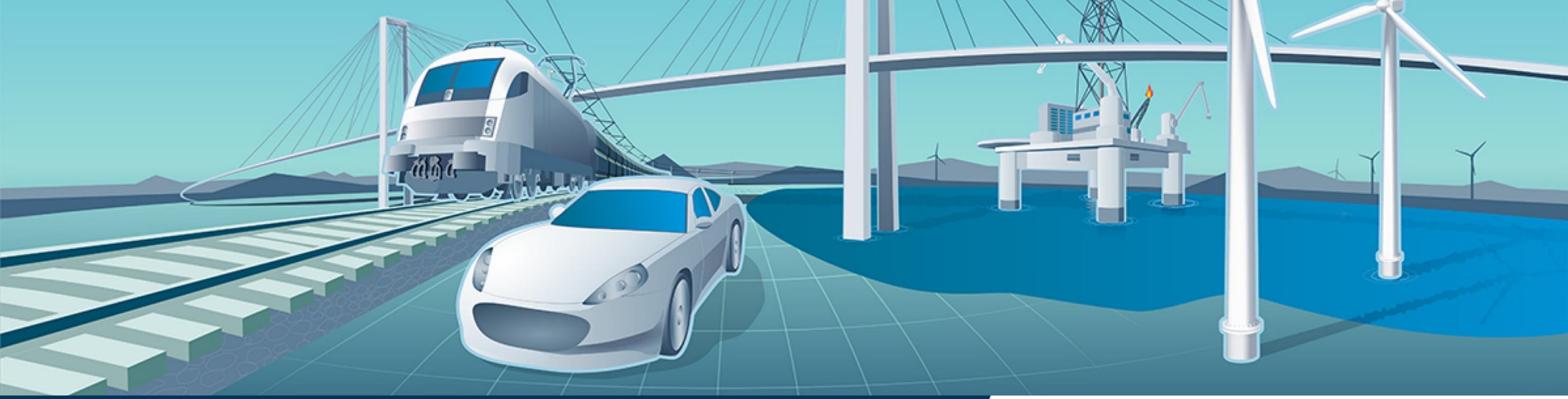

HBK Technology Days – Virtual Seminar Series

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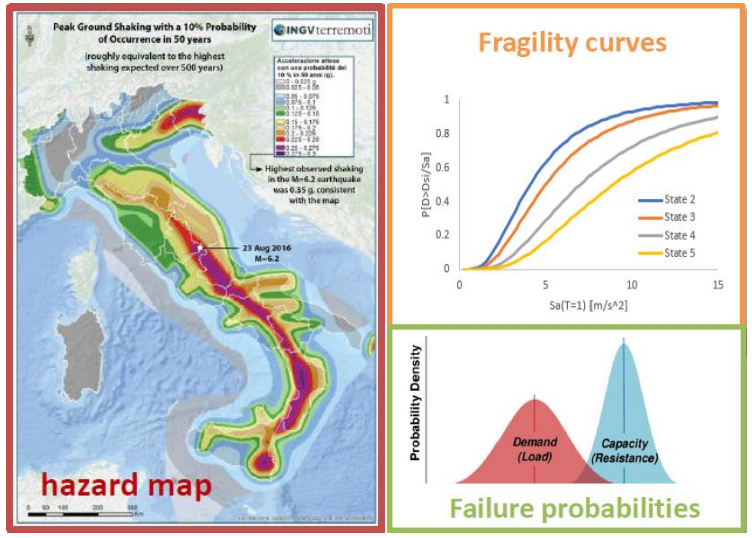

Value of Information from Structural Health Monitoring for Emergency Management

Presented by Prof. Maria Pina Limongelli,
Department of Architecture, Built Environment and Construction Engineering, Politecnico di Milano

Value of Information from Structural Health Monitoring for Emergency Management

Abstract

The management of civil infrastructures in the aftermath of a disruptive event is a concern for decision makers, which have to choose quickly among alternative actions with limited knowledge on the actual structural conditions. Structural Health Monitoring (SHM) information can support these decisions. However, information comes with a cost and the relevant benefit must be assessed before the acquisition of the SHM system is decided. A powerful tool to estimate the benefits and to optimize the SHM system design for specific applications is the Value of Information (VoI) analysis based on pre-posterior Bayesian analysis. In the presentation the theory will be shortly described and demonstrated through a couple of exemplary case studies.

About the presenter, Prof. Maria Pina Limongelli, Department of Architecture, Built Environment and Construction Engineering, Politecnico di Milano

Prof. Maria Pina Limongelli is Associate professor of Structural and seismic engineering at Politecnico di Milano and Guest Professor of Digital Structural Health Monitoring and Integrity Management at Lund University in Sweden. She holds a M.S. (1991) in Structural Engineering and a Ph.D. (1995) in Seismic Engineering. Her primary research interests are related to Value of SHM information analysis, Vibration-based monitoring, and SHM standardization. She is author of more than 200 scientific peer-reviewed papers and participates, with leading roles, in several national and international funded projects Structural Health Monitoring and performance assessment of roadway bridges. She coordinates activities in several committees, and associations such as ISHMII, fib, IABSE, and JCSS..

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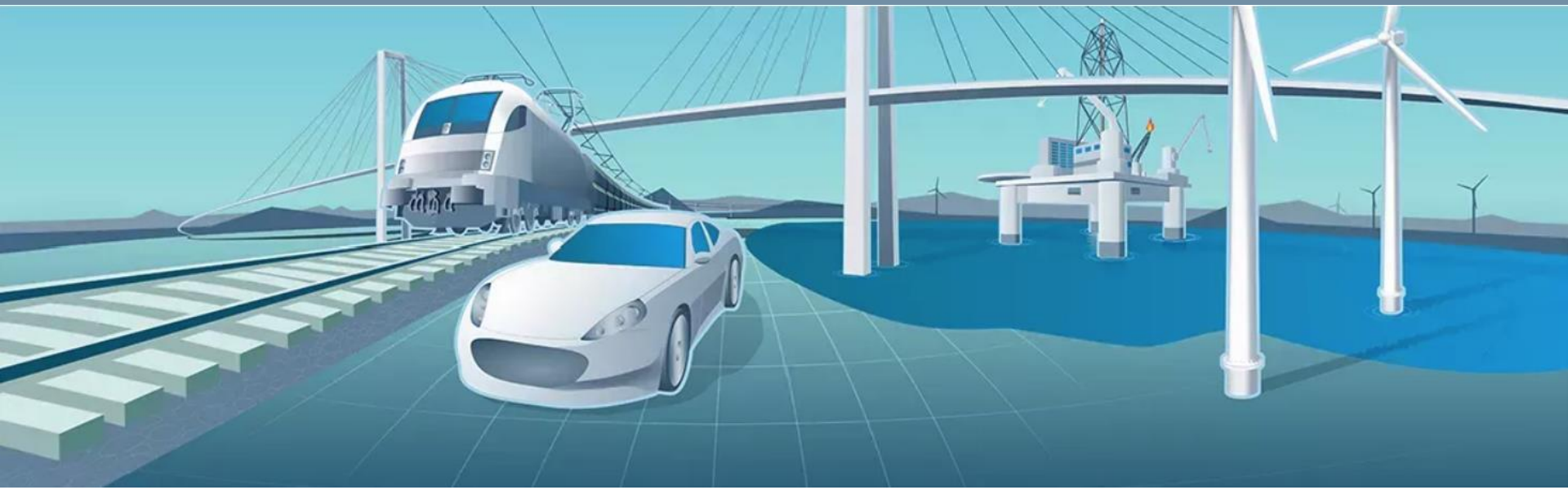

Value of information from SHM for emergency management

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Structural Performance Modeling, Management & Monitoring Research Group

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The problem: an example

Seismic emergency management of a bridge

After an earthquake the bridge can collapse (e.g. due to traffic).

Leaving it open may entail fatalities. Closing it entails indirect costs

Open or close?

Is it worth to install an SHM system

to support this decision?

Outline of the presentation

- Motivation of Value of Information of SHM
- Quantification of VoI
- VoI for emergency management
- Ongoing and future work

Motivations

Motivations of value of SHM information analysis

SHM can provide **continuous information** about the system state. It is effective to support emergency management.

However it is **not yet extensively and routinely used** to this goal.

One of the main reasons is the difficulty to estimate the **return on investment** associated with the SHM. This has often caused **reluctance of the owners** in investing in these technologies.

Recently **research efforts** have been invested in procedures to quantify the value of an SHM system before its implementation.

COST Action TU1402:
Quantifying the Value of
Structural Health Monitoring

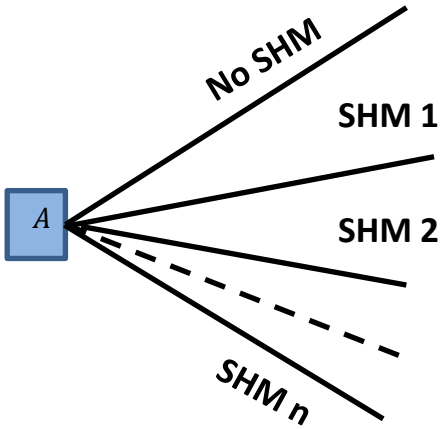
How can we use VoI analisys?

Some examples…..

- to help the manager decide if it is worth to install **a specific SHM** to support their decisions
- to help the manager decide **which SHM system,** among several alternatives, is optimal to support their decisions
- to help the manager decide **which setup of a given SHM** is optimal to support their decisions

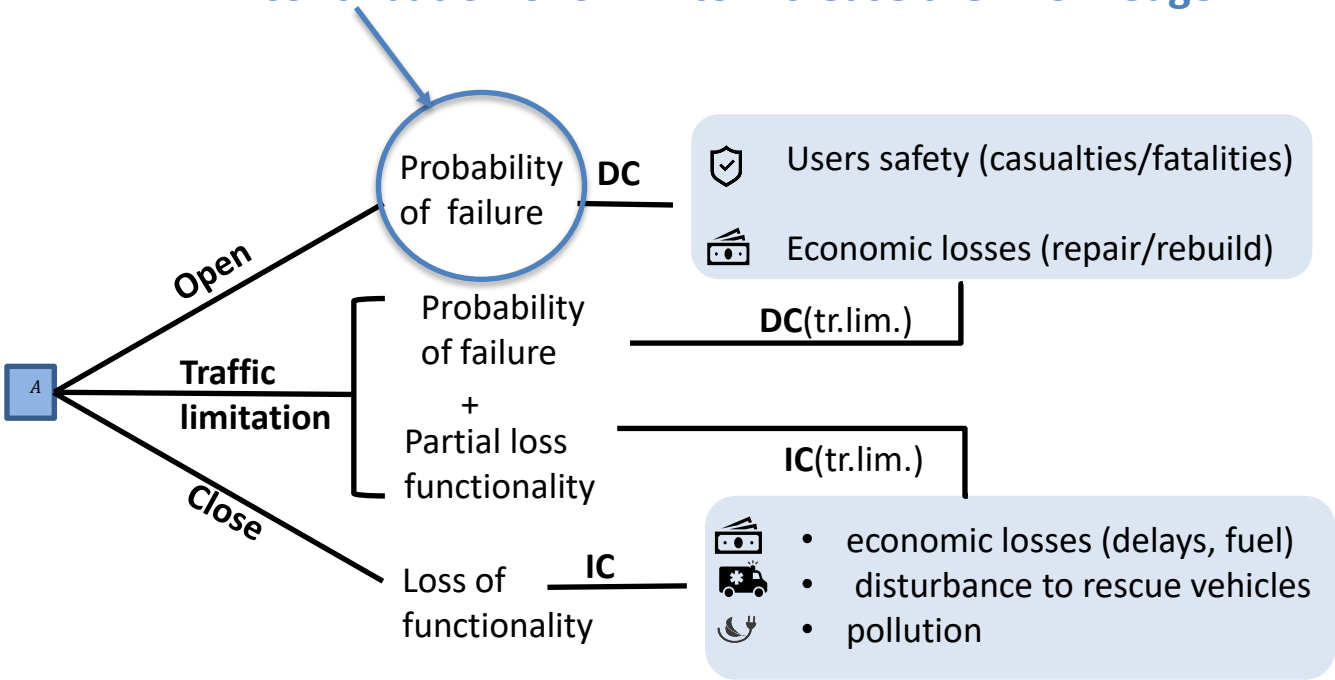
Two decision problems

BEFORE THE EMERGENCY
install an SHM system?
which one?



DURING THE EMERGENCY
limit the functionality?

contribution of SHM: to increase the knowledge



Quantification of Value of Information

Framework to quantify the VoI

Prob. state of the system without SHM

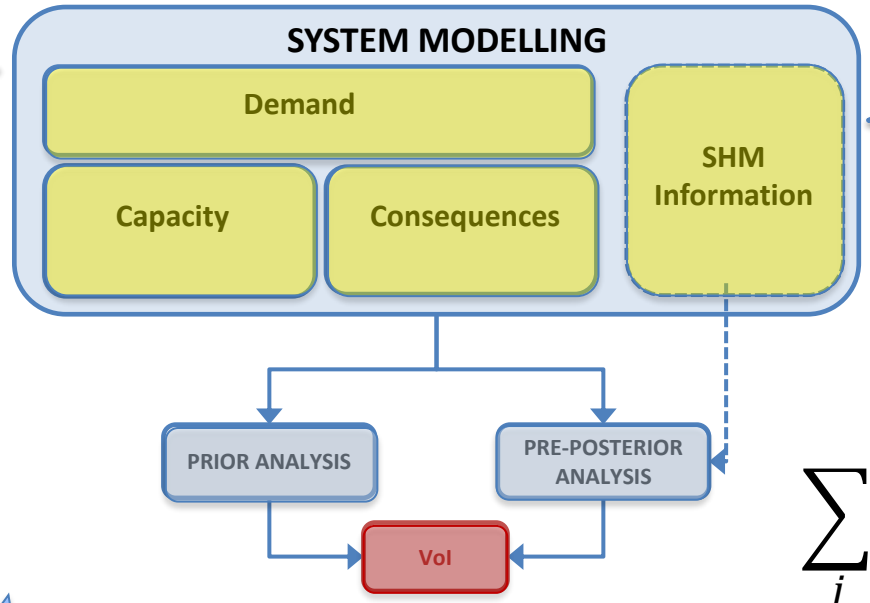
$P(s)$

Cost evaluation without SHM

Choice of the optimal action

Expected cost of the optimal action

$$VoI = C_{NO\ SHM} - C_{SHM}$$



Prob. state of the system with SHM

$P(s|z_{SHM})$

Cost evaluation with SHM

Choice of the optimal action for each SHM outcome z_{SHM_j}

Expected cost of the expected costs of the optimal actions

$E[A_{opt,NO\ VBM}]$

$\sum_j E[A_{opt,SHM_j}]\,P(z_{SHM_j})$

$$VoI = E[A_{opt,NO\ SHM}] - \sum_j E[A_{opt,SHM_j}]\,P(z_{SHM_j})$$

Quantifying the VoI

$$VoI = E\left[A_{opt,NO\ SHM}\right] - \sum_j E\left[A_{opt,SHM_j}\right] P\left(z_{SHM_j}\right)$$

$$=$$

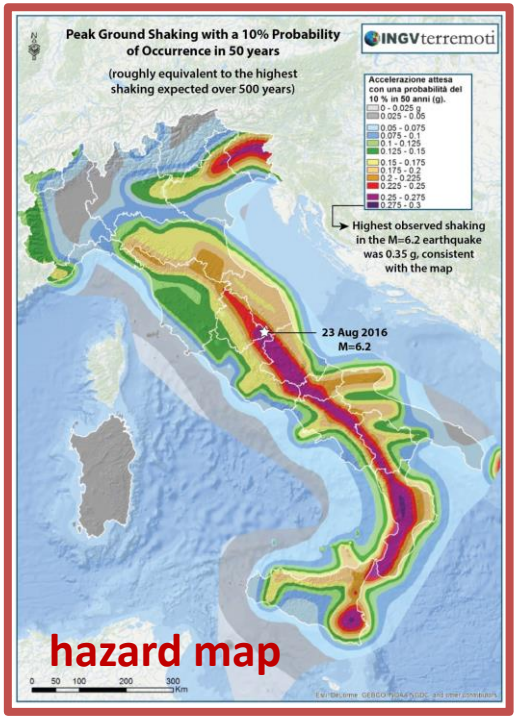
$$\sum_{l=1}^{L} E\left[c\left(A_{opt}\right)\middle|s_l\right] P(s_l) - \sum_{j=1}^{J}\sum_{l=1}^{L} E\left[c\left(A_{opt_{z_j}}\right)\middle|s_l\right] P\left(s_l\middle|z_j\right) P(z_j)$$

Prior probability of the system state

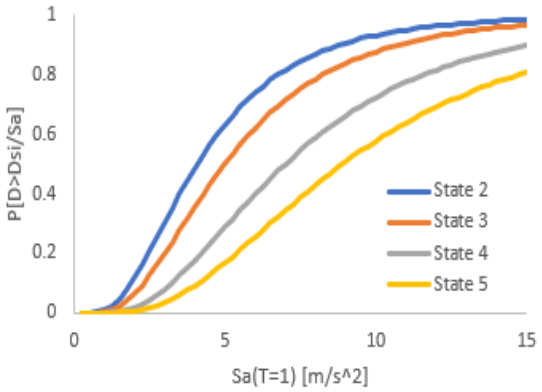
Posterior probability of the system state for outcome z_j of the SHM

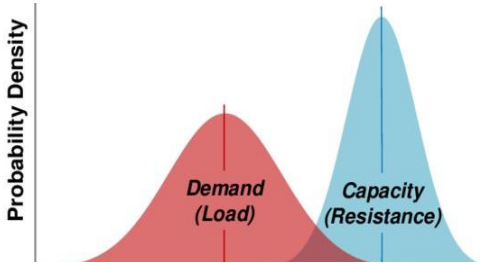
‘Ingredients’ for Prior analysis

$P(s_l)$



Fragility curves





Failure probabilities

Consequences

Direct: due to the collapse (cost of the bridge + fatalities + injuries)

Indirect: due to the loss of functionality (delays, increased travel time, increased fuel consumption, pollution.

capacity **demand** **consequences**

Quantifying the VoI

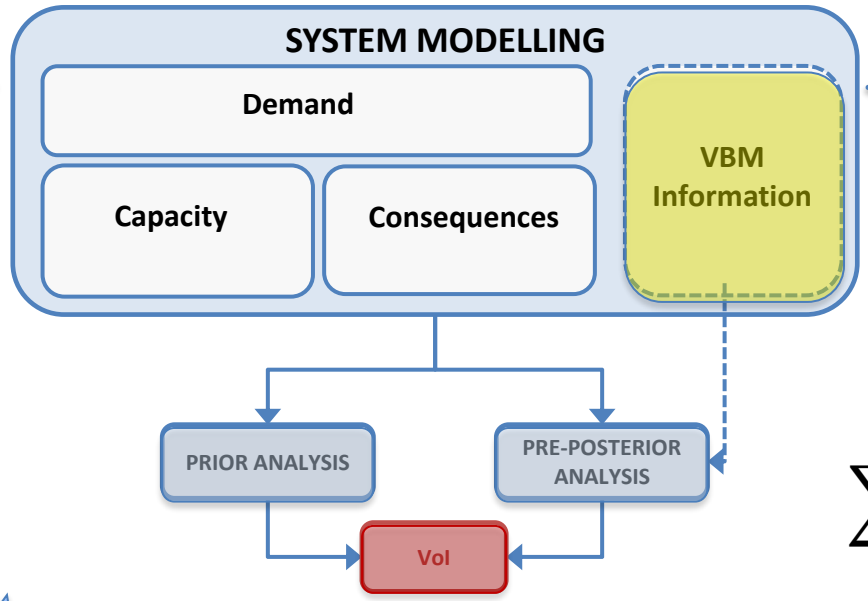
Prob. state of the system without VBM

$$P(s_l)$$

Risk evaluation without VBM

Choice of the optimal action

Expected cost of the optimal action



Prob. state of the system with VBM

$$P(s_l|z_{VBM})$$

Risk evaluation with VBM

Choice of the optimal action for each SHM outcome

Expected cost of the expected costs of the optimal actions

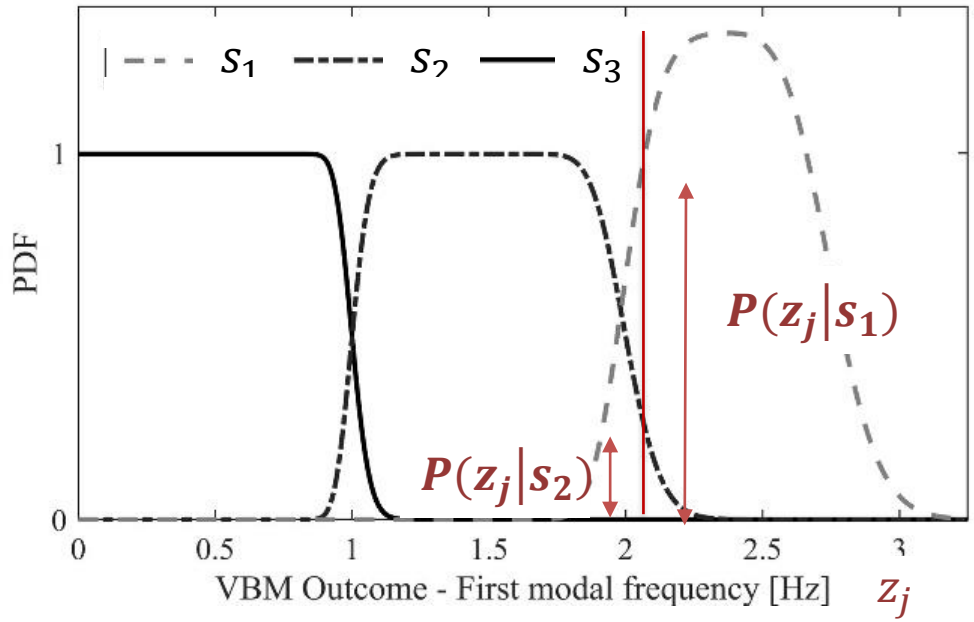
$$E\left[C\left(A_{opt,no\ VBM}\right)\right]$$

$$\sum_j E\left[C\left(A_{opt,VBM_j}\right)\right] P\left(z_{VBM_j}\right)$$

$$VoI = E\left[C\left(A_{opt,no\ VBM}\right)\right] - \sum_j E\left[C\left(A_{opt,VBM_j}\right)\right] P\left(z_{VBM_j}\right)$$

Additional 'ingredients' for Pre-posterior analysis

$$\sum_{l=1}^{L} E\left[c\left(A_{opt}\right)\middle|s_l\right]P(s_l) - \sum_{j=1}^{J}\sum_{l=1}^{L} E\left[c\left(A_{opt_{z_j}}\right)\middle|s_l\right]P\left(s_l\middle|z_j\right)P(z_j)$$



$$P(s_l|z_j) = \frac{P(z_j|s_l)}{P(z_j)}P(s_l)$$

Information model: likelihood functions

VoI for emergency management

The problem: an example

Seismic emergency management of a bridge

After an earthquake the bridge can collapse (e.g. **due to traffic**).

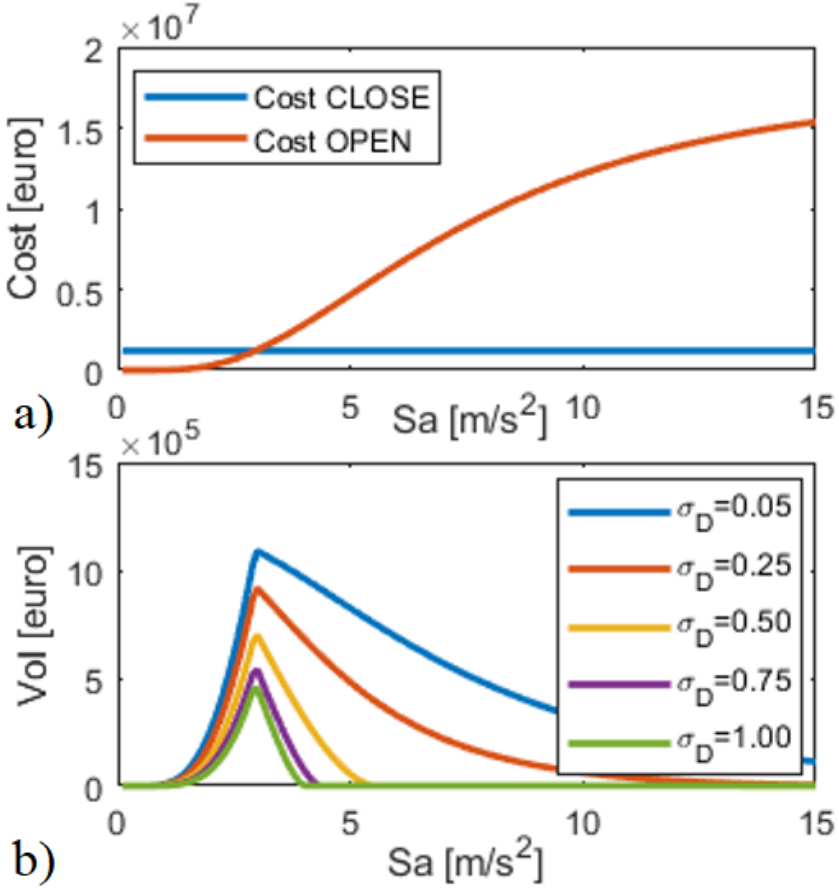
Leaving it open may entail fatalities. Closing it entails indirect costs

Open or close?

Is it worth to install an SHM system

to support this decision?

Prior costs and VoI



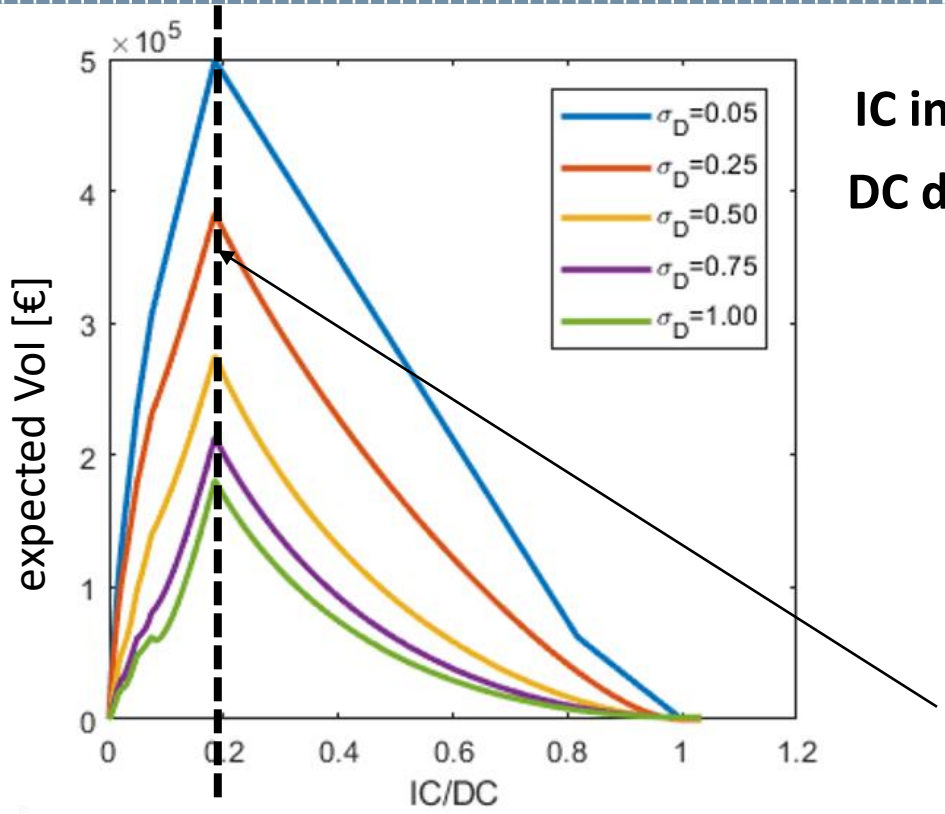
$E\left[C\left(A_{opt,NO\ SHM}\right)\right]$

expected costs of the 2 actions without VBM

Value of information

Giordano P.F., Miraglia S., Limongelli M.P (2019). The benefit of permanent monitoring for seismic emergency management. *SHMII-9th International Conference on Structural Health Monitoring of Intelligent Infrastructures*. 400-405. St Louis, Missouri. August 4-7, 2019

Impact of consequences



IC indirect consequences (loss of functionality)

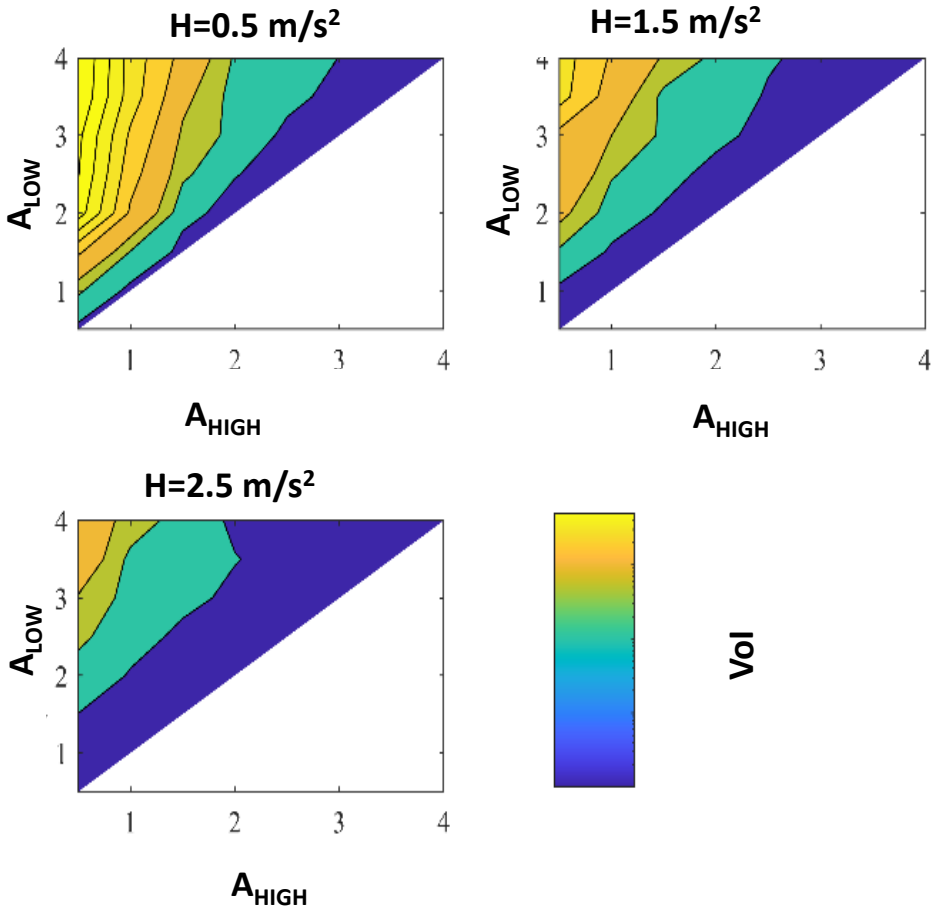
DC direct consequences (collapse)

Equal prior expected cost of the two decision alternatives (close/open)

In this case only DC depend on the system state

Giordano P.F., **Limongelli M.P.** (2021) The value of seismic structural health monitoring for road bridges. SHMII-10 Porto. June 30- July 2, 2021.

Impact of vulnerability and reliability



H intensity of the mainshock leading to a HIGH damage state

$A_{LOW/HIGH}$ index of prob. failure of the structure in LOW/HIGH damage state after the mainshock

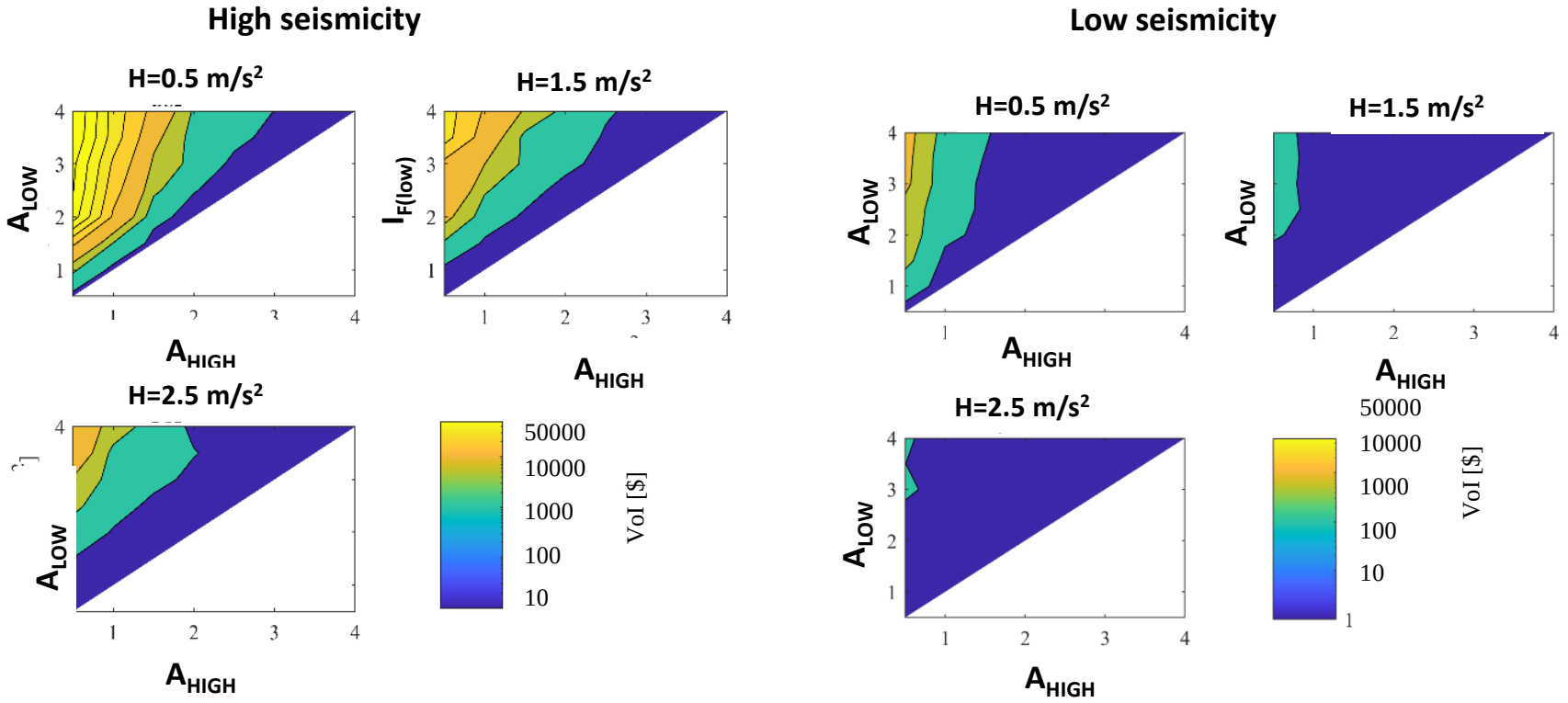
If $A_{LOW} = A_{HIGH}$ the knowledge about the system state after the mainshock does not provide support to decision-making

VoI increases with:

- vulnerability
- differences between reliability in the two system states

Giordano P.F., Limongelli M.P. (2021) The value of seismic structural health monitoring for road bridges. SHMII-10 Porto. June 30- July 2, 2021.

Impact of hazard level



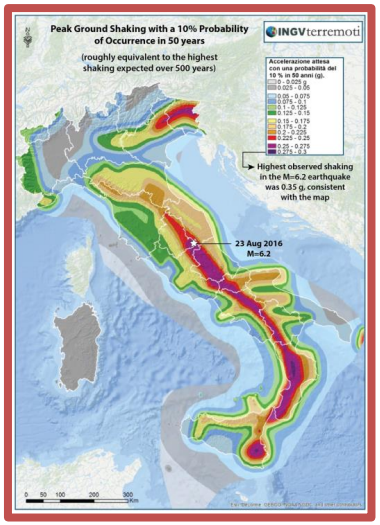
VoI increases with seismicity level

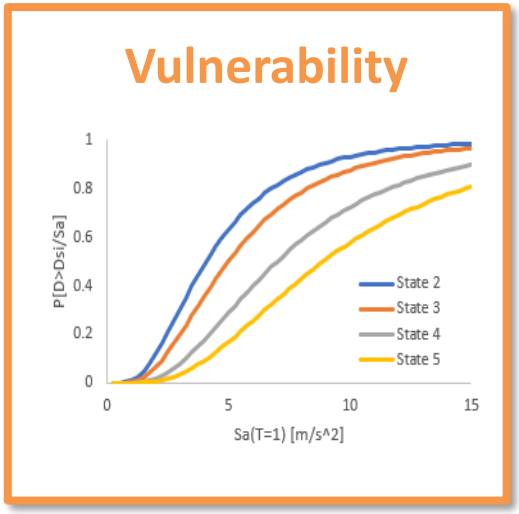
$$VoI = E\left[C\left(A_{opt,noVBM}\right)\right] - \sum_j E\left[C\left(A_{opt,SHVB}\right)\right] P\left(z_{VBM_j}\right)$$

Giordano P.F., Limongelli M.P. (2021) The value of seismic structural health monitoring for road bridges. SHMII-10 Porto. June 30- July 2, 2021.

Value of SHM increases with risk

$$\sum_{l=1}^{L} E\left[c\left(A_{opt}\right)\middle|s_l\right]P(s_l) - \sum_{j=1}^{J}\sum_{l=1}^{L} E\left[c\left(A_{opt_{z_j}}\right)\middle|s_l\right]P\left(s_l\middle|z_j\right)P(z_j)$$





Consequences

Direct: related to safety
Indirect: related to functionality

VoI increases with the expected prior and pre-posterior costs that is **with risk** (hazard, vulnerability, consequences)

Recap

TWO DECISIONS

BEFORE THE EMERGENCY install a VBM system?

AFTER THE EMERGENCY interrupt the functionality?

$$\sum_{l=1}^{L} E\left[c\left(A_{opt}\right)\middle|s_l\right]P(s_l) - \sum_{j=1}^{J}\sum_{l=1}^{L} E\left[c\left(A_{opt_{z_j}}\right)\middle|s_l\right]P\left(s_l\middle|z_j\right)P(z_j)$$

Expected cost of the optimal action computed **without VBM**

Expected cost of the expected costs of the optimal actions each computed **for a VBM outcome**

VoI is zero if the information does not change the decision

Ongoing and future work

Ongoing work

Quality of SHM data: is there a value in monitoring the monitoring system?

Drift, noise, loss may affect monitoring information

Monitoring information depends on the state of the structure and on the state the VBM system.

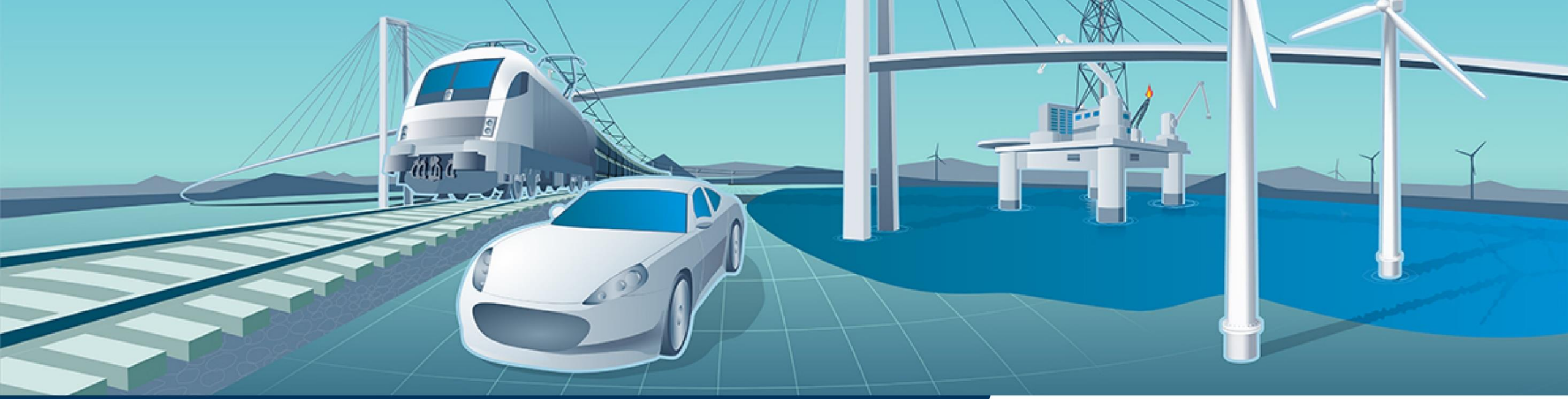
How much is it worth investing on a system to monitor the outcome of the SHM system?

P. F. Giordano, S. Quqa, and M. P. Limongelli, (2023). The value of monitoring a structural health monitoring system. Structural Safety. https://doi.org/10.1016/j.strusafe.2022.102280.

Future developments

- Value of monitoring for different maintenance policies (condition-based, predictive)
- Value of monitoring to increase service life (sustainability)
- Value of monitoring demand
- Value of local monitoring (several structural components)

Questions?



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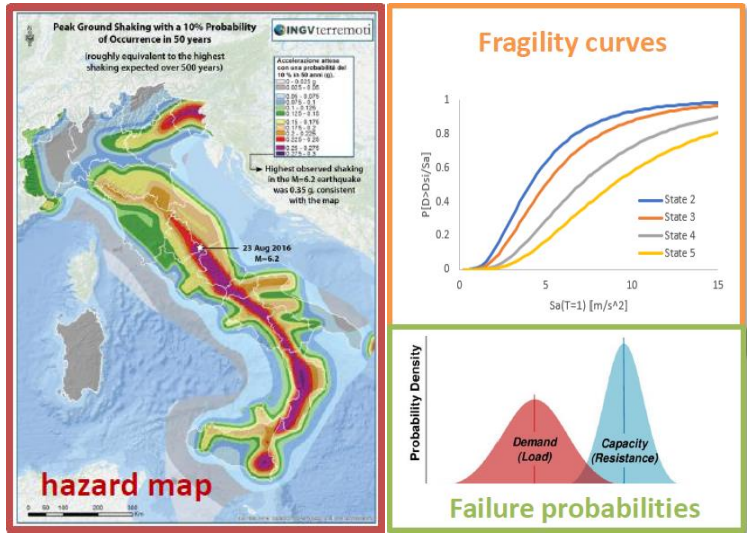

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