Maximisation of the expected value of the utlity

- Decision variables
  - SHI strategies and parameters
  - Risk and integrity management strategies

Value of Structural Health Information



Structural health information is information with relevance for the decisions influencing a technical system performance and utility. SHI are modelled by type, precision and cost.

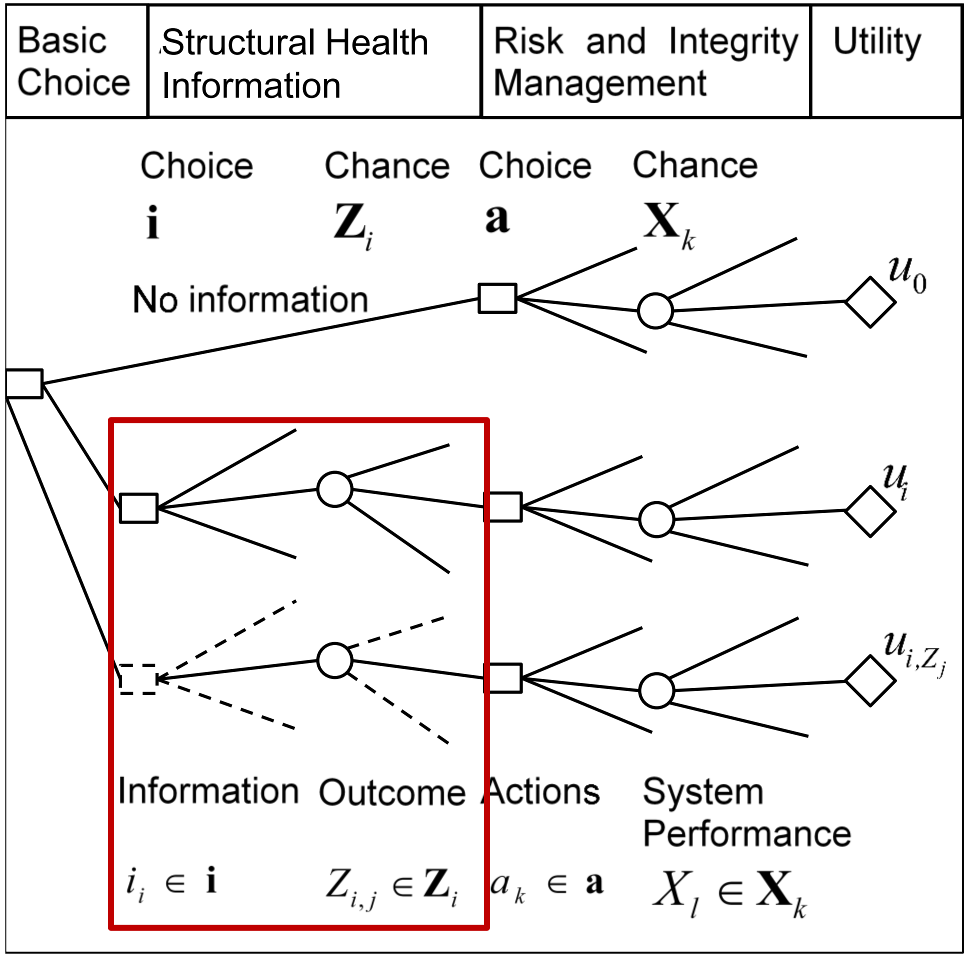
Classification in relation to the technical system:

(1) **Direct** measurement of structural system model parameter or **indirect** event probability information

(2) Technical **system space** (e.g. constituent, subsystem, system)

(3) **Temporal period** within a structural system life cycle period (e.g. discrete, periodically, continuous).

Value of Structural Health Information

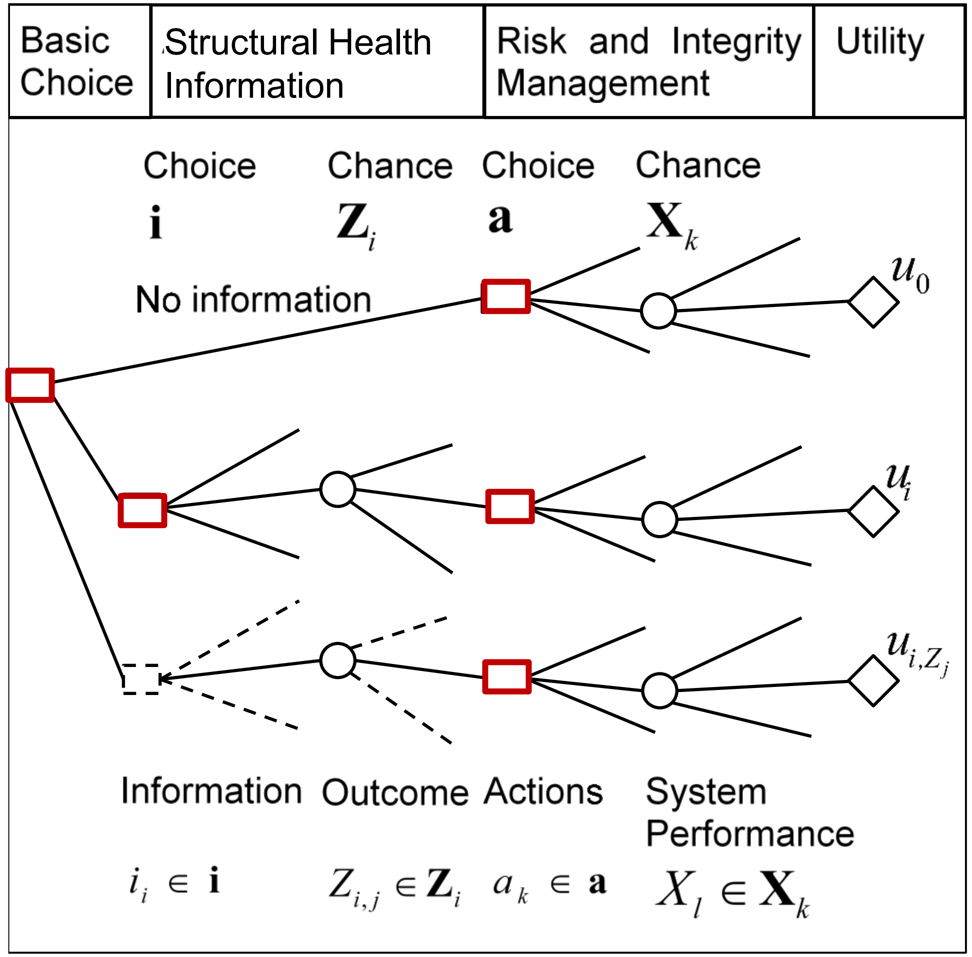


Structural Health Information models are developed for:

- Inspections
- Damage detection
- Monitoring
- Load testing information
- Destructive and non-destructive testing

Formulations for pre-posterior and posterior updating of the component and system performance.

Value of Structural Health Information



What is it good for? Decision support before implementing a SHI system or performing an action.

1. Implement SHI or not?
2. Optimal SHI system?
3. Optimal risk and integrity management strategies?

System performance analysis

Information model		Action model		System and utility model		Analysis type
Choice Information i_i	Chance Outcomes $Z_{i,j}$	Choice Actions a_k	Chance Implementation $Y_{k,m}$	Chance System states X_l	Chance Utility $U(\dots)$	
						SP A

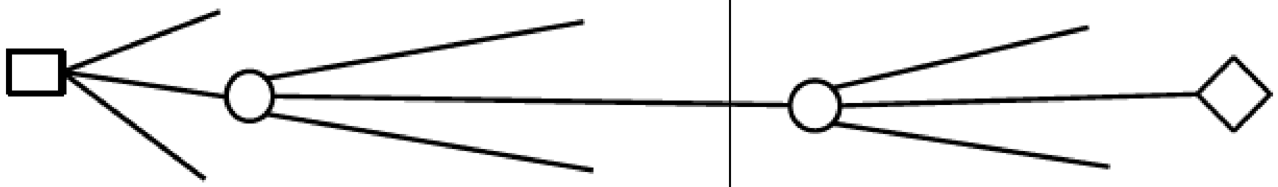
Function for system performance analysis (SP A):

$$U_{SP} = E_{X_l}\left[U\left(X_l\right)\right]$$

Thöns, S., C. Caprani, M. H. Faber, D. M. Frangopol, P. Gardoni, P. F. Giordano, D. Honfi, L. Iannacone, M. S. Khan, J. Köhler, S. Kim, N. de Koker, M. P. Limongelli, S. Miraglia, J. S. Nielsen, M. Pandey and C. Viljoen (2025). On information value and decision analyses. Structural Safety 113: 102481. DOI: https://doi.org/10.1016/j.strusafe.2024.102481

Thöns, S. (2024). On the derivation of the delta formulation for decision value. Structural Safety 109: 102466. DOI: https://doi.org/10.1016/j.strusafe.2024.102466

Bayesian decision analysis: Decision trees and objective functions

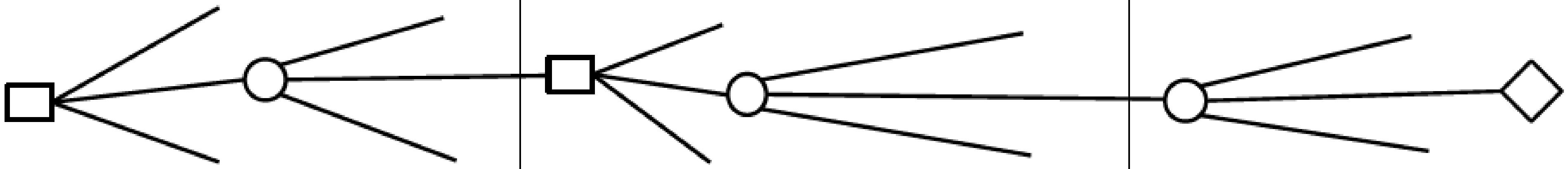
Information model		Action model		System and utility model		Analysis type
Choice Information i_i	Chance Outcomes $Z_{i,j}$	Choice Actions a_k	Chance Implementation $Y_{k,m}$	Chance System states X_l	Chance Utility $U(\ldots)$	
						PA DA

Objective function for predicted action decision analysis (PA DA):

$$U_{PA} = \max_{a_k} E_{Y_{k,m}}\left[E_{X_l(a_k,Y_{k,m})}\left[U\left(X_l, a_k, Y_{k,m}\right) - E\left[C\left(a_k\right)\right]\right]\right]$$

Thöns, S., C. Caprani, M. H. Faber, D. M. Frangopol, P. Gardoni, P. F. Giordano, D. Honfi, L. Iannacone, M. S. Khan, J. Köhler, S. Kim, N. de Koker, M. P. Limongelli, S. Miraglia, J. S. Nielsen, M. Pandey and C. Viljoen (2025). On information value and decision analyses. Structural Safety 113: 102481. DOI: https://doi.org/10.1016/j.strusafe.2024.102481
Thöns, S. (2024). On the derivation of the delta formulation for decision value. Structural Safety 109: 102466. DOI: https://doi.org/10.1016/j.strusafe.2024.102466

Bayesian decision analysis: Decision trees and objective functions

Information model		Action model		System and utility model		Analysis type
Choice Information i_i	Chance Outcomes $Z_{i,j}$	Choice Actions a_k	Chance Implementation $Y_{k,m}$	Chance System states X_l	Chance Utility $U(\ldots)$	
						PIPA DA

Objective function for predicted information and predicted action decision analysis (PIPA DA):

$$U_{PIPA} = \max_{i_i, a_k} E_{X_l(Y_{k,m}, a_k)} \left[E_{Y_{k,m}} \left[E_{Z_{i,j}|X_l(Y_{k,m}, a_k)} \left[U(X_l, Y_{k,m}, a_k) - E\left[C(a_k)\right] \right] \right] - E\left[C(i_i)\right] \right]$$

Thöns, S., C. Caprani, M. H. Faber, D. M. Frangopol, P. Gardoni, P. F. Giordano, D. Honfi, L. Iannacone, M. S. Khan, J. Köhler, S. Kim, N. de Koker, M. P. Limongelli, S. Miraglia, J. S. Nielsen, M. Pandey and C. Viljoen (2025). On information value and decision analyses. Structural Safety 113: 102481. DOI: https://doi.org/10.1016/j.strusafe.2024.102481
Thöns, S. (2024). On the derivation of the delta formulation for decision value. Structural Safety 109: 102466. DOI: https://doi.org/10.1016/j.strusafe.2024.102466

Information value metrics

$$V_{PI} = U_{PIPA} - U_{PA}$$

Value of information (difference)

$$\overline{V}_{PI/U_{PA}} = \left(U_{PIPA} - U_{PA}\right) / U_{PA}$$

- Value of information scaled with predicted action decision analysis

$$\overline{V}_{PI/U_{SP}} = \left(U_{PIPA} - U_{PA}\right) / U_{SP}$$

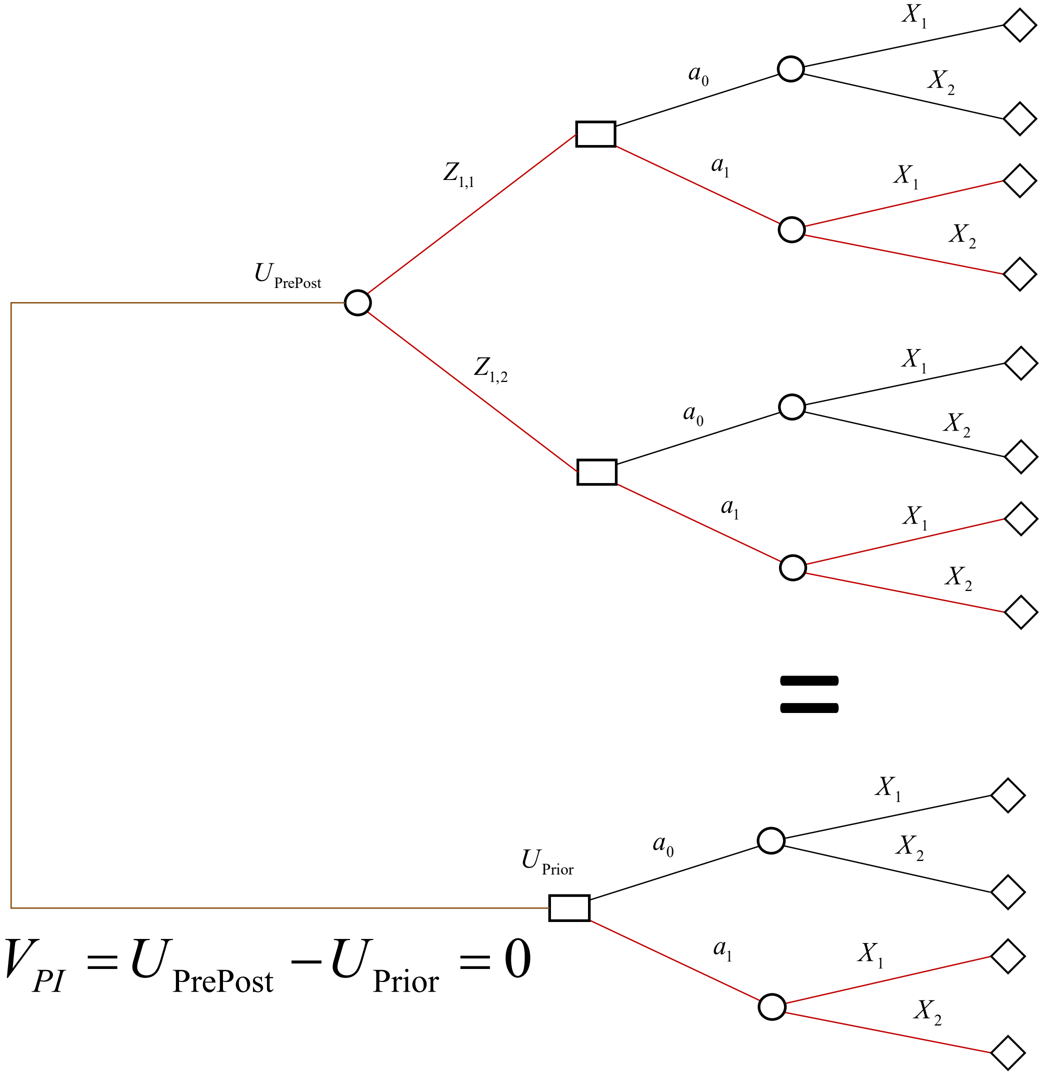
- Value of information scaled with system performance analysis

$$\overline{V}_{PI/c(i)} = \left(U_{PIPA} - U_{PA}\right) / C\left(i\right)$$

- Value of information scaled with predicted action decision analysis

Thöns, S., M. Chadha, Z. Hu and M. D. Todd (2023). On metrics for information value quantification. 14th International Workshop on Structural Health Monitoring (IWSHM 2023), Stanford, USA, September 12 to 14, 2023.

What happens if the action does nor change for different information outcomes?



$$V_{PI} = U_{\text{PrePost}} - U_{\text{Prior}} = 0$$

Objective function for pre-posterior decision analysis:

$$U_{PrePost} = \max_{i_i, a_k} \sum_{Z_{i,j}} \sum_{X_l} u(a_k, X_l) \cdot P(X_l \mid Z_{i,j}) \cdot P(Z_{i,j})$$

If the utility is constant, we can take the utility out of the sum:

$$U_{PrePost} = \max_{i_i, a_k} \sum_{X_l} u(a_k, X_l) \sum_{Z_{i,j}} P(X_l \mid Z_{i,j}) \cdot P(Z_{i,j})$$

We remember the total probability theorem:

$$\sum_{Z_{i,j}} P(X_l \mid Z_{i,j}) \cdot P(Z_{i,j}) = P(X_l)$$

$$U_{PrePost} = \max_{a_k} \sum_{X_l} u(a_k, X_l) \cdot P(X_l) = U_{Prior}$$

The pre-posterior decision analysis equals the prior decision analysis (before information cost).
The value of information (before information cost) is zero.

How to use the total probability theorem? With the delta formulation.

Objective function for predicted information value with utility actions

$$V_{PI_U} = \max_{o_i, a_k}\left(E\left[\Delta U - \Delta c\left(a_k\right)\right] - c\left(o_i\right)\right)$$

The value of information is proportional by the system state utility difference (utility delta) and the action cost difference (delta)

Objective function for predicted information value with system state actions

$$V_{PI_S} = \max_{o_i, a_k}\left(\Delta E\left[u\left(X_l\right) - \Delta c\left(a_k\right)\right] - c\left(o_i\right)\right)$$

The value of information is proportional by the system state probability delta and the action cost delta.

.

Thöns, S. (2024). On the derivation of the delta formulation for decision value. Structural Safety 109: 102466. DOI: https://doi.org/10.1016/j.strusafe.2024.102466.

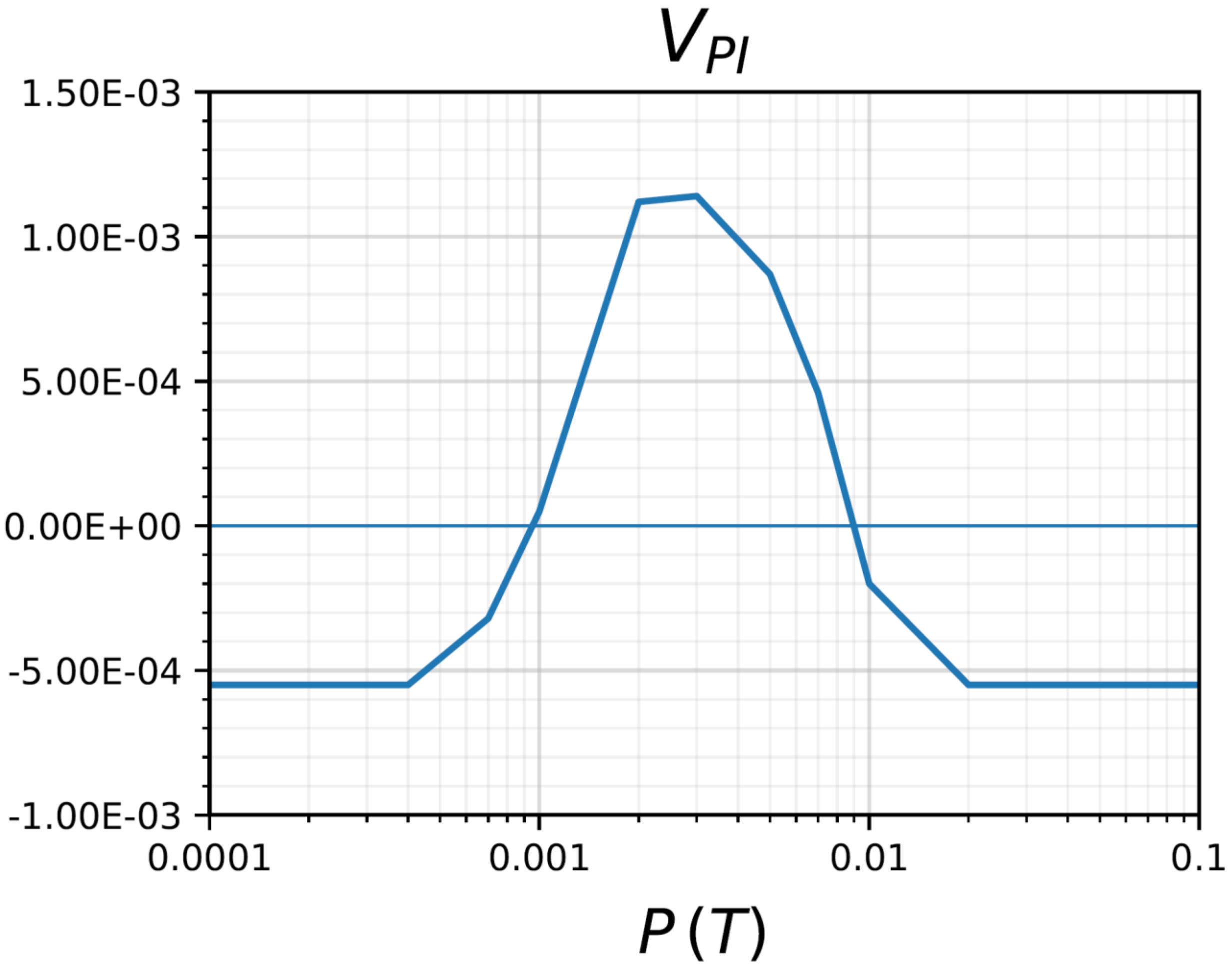
Case study

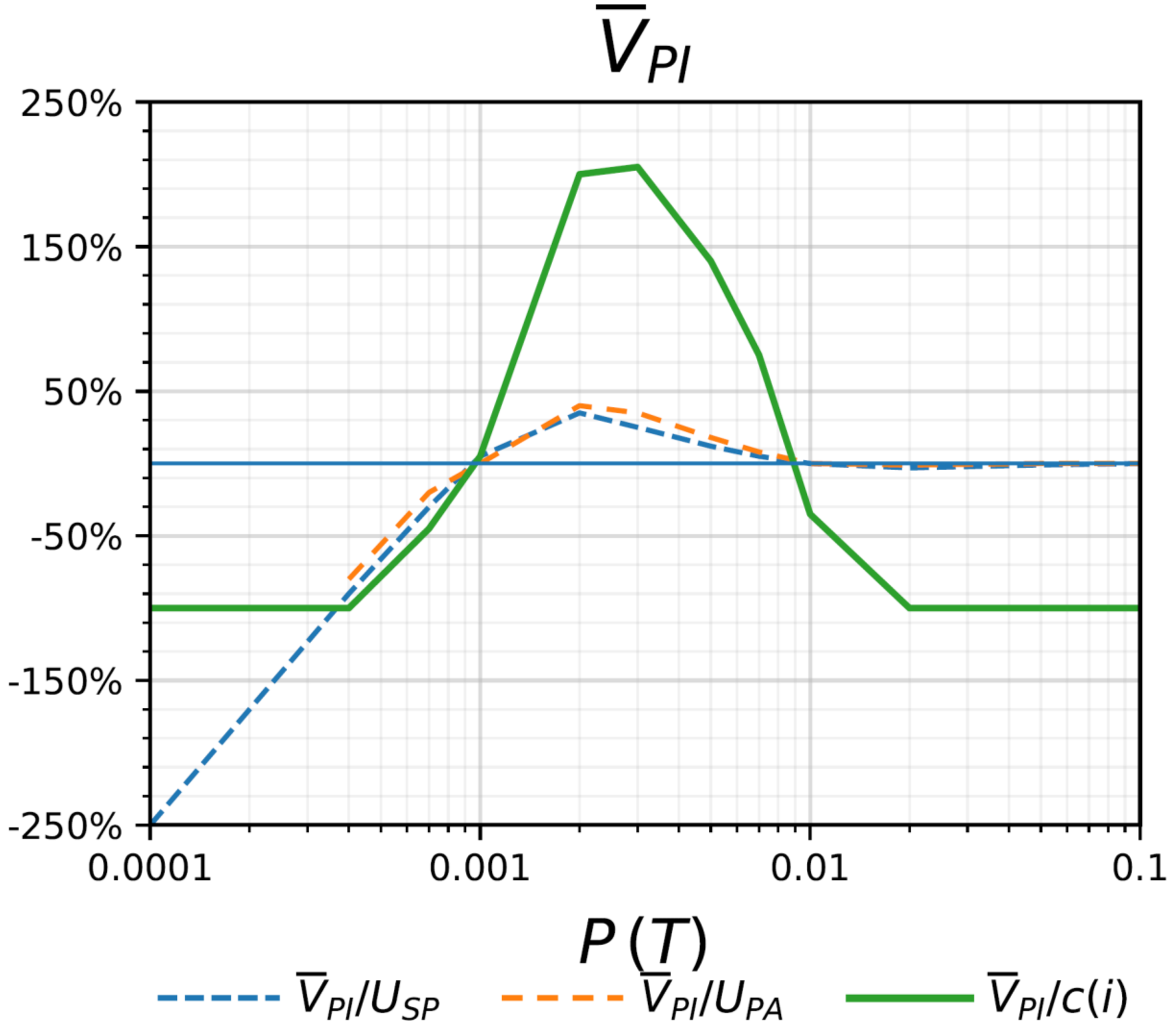
We analyse the value of a risk mitigation strategy for terrorist attacks with Improvised Explosive Devices (IEDs) for an iconic bridge structure.

- Bridge value: €2.0 Billon, 100-year design life, interest rate of 4%
- Bridge failure: conditional probabilities of threat (probability of a plot), hazard (probability of actual detonation of IED) and collapse
- Consequences of bridge failure: between 5 to 25 (mode at 10) of the bridge value due to traffic diversions, user delays, business losses
- Mitigation strategy: surveillance (threat indication) and bridge closing (consequence reduction)

Thöns, S. and M.G. Stewart, 2020. On the cost-efficiency, significance and effectiveness of terrorism risk reduction strategies for buildings. Structural Safety. 85: p. 101957. https://doi.org/10.1016/j.strusafe.2020.101957

Case study: Information values V_{PI} and threat probability $P(T)$





Thöns, S., M. Chadha, Z. Hu and M. D. Todd (2023). On metrics for information value quantification. 14th International Workshop on Structural Health Monitoring (IWSHM 2023), Stanford, USA, September 12 to 14, 2023.

Contents

1) Introduction: Detection theory, Decision theory, Bayes risk and interrelations

2) Value of structural health information

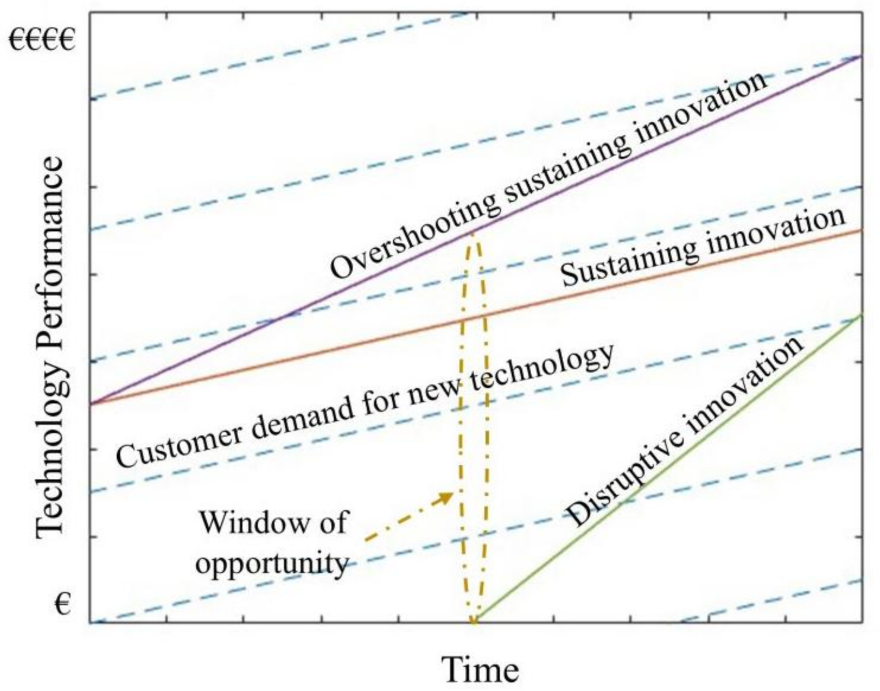
3) Actual research: Decision support for innovation and service life extension

Decision support for innovation

Technology readiness

TRL 1	Basic principles observed
TRL 2	Technology concept formulated
TRL 3	Experimental proof of concept
TRL 4	Technology validated in lab
TRL 5	Technology validated in relevant environment
TRL 6	Technology demonstrated in relevant environment
TRL 7	Prototype demonstration in operational environment
TRL 8	System complete and qualified
TRL 9	Actual system proven in operational environment

Disruptive innovation theory (Bower and Christensen 1995)



Innovation diffusion (Rogers 2003)

Costa, G. (2025). Value of information driven innovation in structural health monitoring technology. PhD thesis. Department of Architecture, Built Environment and Construction Engineering. Politecnico di Milano, Italy. https://www.politesi.polimi.it/handle/10589/238898
Bower, J. L. and C. M. Christensen (1995). Disruptive Technologies: Catching the Wave. Harvard Business Review 73(1): 43-53.
Rogers, E. M. (2003). Diffusion of innovations. New York, Free press. ISBN: 0743222091.

Decision support for innovation

TRL 1	Basic principles observed
TRL 2	Technology concept formulated
TRL 3	Experimental proof of concept
TRL 4	Technology validated in lab
TRL 5	Technology validated in relevant environment
TRL 6	Technology demonstrated in relevant environment
TRL 7	Prototype demonstration in operational environment
TRL 8	System complete and qualified
TRL 9	Actual system proven in operational environment

Concept-based value quantification

Experiment-based value quantification

Operation-based value quantification

Costa, G. (2025). Value of information driven innovation in structural health monitoring technology. PhD thesis. Department of Architecture, Built Environment and Construction Engineering. Politecnico di Milano, Italy. https://www.politesi.polimi.it/handle/10589/238898

Value of Information for Innovation

Concept-based value quantification

Research and technology screening

Experiment-based value quantification

Determination and optimization of technology performance parameters

Operation-based value quantification

Technology employment optimization

Costa, G. (2025). Value of information driven innovation in structural health monitoring technology. PhD thesis. Department of Architecture, Built Environment and Construction Engineering. Politecnico di Milano, Italy. https://www.politesi.polimi.it/handle/10589/238898

Contents

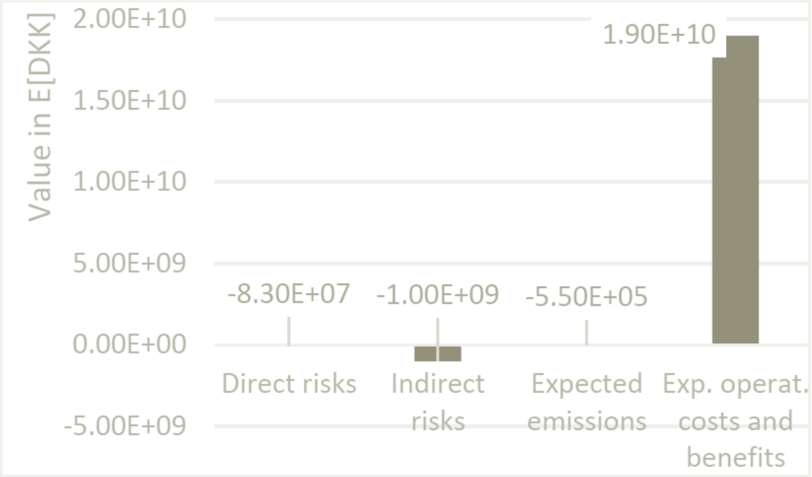
1) Introduction: Detection theory, Decision theory, Bayes risk and interrelations

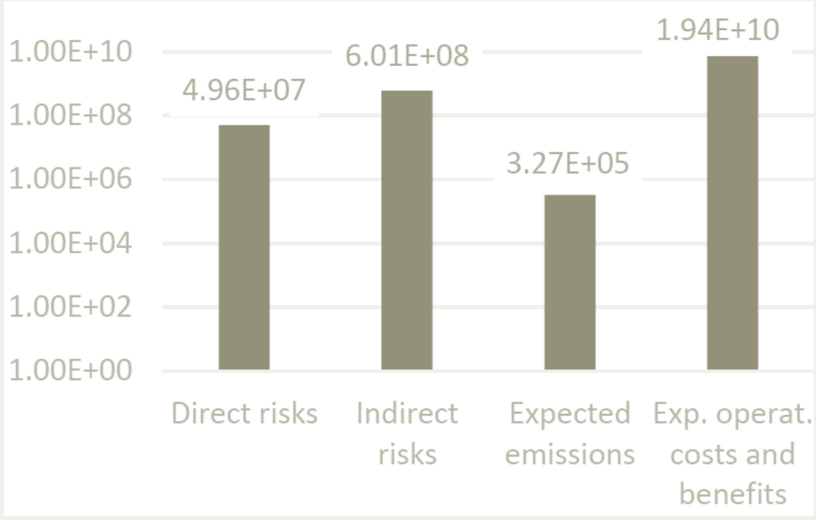
2) Value of structural health information

3) Actual research: Decision support for innovation and service life extension

Example: Towards a service life extension of the Öresund Fixed Link

Value quantification for service life extension with and without monitoring





Service life extension is driven by extended operational benefits.

1) Without additional information (observation) or measures (repair, strengthening): Risks including emission risks increase (top diagram)
2) Additional information have the potential (as they are predicted) for risk reduction value (bottom diagram)
3) Value indicate the monitoring system budget (development, employment) from different stakeholders (operators; industry and society)

Thöns, S., I. Björnsson and B. Hergart (In Press). Risk, life cycle cost and environmental impact analysis for service life extension. Procedia Structural Integrity.

Summary

Added information value

- Potentially by Detection theory and Bayes risk formulation
- Utilisation of information for an action change in infrastructure operation
- Future utilisation of provided information

There is per se no added information value but information value potentials by information utilisation.

- For infrastructure operation
- For innovation decision support
- For research priotarisation

LUND UNIVERSITY

Thank you for your attention

SEBASTIAN.THONS@KSTR.LTH.SE

Sebastian Thöns
sebastian.thoens@mailbox.org