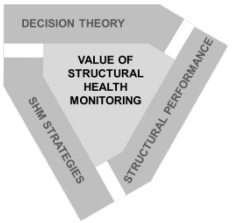


# Value of Information in System Resilience Modelling

Short Term Scientific Mission

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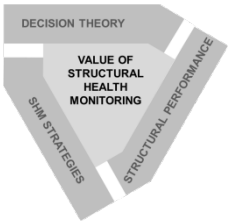


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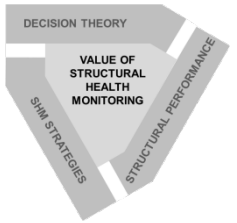
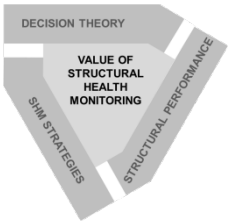
- Bayesian Net and evaluation of VoI
- Conclusions




# Motivation and Scope

- Information is an asset itself ✓
- When resources are limited, their use needs to be optimal ✓
- System performance under hazards depends on the degree of interaction among its components and the degradation state of the components ✓
- SHM allows assessing the conditions of system components to support asset management decisions ✓
- Can we use VoI for wider purpose besides SHM? 
- When modelling system resilience, which information are we really seeking for? 



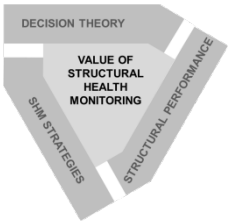

# Resilience Modelling : Definition

- Complex system of humans, infrastructures and nature

- Devastating consequences (functionality losses, economic losses, safety and health of people, environmental damages, etc..)

- Resilience is a core issues in many fields of science:
  - Psychology, '*individual's tendency to cope with stress and adversity*';
  - Material science, '*capacity of material to absorb energy when it is elastically deformed*';
  - Engineering context , '*ability of the system to return to a stable state after a perturbation*';
  - Ecology, '*ability of the system to maintain their integrity when subject to disturbance, i.e. to return to a position of equilibrium when disturbed*'.

The '*return of information theory*' in the context of resilience assessment is mentioned only in Ulanowicz et al.(2009): *'Quantifying sustainability: Resilience, efficiency and the return of information theory'.*



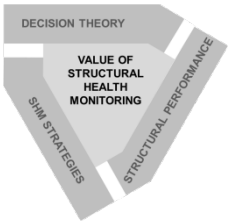

# Resilience Modelling: Approaches

- The approaches to resilience assessment can be divided in three main groups:

1- Mathematical approaches which are using system stochastic dynamics and classic operative research algorithms to find the final (or sequential) equilibrium point for the system adapting and recovering after disturbance;

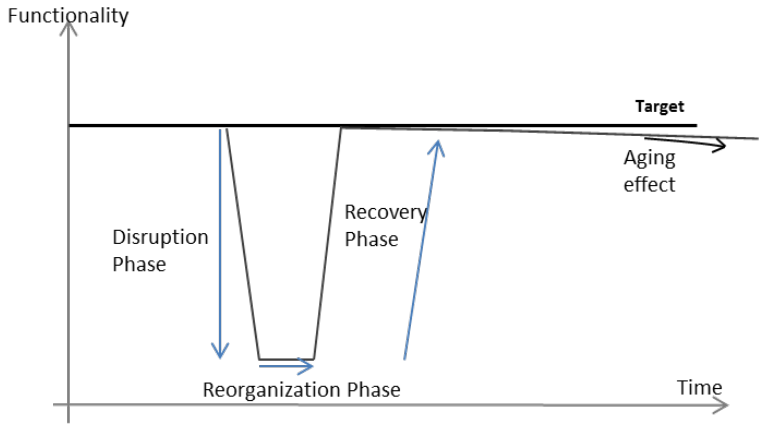
2- Engineering system approaches focused on the recovery time merely of structural/electronic/IT network systems;

3- Eco-system service approaches where resilience property focuses on modelling eco-system equilibrium and assessment of the eco-system service in both evolutionary context (anthropology and palaeontology) and toxicology and ecological disaster management (pollution and loss of species).




# Resilience Modelling: Resilience curve

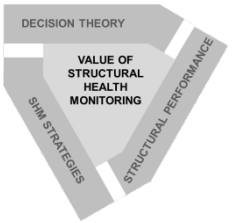
- Common basis for most engineered system approaches for resilience characterization is the identification of three main phases of functionality transition of the generic system after disturbance




*- disruption phase due to the damage of the system subject to the perturbation (natural hazard or human interference), whose duration depends on the characteristics of the system (vulnerability and robustness).*

*- reorganization phase, whose duration depends on emergency management policy, represents the phase in which the necessary resources for the rehabilitation of the systems are mobilized and* allocated

*- system rehabilitation phase*, which strictly depends on the recovery ability of the system



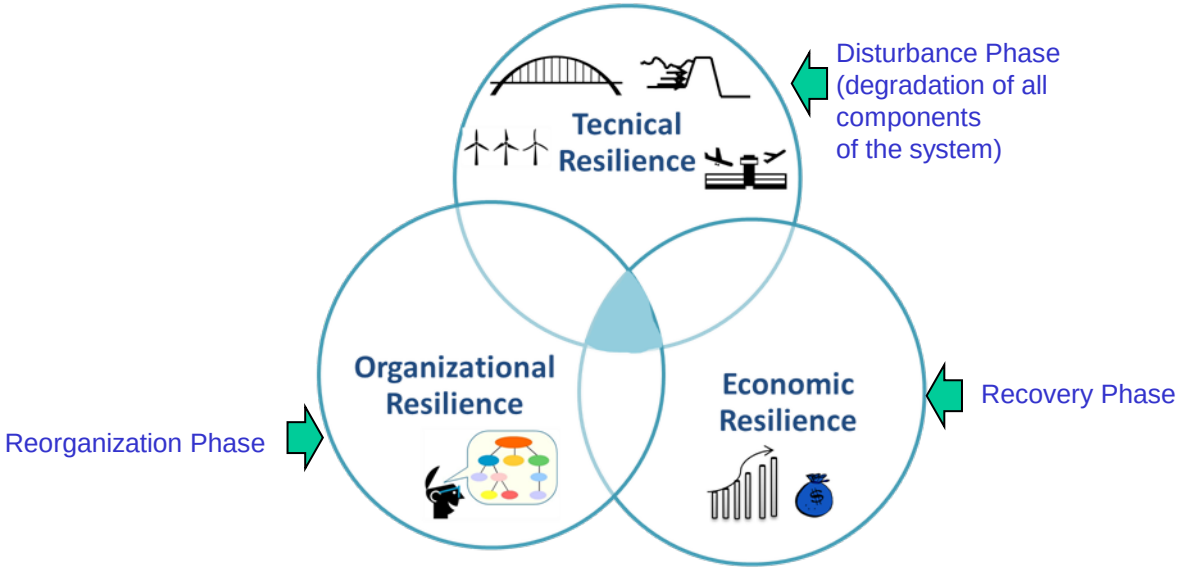

# Resilience Modelling: System representation

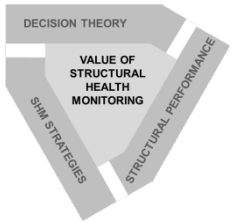
- Chang&Shinozuka: resilience assessment is related to the quantification of total economic losses where three components of the losses are considered: damage to assets, population affected by the disturbance and economic losses.

- Bruneau&Reinhorn: a resilient system shall not be able just to confine the damage within certain limits but also have resources available to speed up recovery where resources are intended as socio-economic resources as well as materials and natural resources.

# Resilience Modelling : 3D

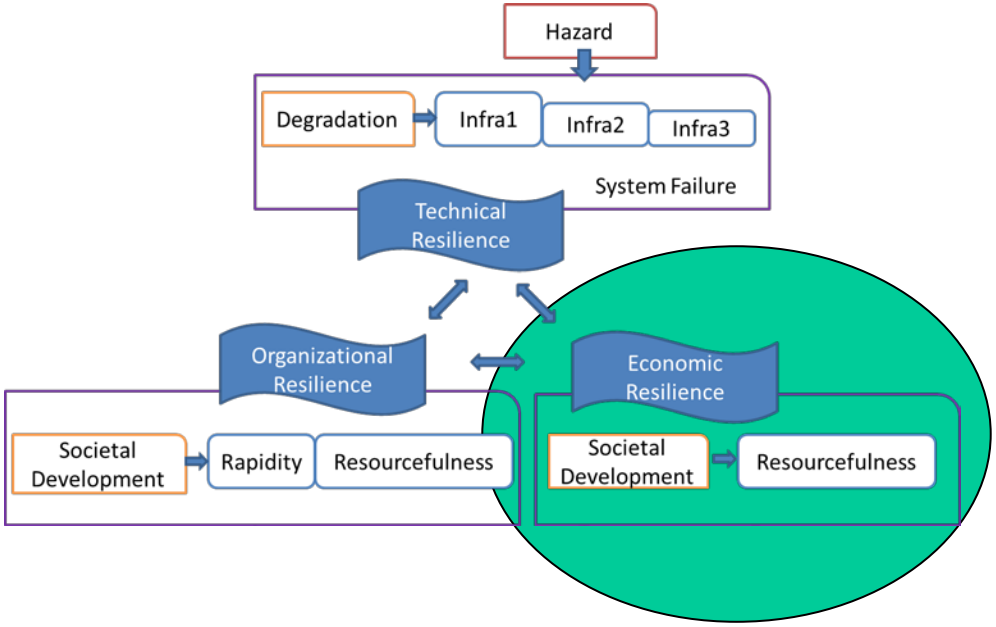
- Three dimensions of resilience :
  1- Technical resilience;
  2- Organizational resilience;
  3- Economic resilience.

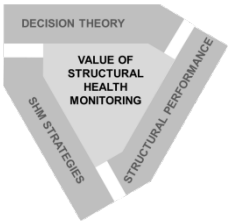





# Resilience Modelling: Economical Resilience

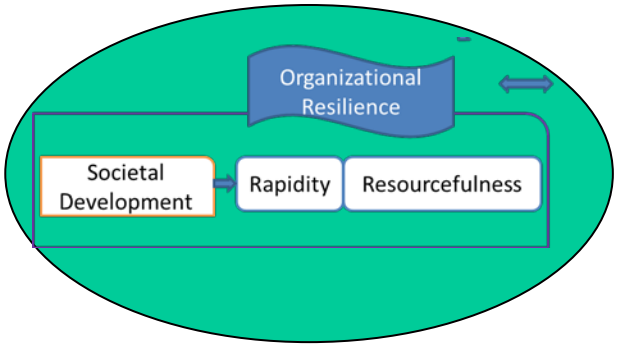
- It is related top Societal Development and Resourcefulness
- Forecast of the economic resilience can be made.

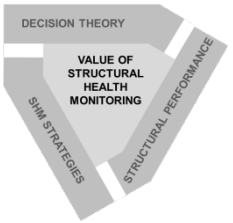





# Resilience Modelling: Organizational Resilience

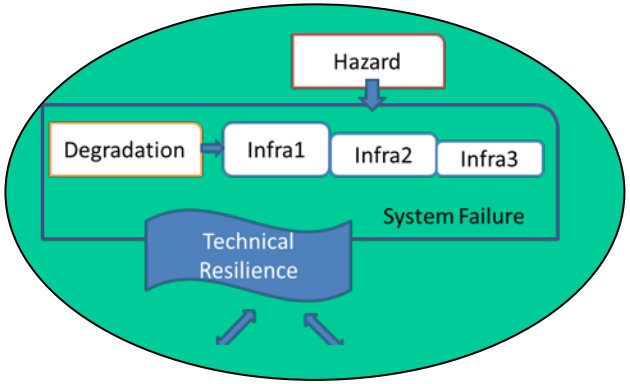
- It reflects resourcefulness and rapidity of the society.
- The rapidity to react and recover can be related to the society development level (developing country, developed country)
- Resourcefulness, depends on the resources available to speed up recovery
- Observation of resourcefulness can be made by observing the availability of resources (for example natural resources for material, energy etc.)

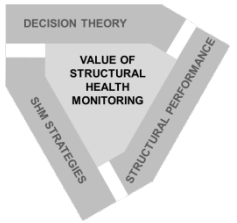





# Resilience Modelling: Technical Resilience

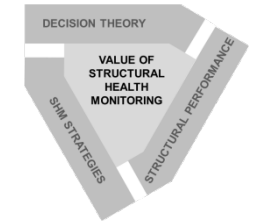
- Performance of a generic infrastructural system subject to a certain hazard (three separate structures, Infra1, Infra2 and Infra3 ordered from the strongest to the weakest with respect to the resistance to the hazard event)
- Three structures has a fixed probability of failure with respect to the intensity level of the hazard (daily maxima, yearly maxima, extreme event)
- Probability of failure depends on the degree of degradation of the structures (low, average, high)
- Observations of the degradation level can be made
- System failure occurs with probability which depends on combinations of Infra1&2&3 failed



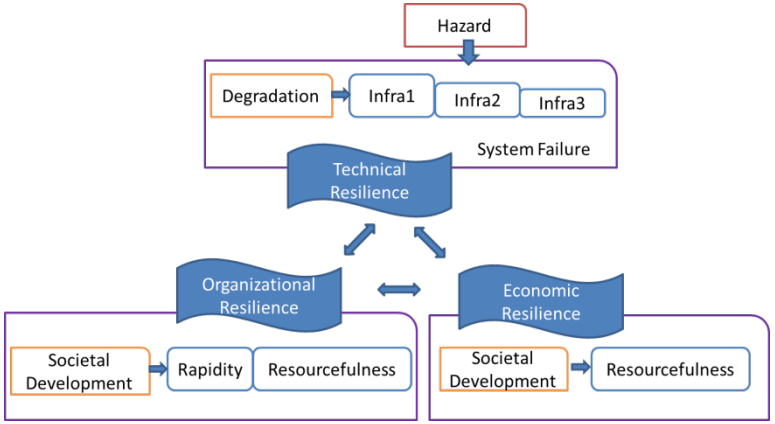


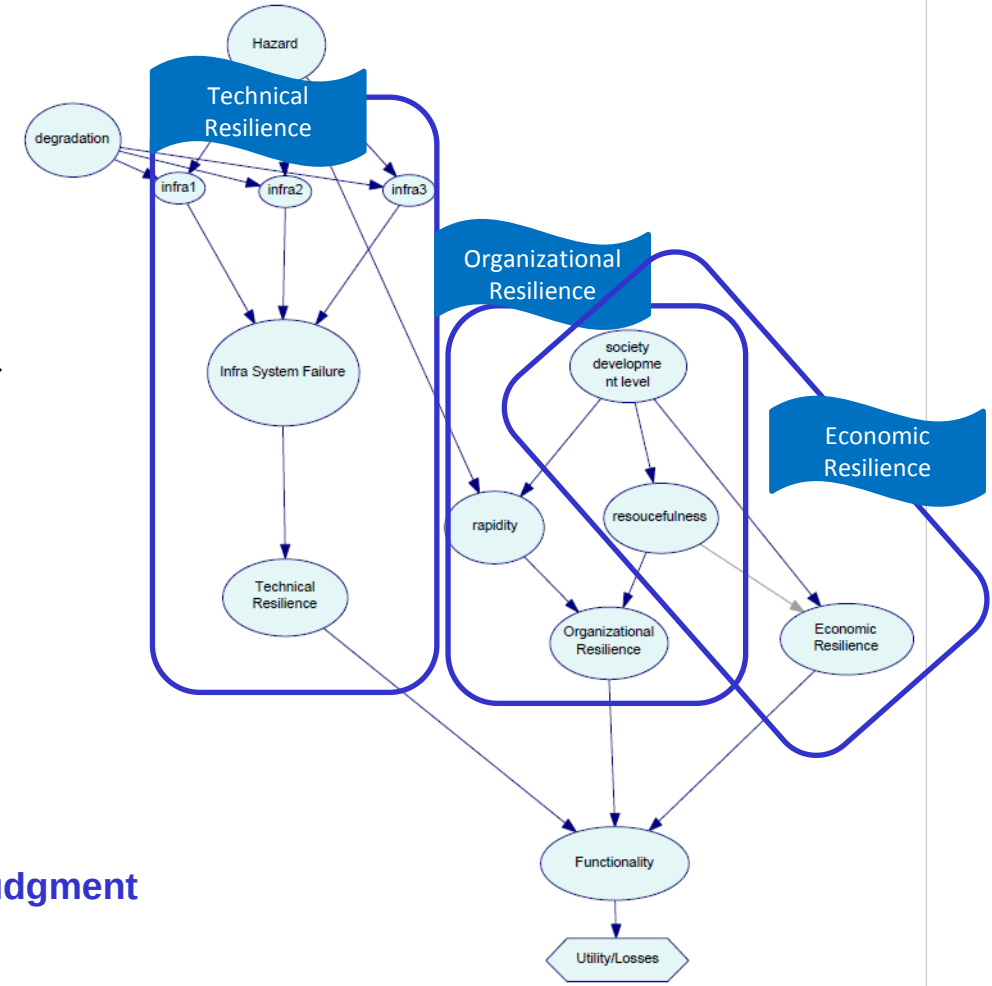

# Resilience Modelling: Utility Model

- The overall functionality is modelled as percentage of total available functionality (none as 100% lost functionality, low as 90% lost functionality, average as 50% of lost functionality, high as fully functioning)
- It is assumed that utility and losses are directly proportional to the functionality ( 1unit for each %functionality)
- Cost of SHM is 5units while the cost of monitoring the resource availability and to forecast economy are 10units each.




# Bayesian Network Model for evaluation of Value of Information

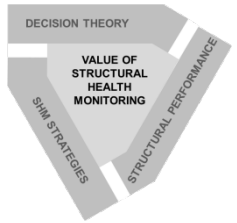



CPTs can be retrieved from:

- Available data;
- Expert Elicitation;
- Simulations.

**For this exercise the CPTs are filled by our own judgment (further work is in progress…)**




# Bayesian Network Model for evaluation of Value of Information

**Three monitoring strategies**

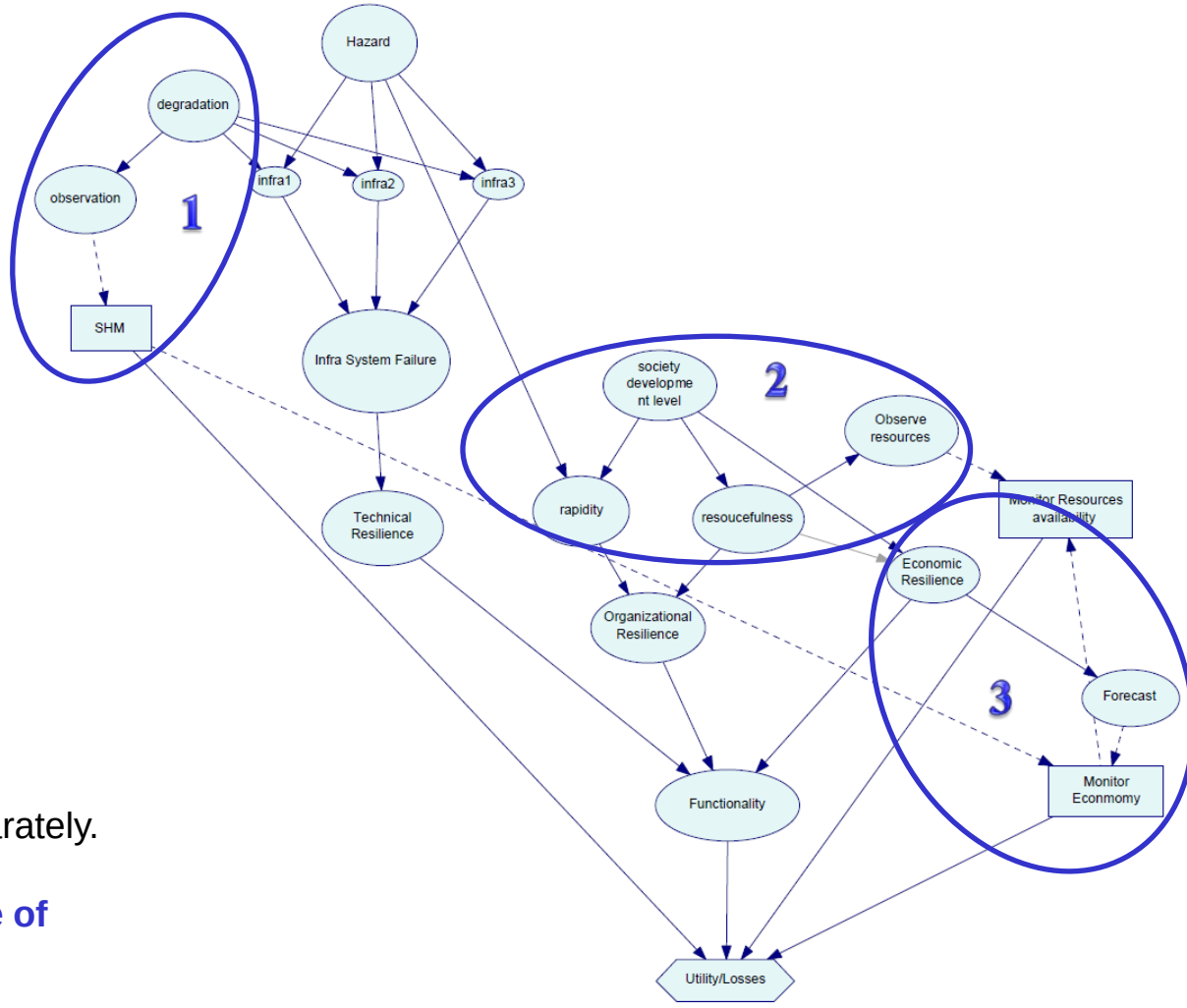
1-SHM finalized to assess the degradation level of the infrastructure system (Technical Resilience component);

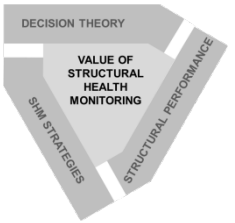
2-Monitor resourcefulness to assess availability of resources (Organizational Resilience component) ;

3-Forecast economy (Economic Resilience component).

The three strategies are assessed separately.

**Which strategy has the highest value of information?**



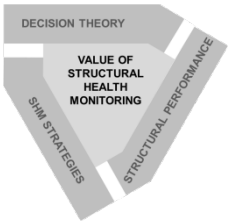



# Example: Value of Information based on Functionality

| General case | |
|---|---|
| Monitoring Degradation. | 0.014 |
| Monitoring Resources | 0.028 |
| Forecasting Economy | 0.028 |

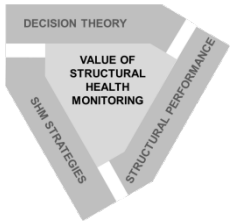
| Developing Country | Daily max | Yearly max | Extreme event |
|---|---|---|---|
| Monitoring Degradation. | 0.004 | 0.009 | 0.057 |
| Monitoring Resources | 0.008 | 0.019 | 0.113 |
| Forecasting Economy | 0.008 | 0.019 | 0.113 |

| Developed Country | Daily max | Yearly max | Extreme event |
|---|---|---|---|
| Monitoring Degradation. | 0.016 | 0.081 | 0.427 |
| Monitoring Resources | 0.032 | 0.163 | 0.925 |
| Forecasting Economy | 0.032 | 0.163 | 0.925 |




# Conclusions

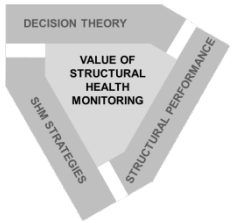
- The Value of Information can be used in wider context than SHM
- Resource  Availability and Economic Resilience have higher impacts on system functionality
- The value of information is higher with respect to the socio-economic-environmental indicators
- Results are quite sensible to model input variables and more testing is needed before generalizing the results




# …….Work in Progress

- Faber, Miraglia, Stewart. *Decision Analysis for Societal Systems in the Anthropocene– on Vulnerability, Robustness and Resilience.* (Journal paper draft)

- Miraglia, Faber, Thöns, Stewart. *Value of information in system resilience modelling: reducing uncertainty on system functionality using monitoring.* (with new model in preparation)




# Thank you for your attention!

## Questions? Comments?