SPECIAL MOBILITY STRAND

On Natural Hazards Risk Management
Michael Havbro Faber
Banja Luka, Bosnia and Herzegovina , December 13, 2018

Michael Havbro Faber,
Department of Civil Engineering, Aalborg University, Denmark

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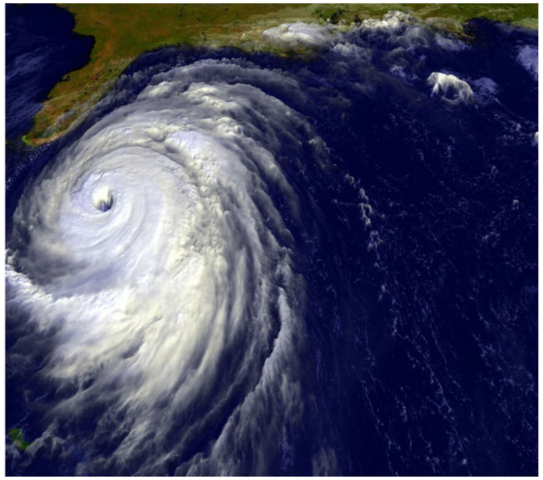

K-FORCE Lectures
Banja Luka
Bosnia and Herzegovina
December 13, 2018

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On Natural Hazards Risk Management

Michael Havbro Faber
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Risk
Reliabiliy
Resilience
Sustainability
Built
Environment

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Introduction – My Group at Aalborg University

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Introduction – Members of my Team

RISK, RELIABILITY, RESILIENCE AND SUSTAINABILITY IN THE BUILT ENVIRONMENT

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Introduction – Collaboration Partners

JCSS

Danish Centre for RISK & SAFETY Management
Support You - Managing Risk

WORLD ECONOMIC FORUM

GLOBAL RISK FORUM GRF DAVOS
GRF

DTU
Centre for Oil and Gas - DTU
GDSI
Global Decision Support Initiative

Knowledge FOr Resilient soCiEty

TWI

哈爾濱工業大學
HARBIN INSTITUTE OF TECHNOLOGY

EUROPEAN YOUTH PARLIAMENT
PARLEMENT EUROPÉEN DES JEUNES

POLITECNICO
MILANO 1863

ATV
Akademiet for de Tekniske Videnskaber

UNIVERSITAS STUDIORUM NEOPLANTENSIS

nsirc
Driving engineering excellence

UNIVERSITETI I TIRANËS

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COST Action TU1402:
Quantifying the Value of
Structural Health Monitoring

TU1406
COST ACTION

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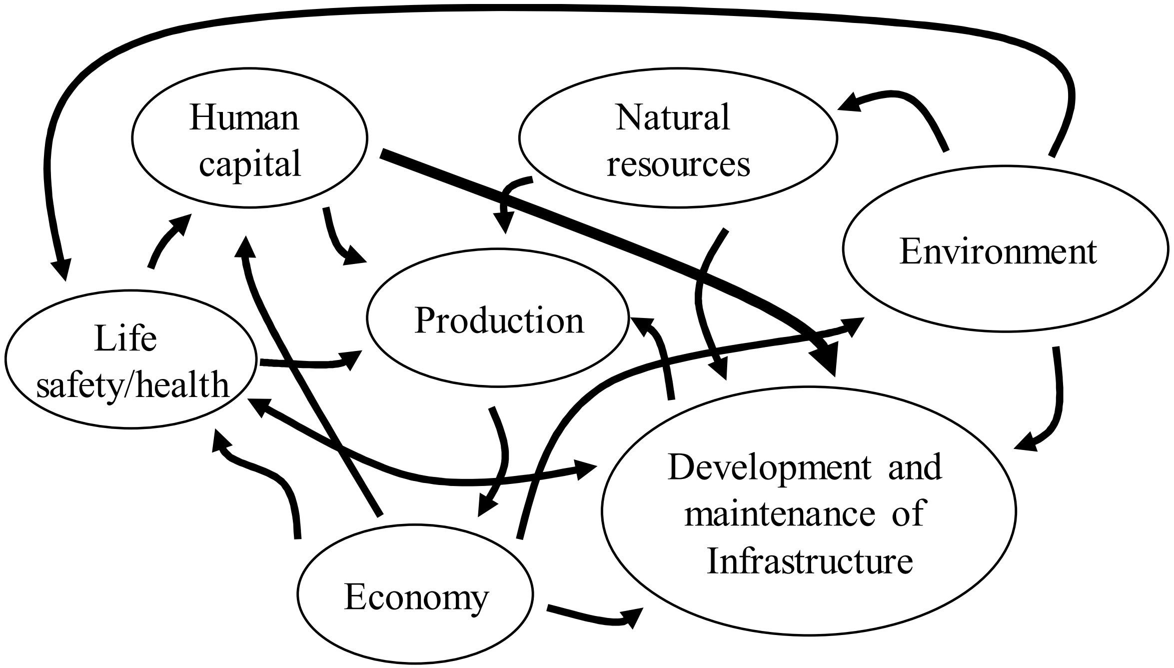
The Challenges of Risk Management

Interrelations of sectors and activities in society

Infrastructures as part of the built environment play a crusial role for the existence and development of society



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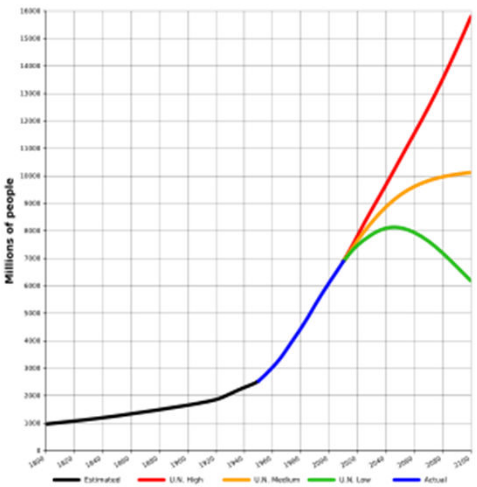
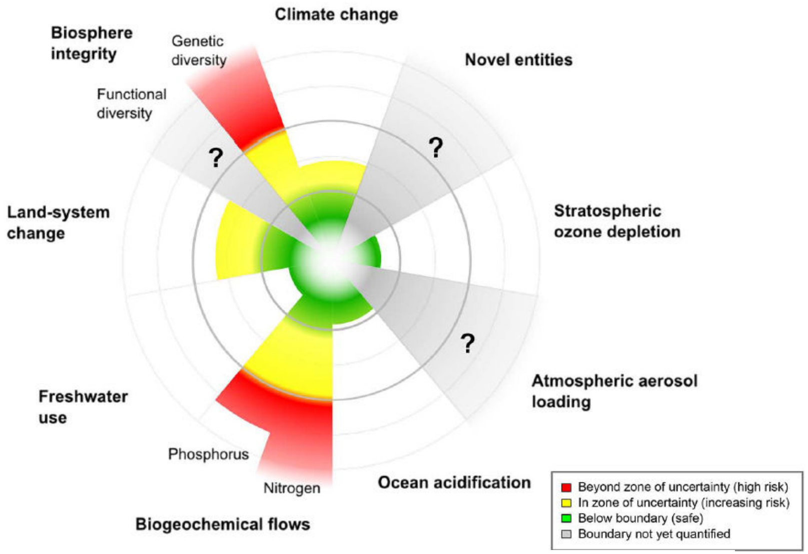
The Challenges of Risk Management

Pressing boundaries for societal developments:

At local and global scales it is increasingly appreciated that societal developments are approaching the limits of the capacities of the ecological systems and the Earth life support system



Population growth, Wikepedia, UN



Planetary boundaries, Steffen *et al.* 2015[1]

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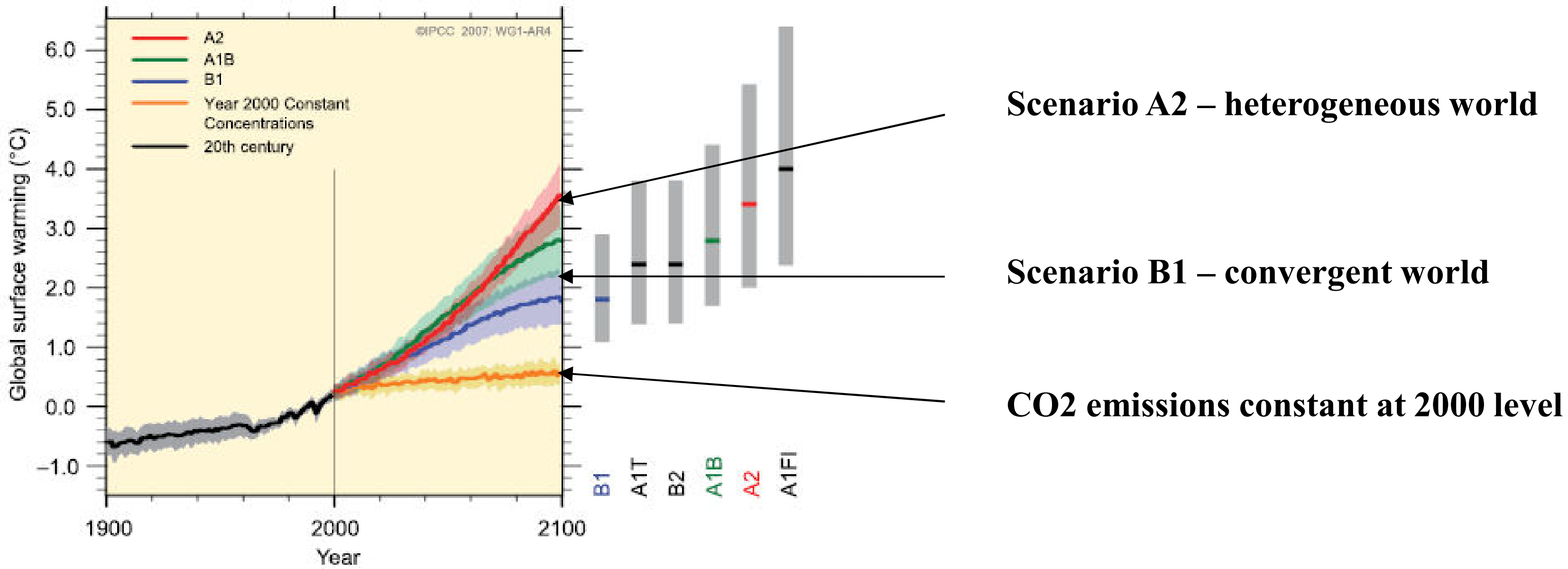
The Challenges of Risk Management

Pressing boundaries for societal developments:

Significant signs of the back-coupling between civilizations and living conditions for civilization are observable



IPCC homepage

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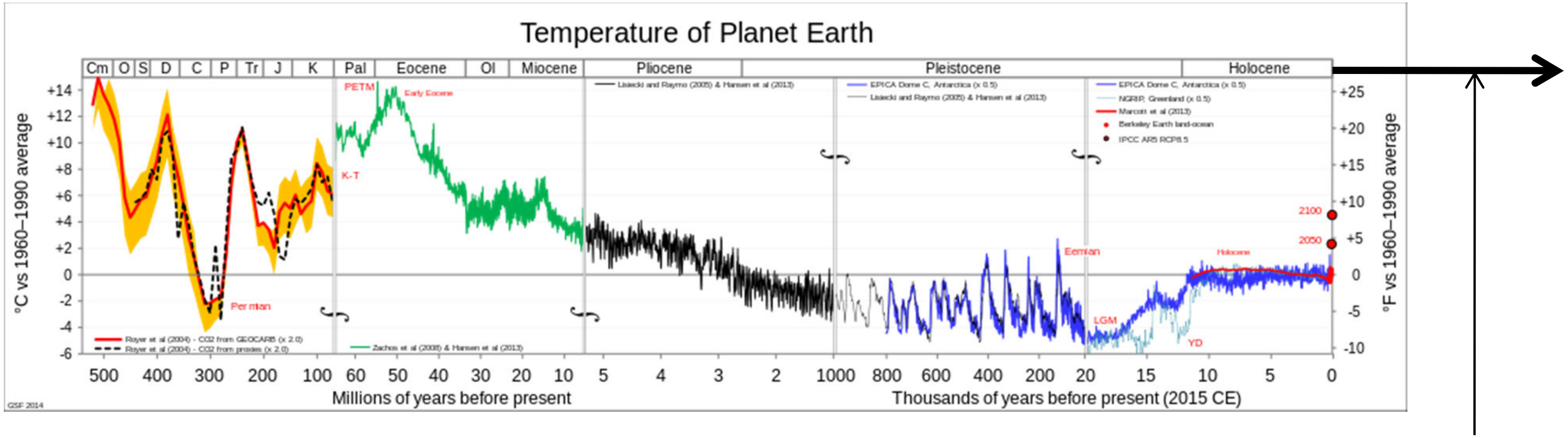
The Challenges of Risk Management

Pressing boundaries for societal developments:

Significant signs of the back coupling between civilizations and living conditions for civilization are observable



Wikepedia

Anthropocene

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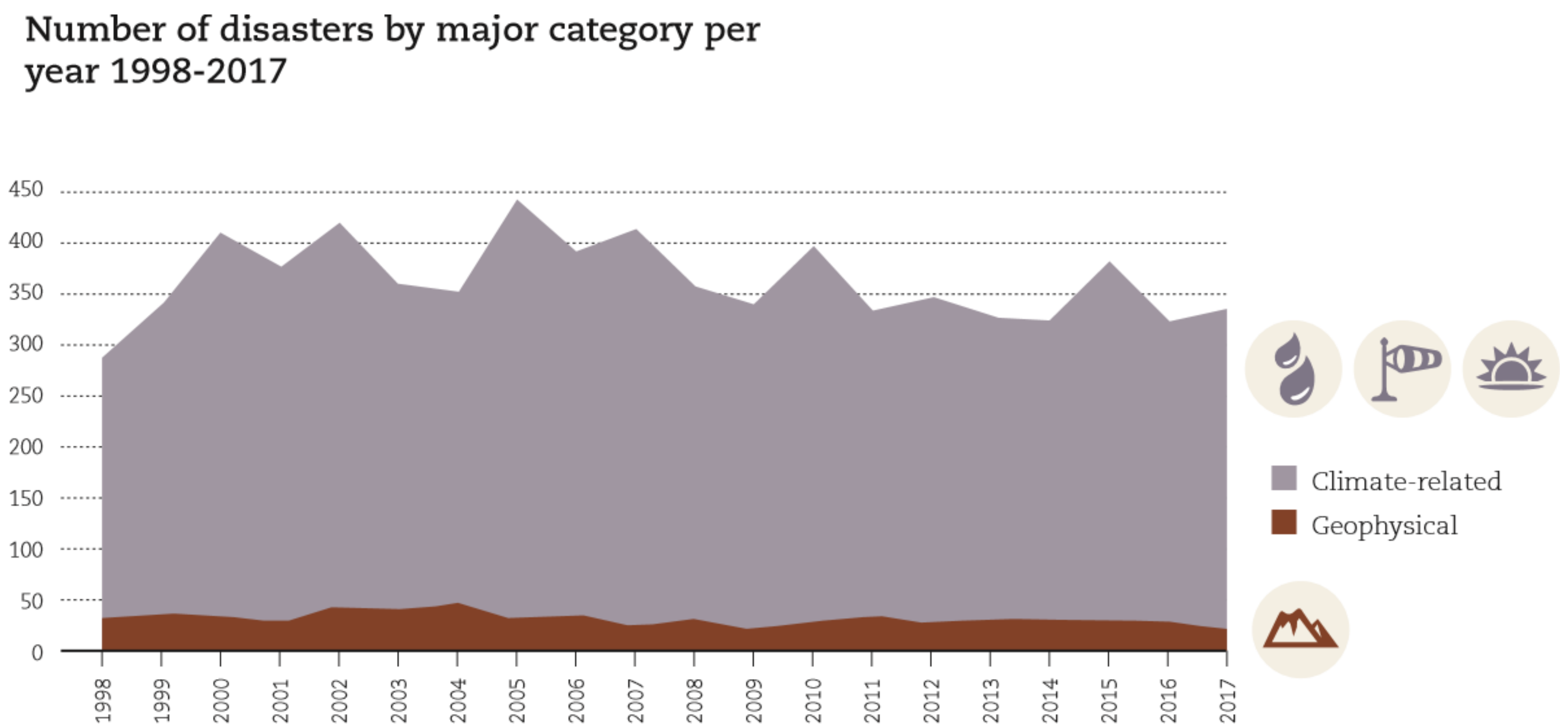
The Challenges of Risk Management



Source: EM-DAT - The OFDA/CRED International Disaster Database.

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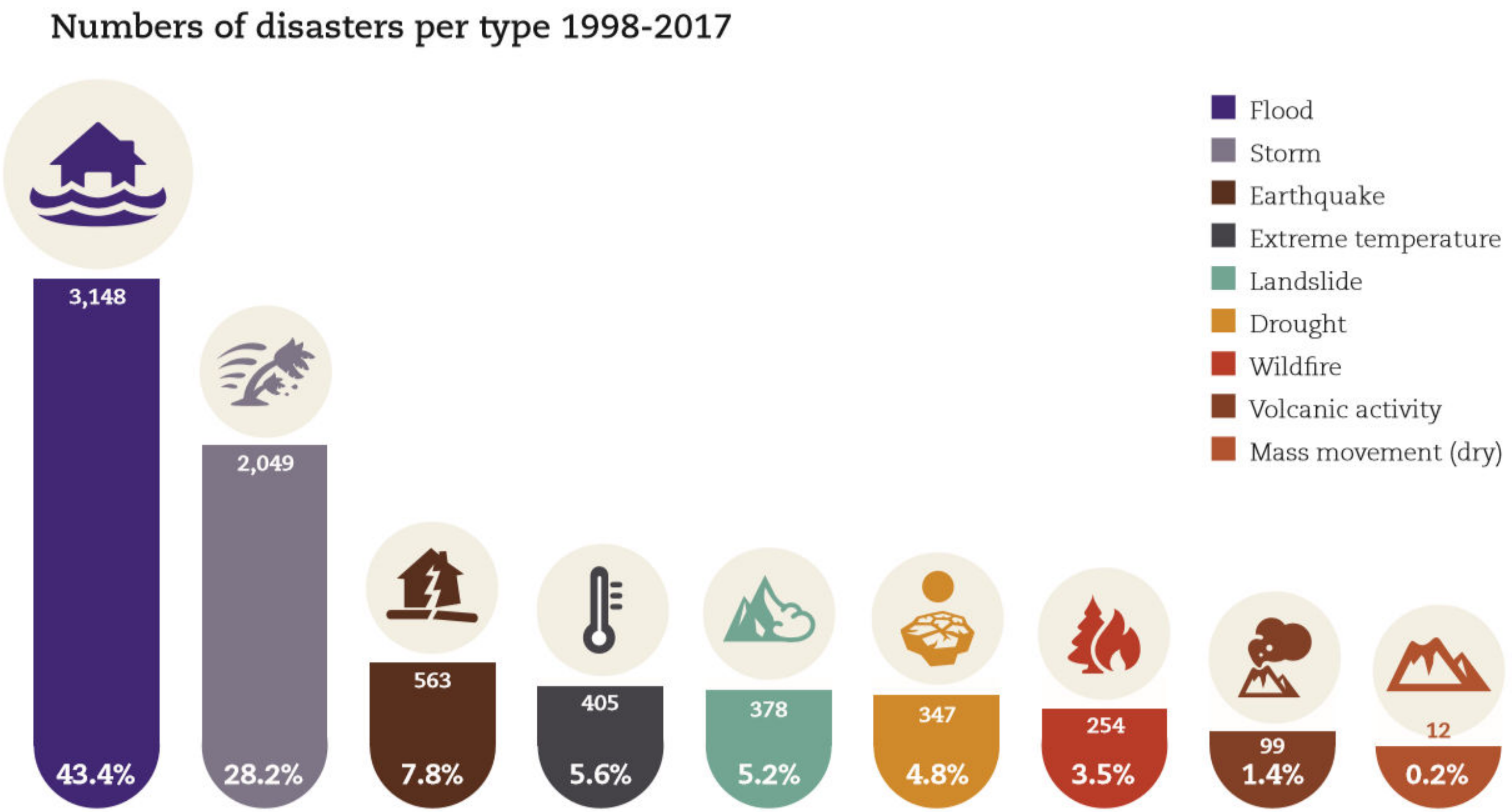
The Challenges of Risk Management



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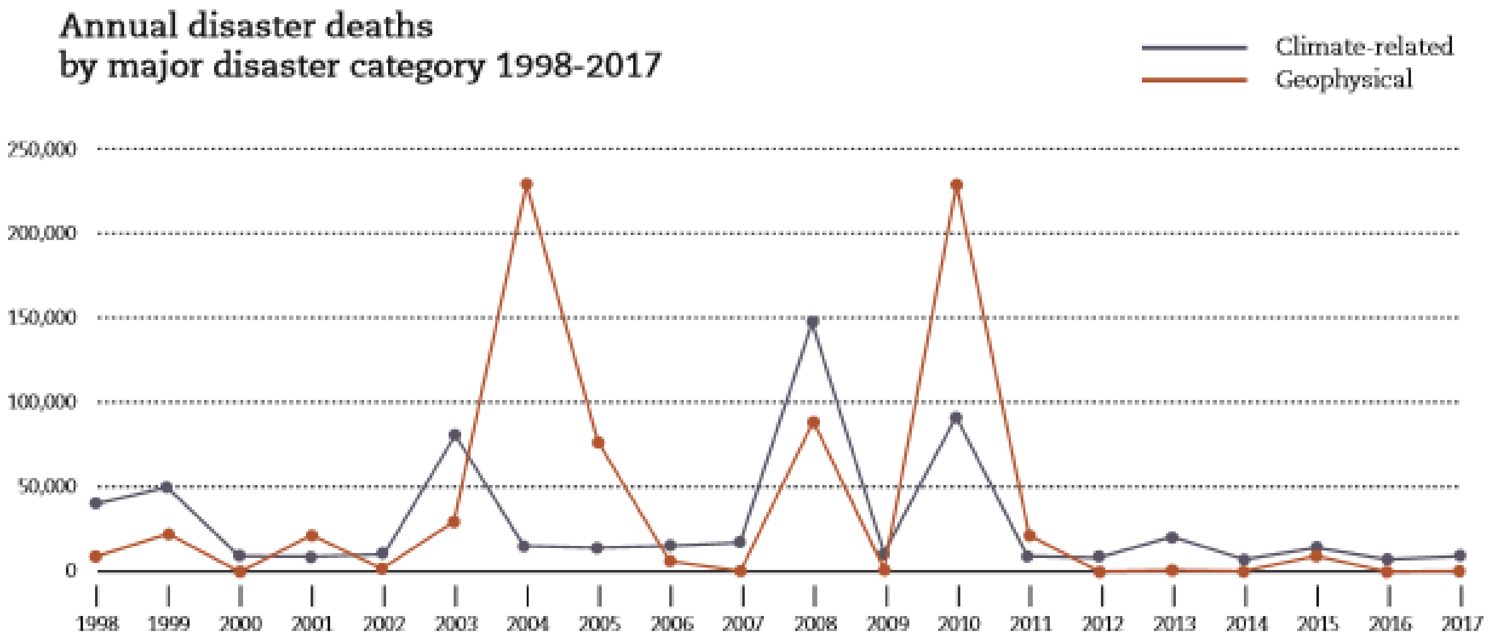
The Challenges of Risk Management



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The Challenges of Risk Management

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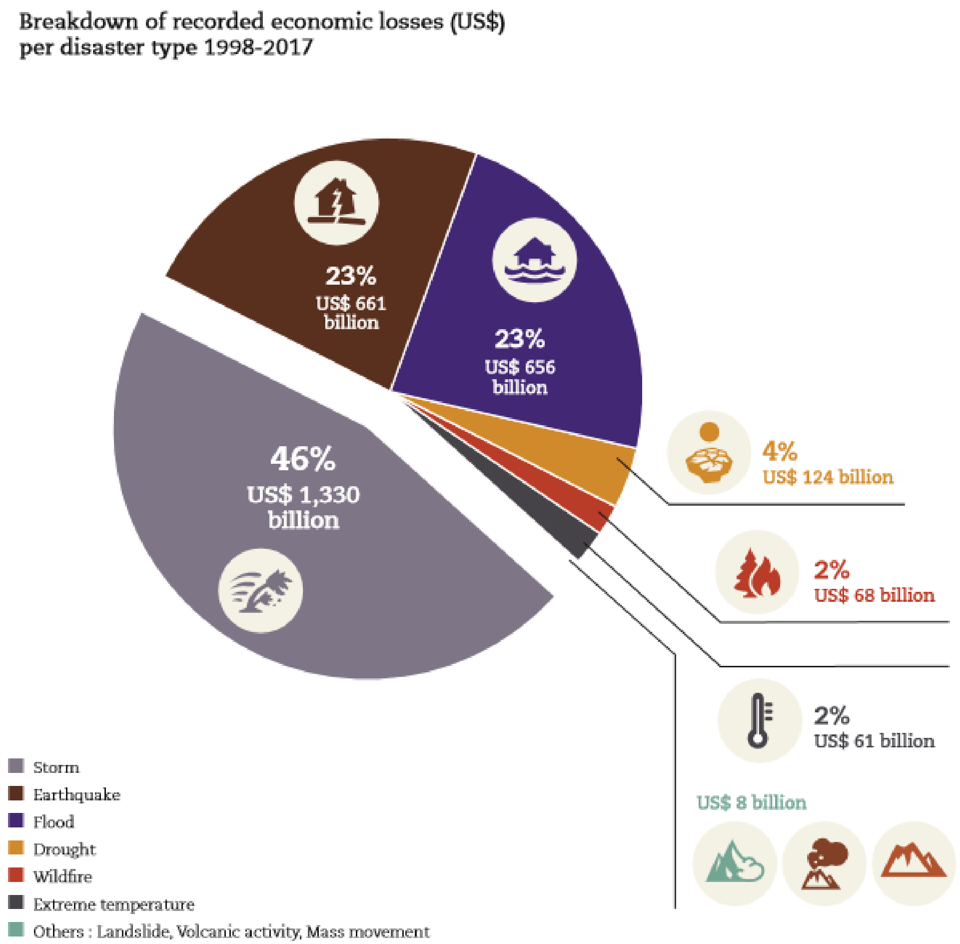
The Challenges of Risk Management



Source: EM-DAT - The OFDA/CRED International Disaster Database.

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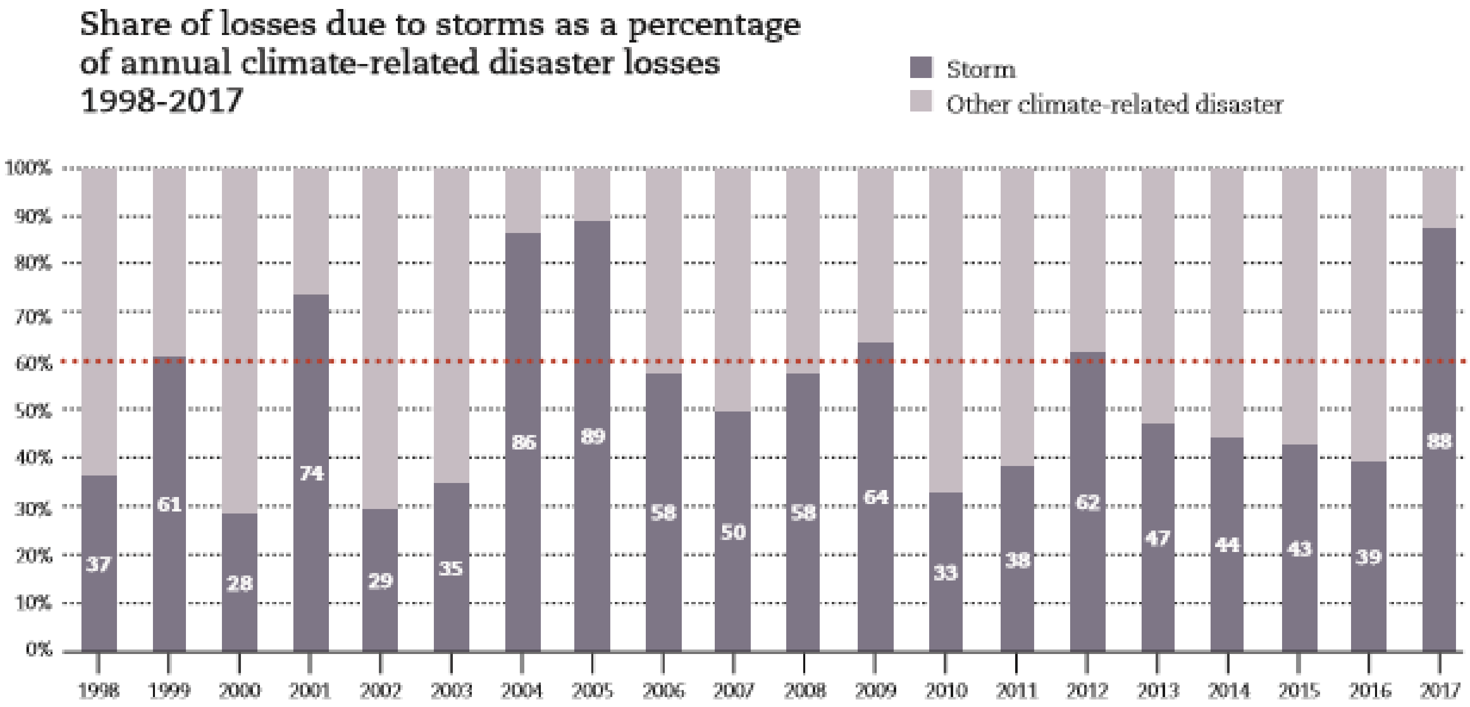
The Challenges of Risk Management



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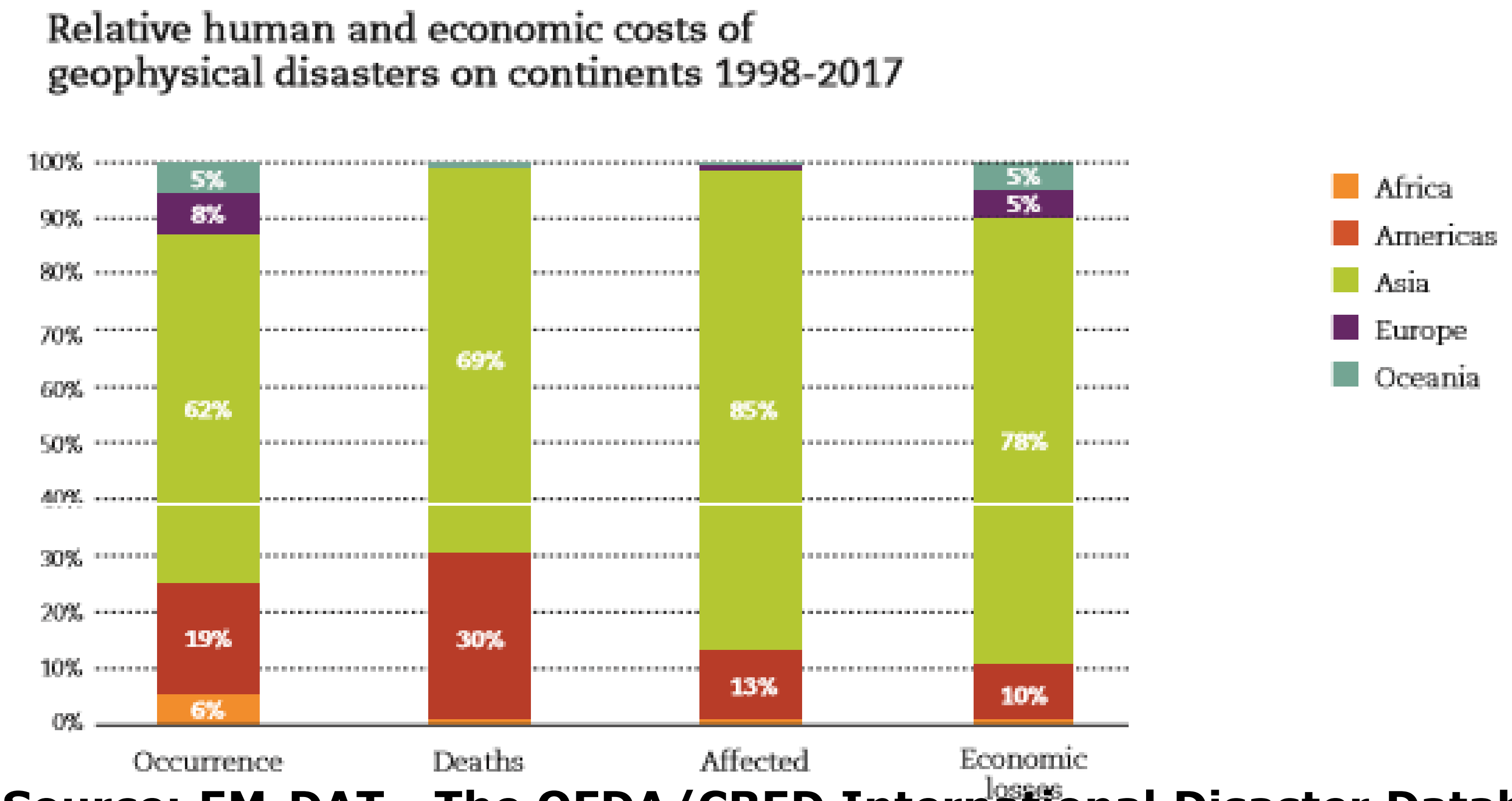
The Challenges of Risk Management



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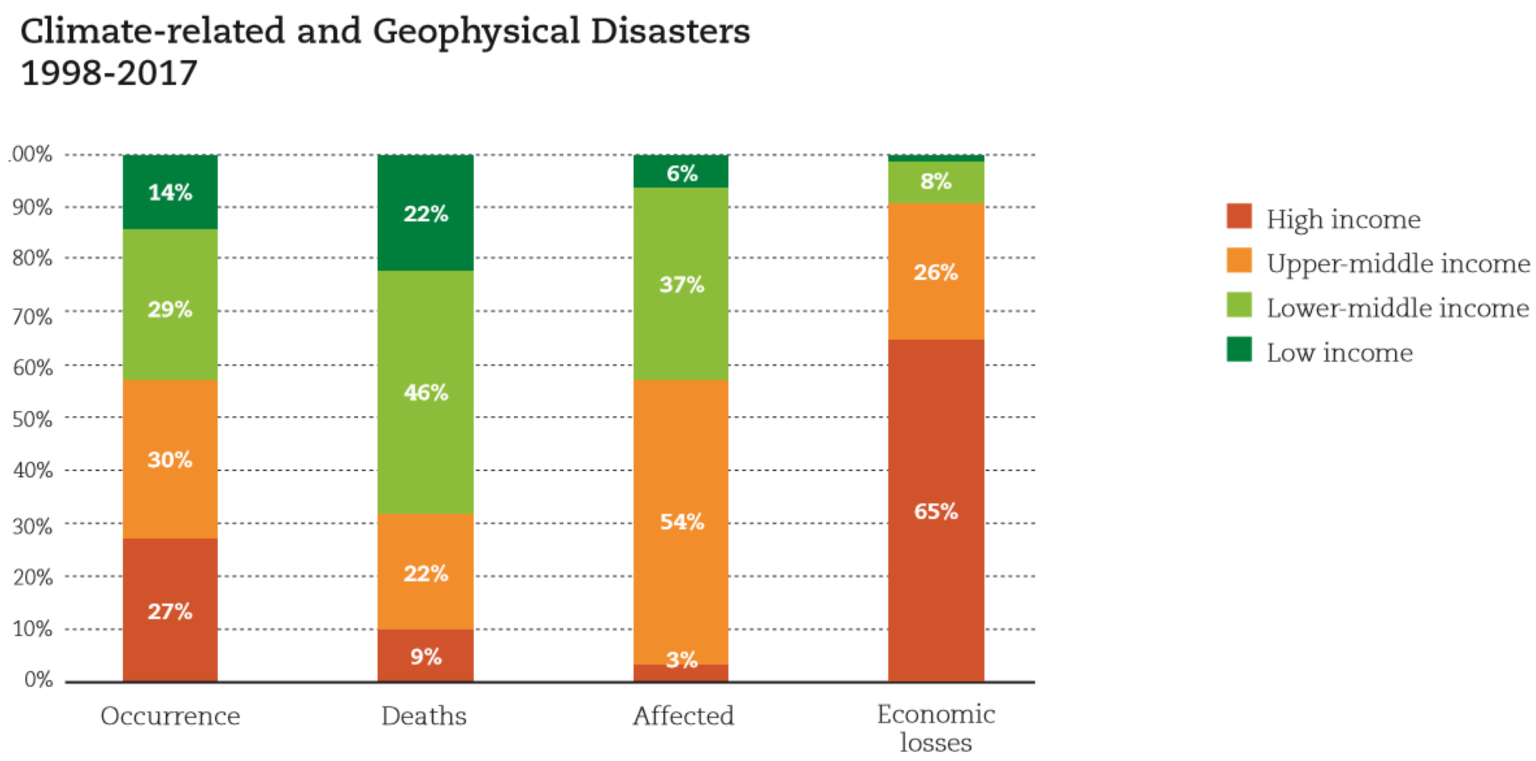
The Challenges of Risk Management



Source: EM-DAT - The OFDA/CRED International Disaster Database.

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The Challenges of Risk Management

Infrastructures accommodating 7.5 billion people

Cities in the world (+1 million inhabitants)	~ 500
Bridges in the USA	~ 600.000
Global road network	> 13 million km
Global rail network	> 1 million km
Airports	~ 50.000
Offshore platforms in the world	~ 6.500
Dams in the world	~ 45.000
Nuclear (civil) reactors in the world	~ 440

……..

……..

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The Challenges of Risk Management

Built environment alone

Contributes with ~10% of GDP in Europe

Responsible for 50% of global energy consumption

Concrete responsible for ~8% of global CO2 emissions

Responsible for ~90% of global material consumption (weight)

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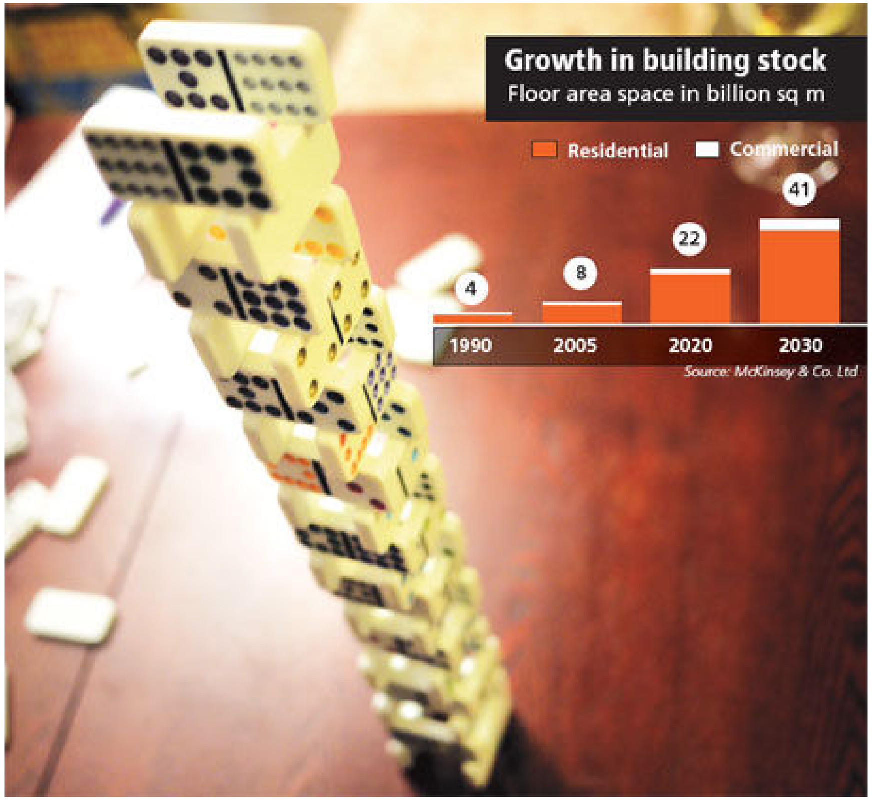
The Challenges of Risk Management

Climate change/sustainability



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The Challenges of Risk Management

Questions to be answered in natural hazards risk management

How to:
- prioritize investments on design and management of interlinked systems (economy, environment, health)?
- plan and budget for the future (economy, qualities of the environment, social capacity, health)?

How to assess vulnerability, risks, robustness, resilience and sustainability consistently, which are the criteria to apply for decision making?

How
safe is safe enough
robust is robust enough
resilient is resilient enough
sustainable is sustainable enough

?

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Contents of Presentation

Resilience/sustainability – definitions and insights

Decision Support Framework

Probabilistic systems representation
- Vulnerability and risks of systems
- Robustness of systems
- Resilience of systems
- Consequences to health and environment
- Sustainability of systems

Examples

Conclusions and outlook

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Resilience/sustainability – Definitions and Insights

Resilience (definitions):
Pimm (1984) - *Resilience….the time it takes till a system which has been subjected to a disturbance returns to its original mode and level of functionality*

Holling (1996) - *Resilience….the measure of disturbance which can be sustained by a system before it shifts from one equilibrium to another*

Cutter (2010) - *Resilience…. capacity of a community to recover from disturbances by their own means*

Bruneau (2009) – *Resilience…. a quality inherent in the infrastructure and built environment; by means of redundancy, robustness, resourcefulness and rapidity*

National Academy of Science (NAS, USA) - *Resilience….a systems ability to plan for, recover from and adapt to adverse events over time*

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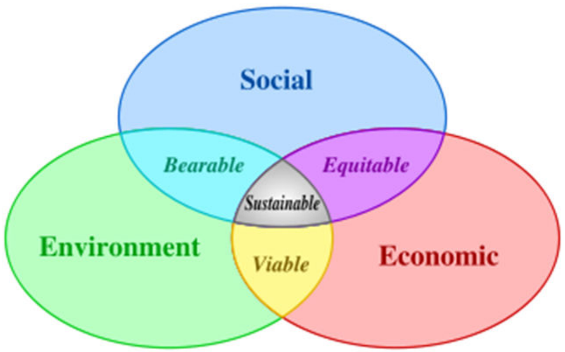
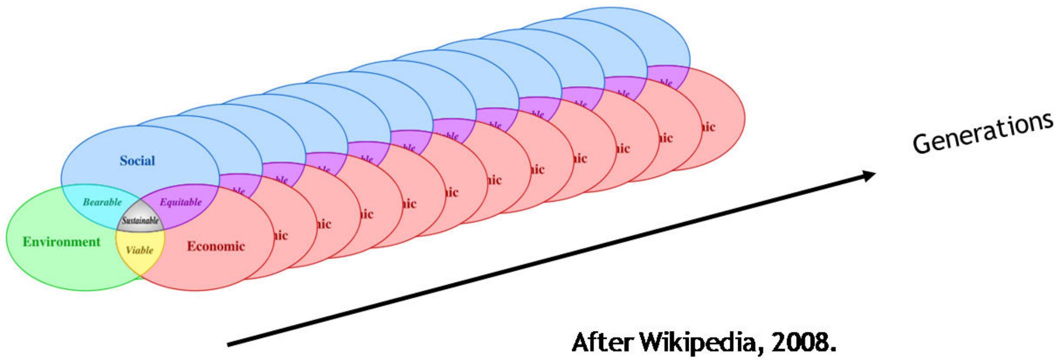
Resilience/sustainability – Definitions and Insights

Sustainability:

Gro Harlin Bruntland report (1987) – Our Common Future

"Humanity has the ability to make development sustainable to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs"





After Wikipedia, 2008.

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Resilience/sustainability – Definitions and Insights

Sustainability (environment):

Kates et al.(2001) recommends to explore and assess the relation between resilience and sustainability and propose to **utilize decision support** systems as a means to identify sustainable paths of societal developments

Steffen et al. (2015) introduce the concept of **Planetary Boundaries** as a concept for representing the capacities of the Earth System (Earth Life Support System - ELSS)

Hauschild (2015) suggests to utilize **quantitative sustainability assessments** to assess the aggregate impacts of human activities at global level with respect to the main parameters controlling safe operating conditions (ELSS) for the planetary system.

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Resilience/sustainability – Definitions and Insights

Strategies for sustainable and resilient systems

- Efficiency/optimality
- Diversity
- Redundancy
- Robustness
- Temporally optimized solutions
- Planned and smart renewals
- Options for buying information and changing strategies
- Additional data collection, monitoring and control
- Optimal balance between efficiency and resilience
- Joint consideration of efficiency/sustainability, resilience, safety, economy and welfare

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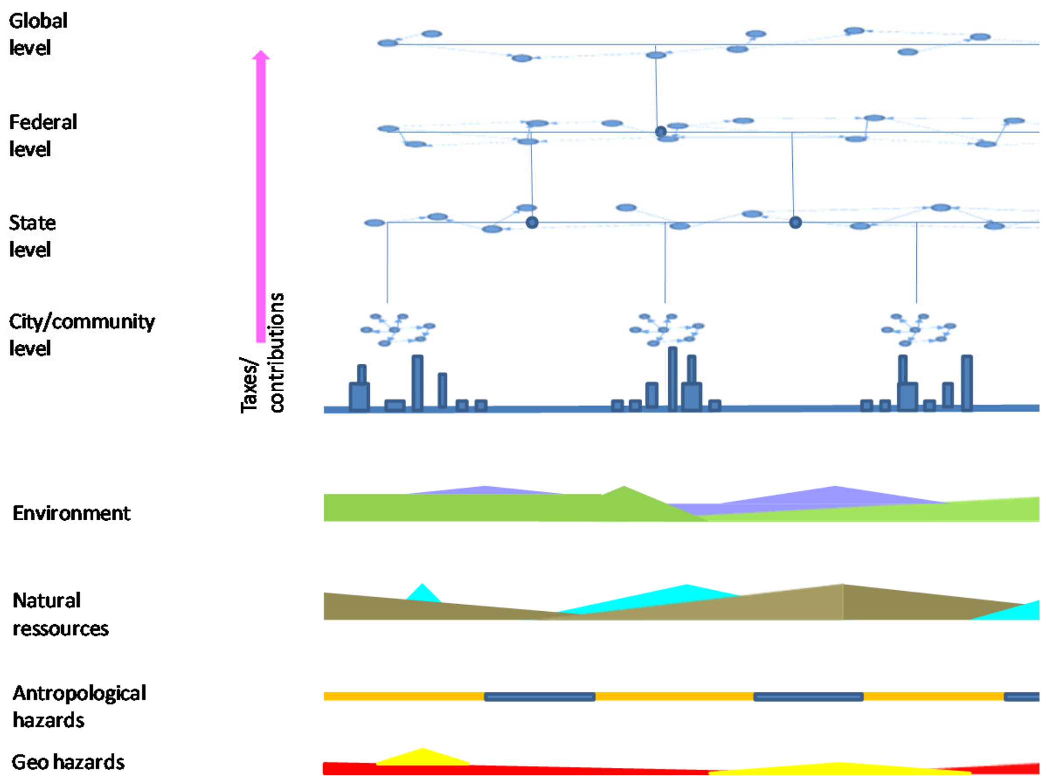
Decision Support Framework

Hierarchies of societal management



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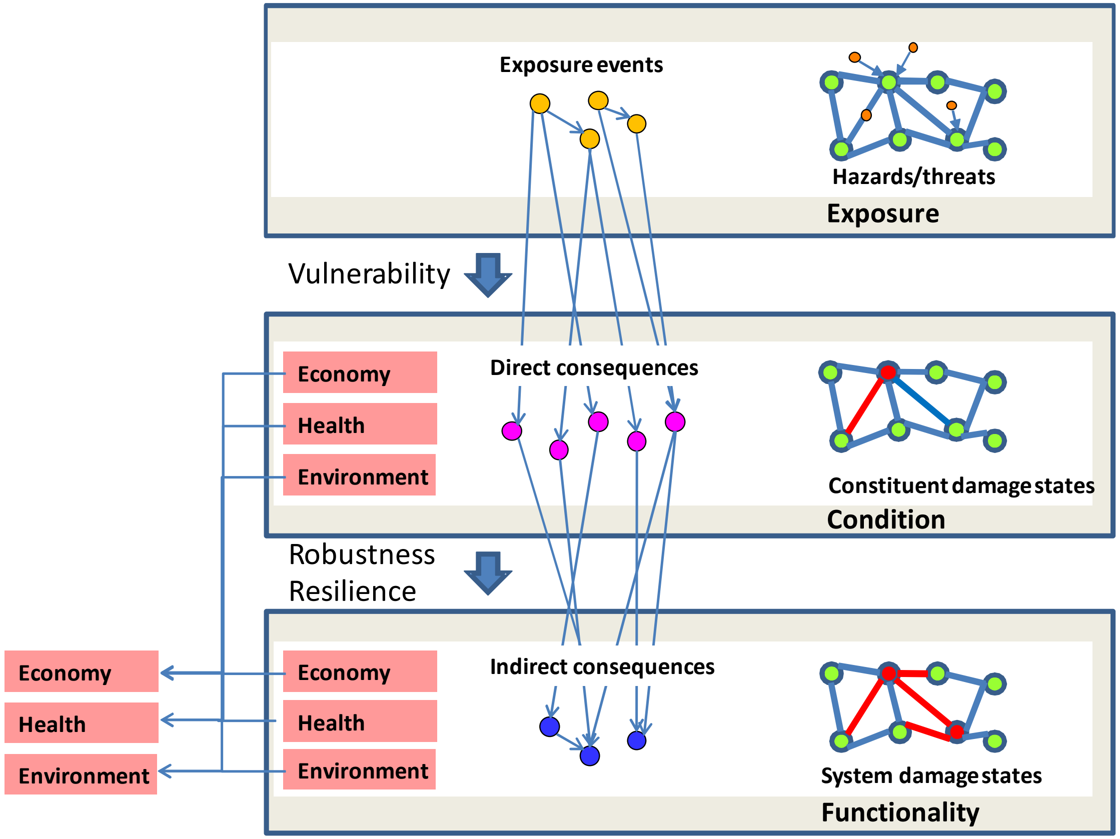
Decision Support Framework

The general framework (traditional)



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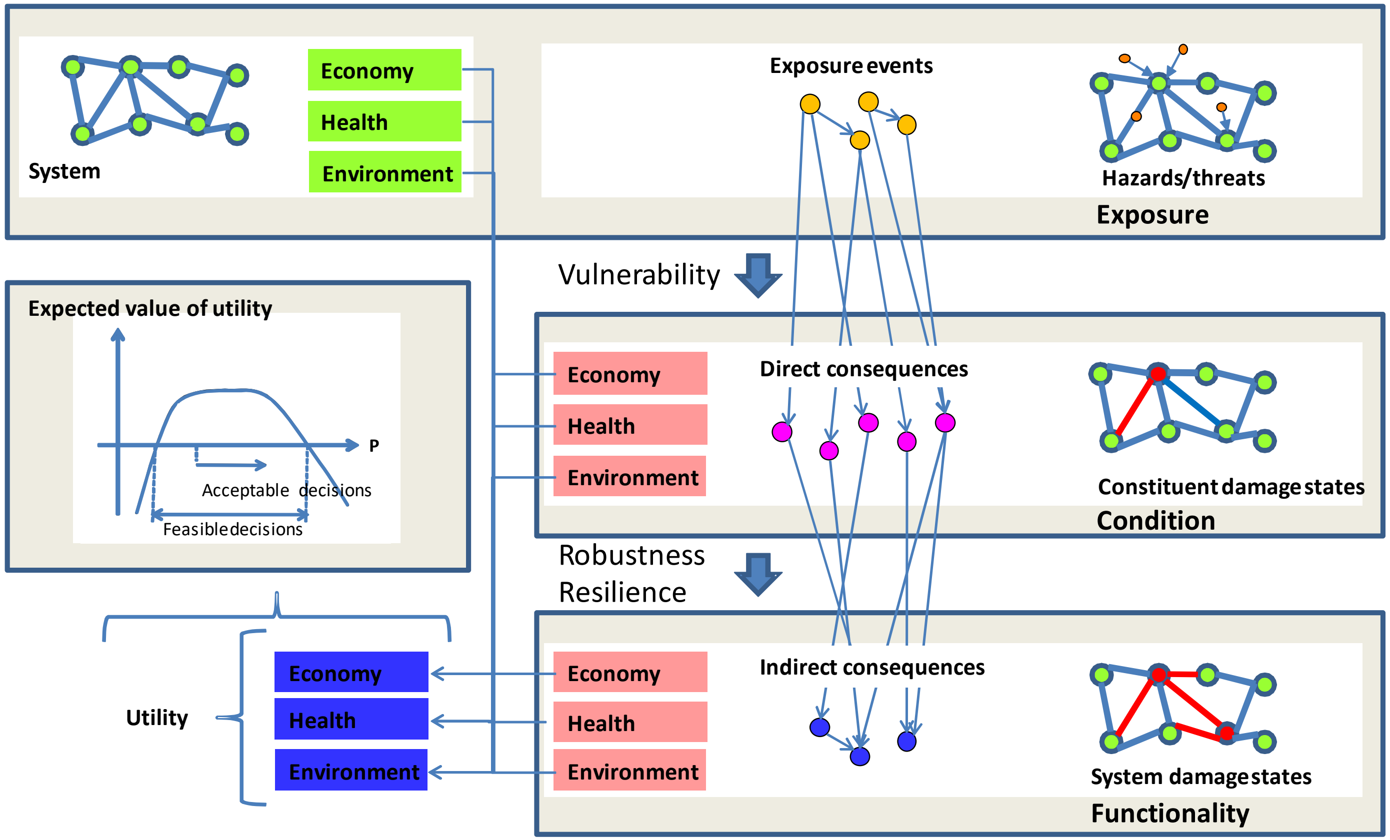
Decision Support Framework

The general framework (enhanced)



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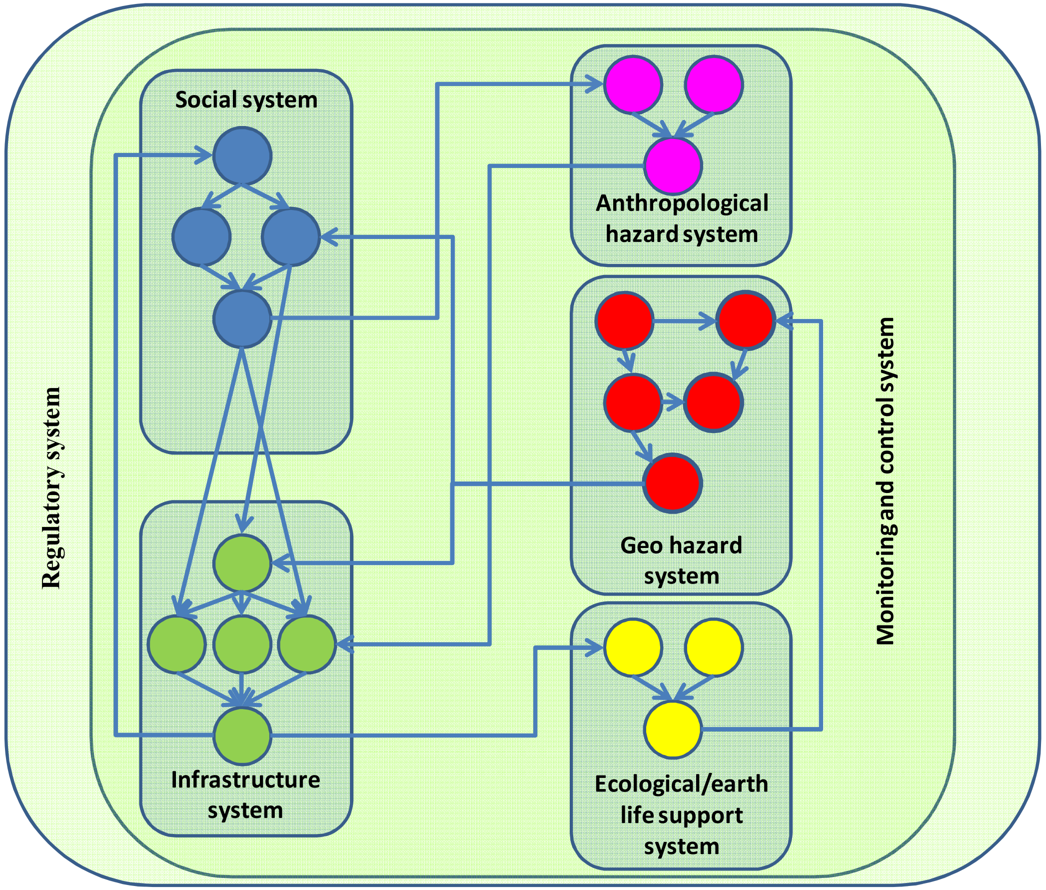
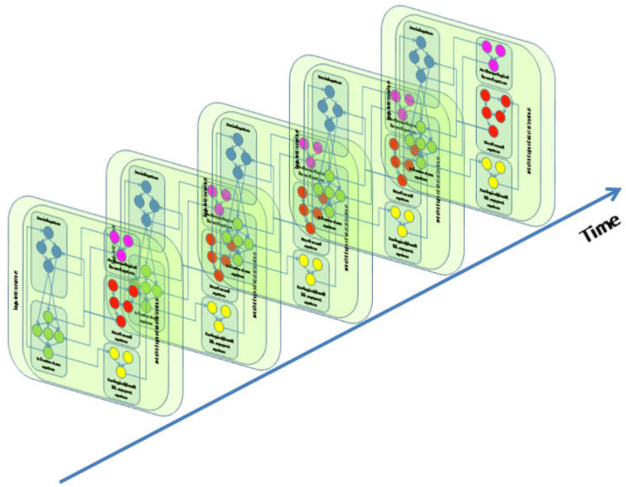
Probabilistic System Representation

Interlinked systems





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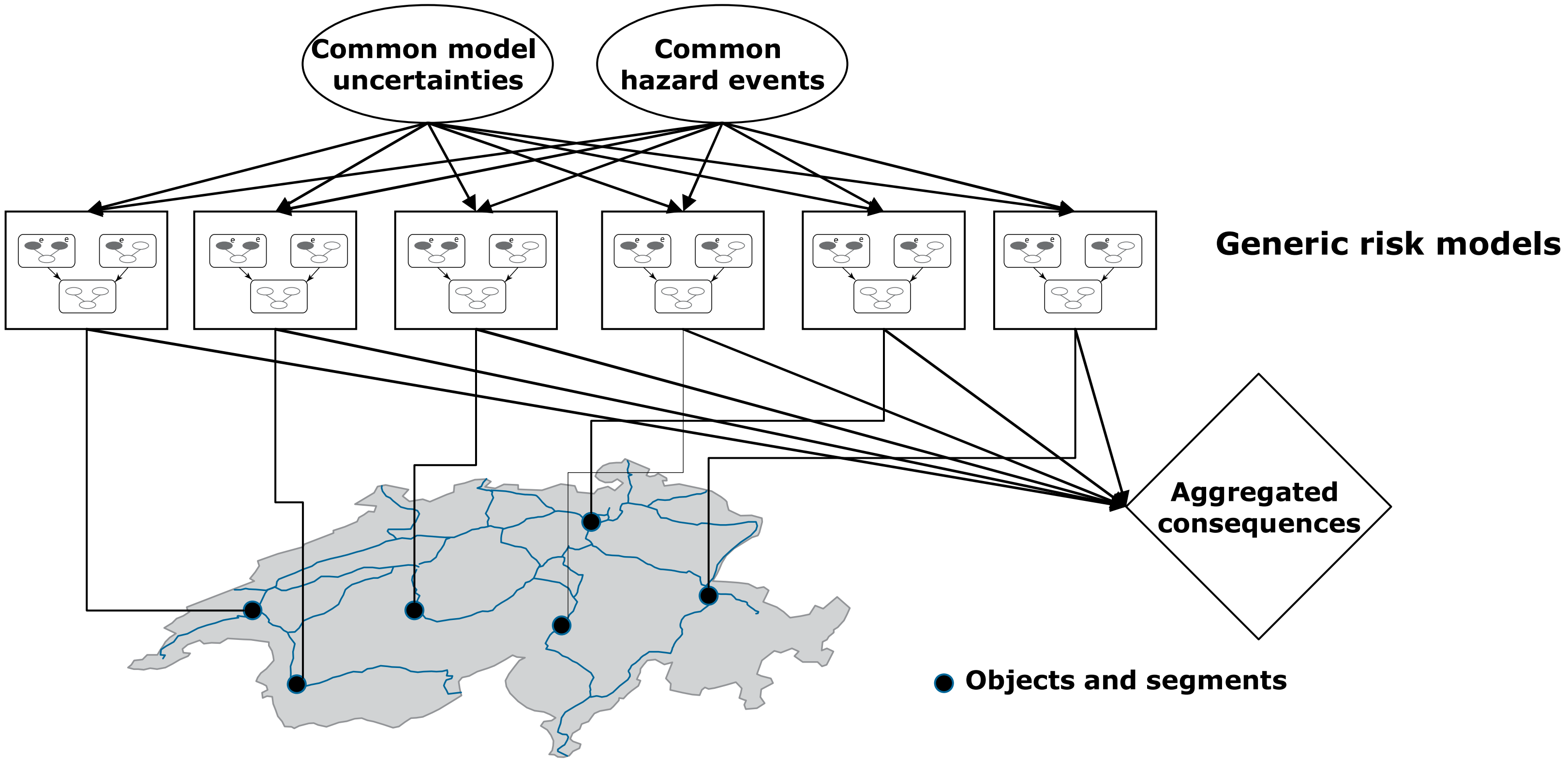
Probabilistic System Representation

Risk aggregation - portfolio risk modeling



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Probabilistic System Representation

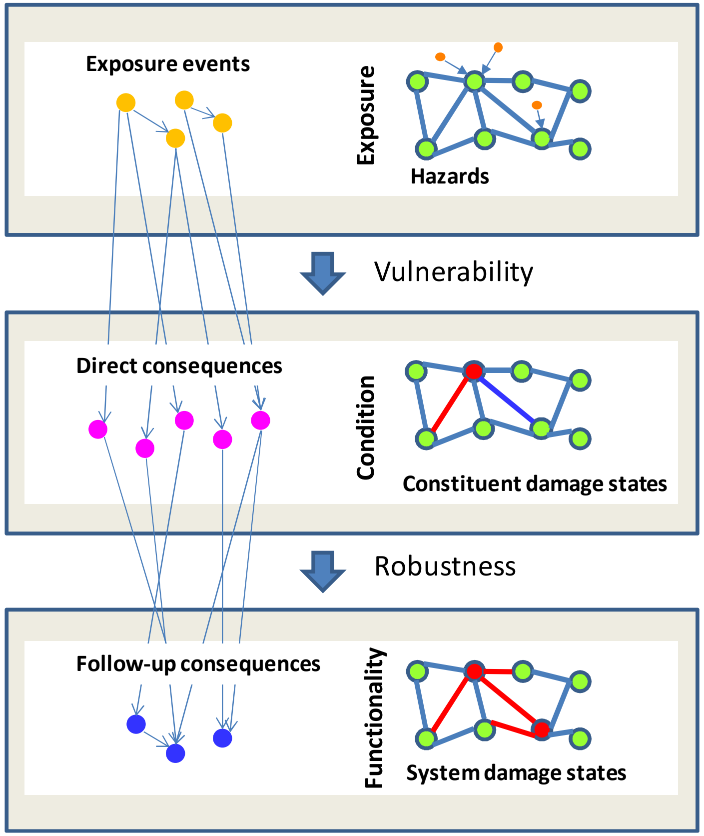
Hazards and disturbances

Type 1: "Large scale averaging events"
- low probability/high consequences

Type 2: "Seepage events"
- high probability/low consequences

Type 3: "Non-averaging events"
- low probability/extreme consequences

Type 4: "Information condition"
- as for Type 1-3



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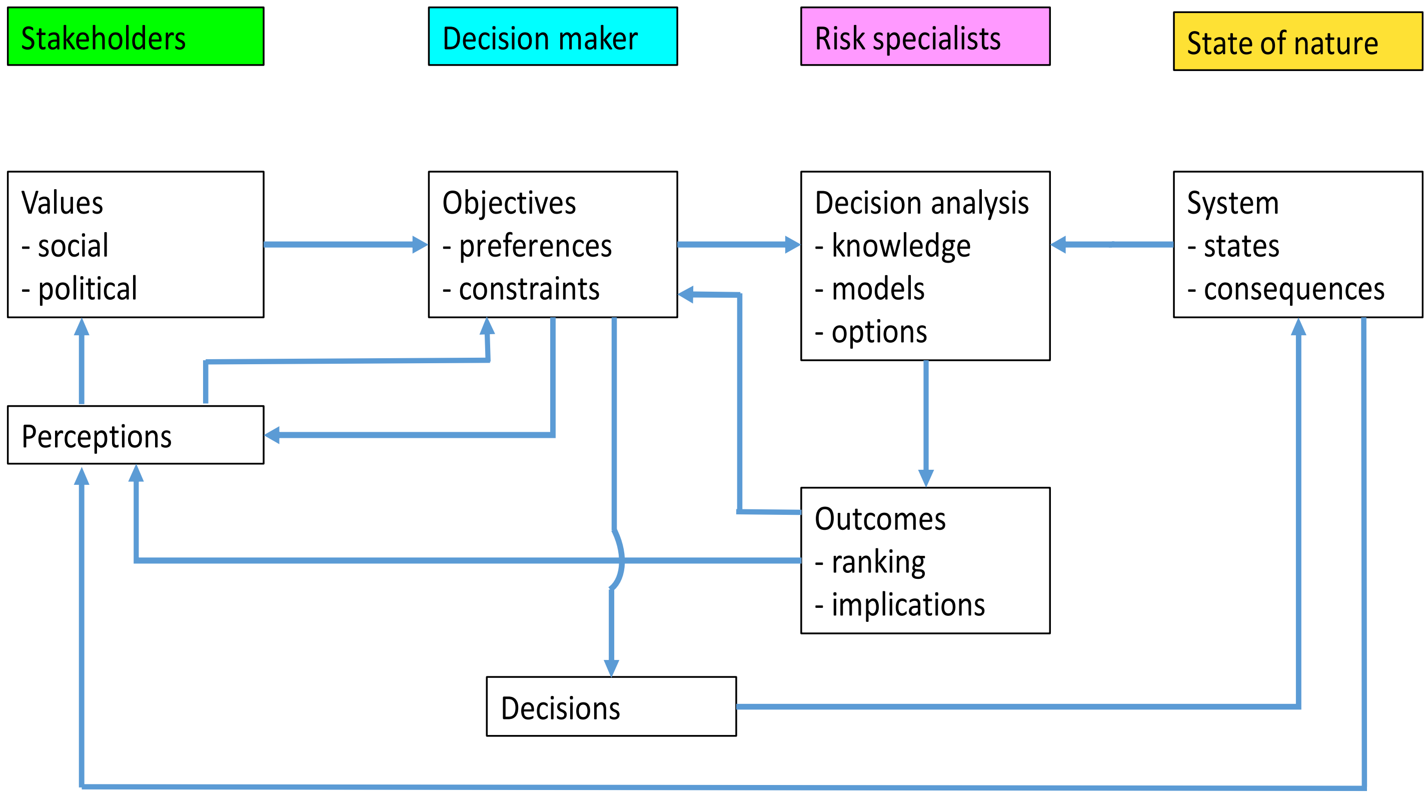
Probabilistic System Representation

Information condition



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Probabilistic System Representation

Information condition

1. The information is relevant and precise.
2. The information is relevant but imprecise.
3. The information is irrelevant.
4. The information is relevant but incorrect.
5. The flow of information is disrupted or delayed.

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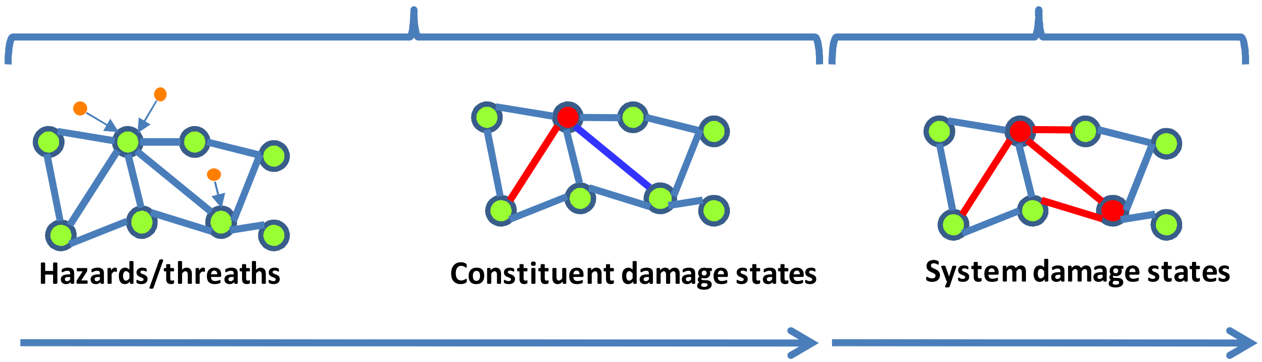
Probabilistic System Representation

Direct and indirect consequences

Phase 1
Disturbance effects

Phase 2
Redistribution effects



Damages and failure caused directly by disturbances

Damages and failures during internal redistribution

Direct consequences are associated with damages and failures of the constituents in phase 1 - marginally

Indirect consequences are associated with loss of functionality of the system caused by damages and failures in phase 1 and phase 2

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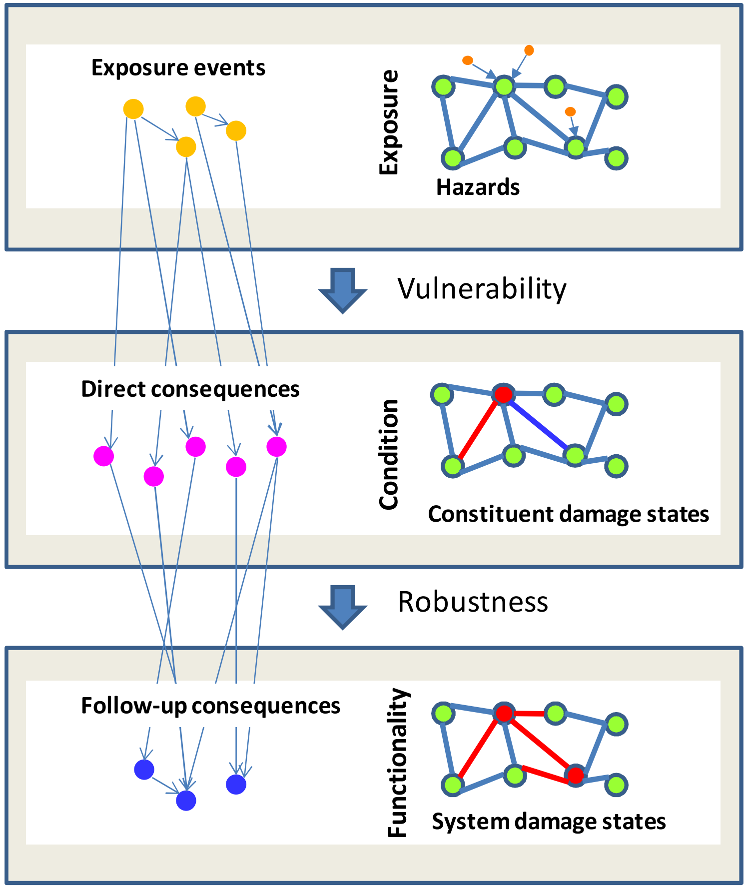
Probabilistic System Representation

Vulnerability and risk modelling



It is assumed that all relevant scenarios have been identified

$$\mathbf{S} = (i, p(i), c_{D,I}(i), c_{D,P}(i), c_{ID}(i))$$

$$i = 1, 2, .., n_s$$

$$I_{VS}(i) = \frac{c_{D,I}(i) + c_{D,P}(i)}{c_R}$$

c_R : total replacement costs

$$I_{VT} = \frac{1}{c_R} \sum_{i=1}^{n_s} I_{VS}(i)$$

$$R = \sum_{i=1}^{n_S} c_{D,I}(i) + c_{D,P}(i) + c_{ID}(i)$$

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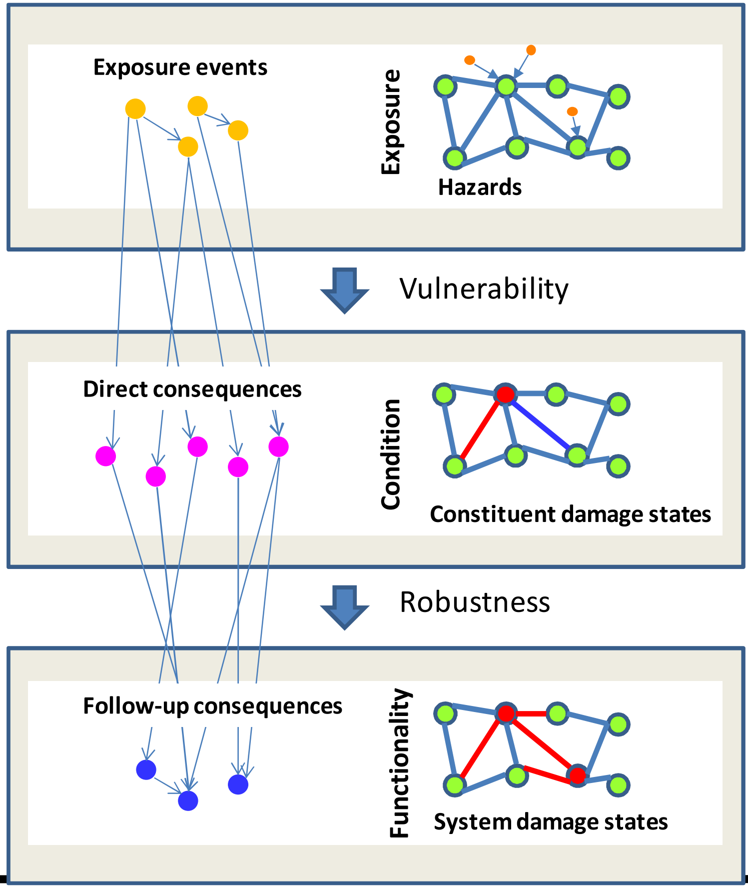
Probabilistic System Representation

Robustness modeling



It is assumed that all relevant scenarios have been identified

$$\mathbf{S} = (i, p(i), c_{D,I}(i), c_{D,P}(i), c_{ID}(i)))$$

$$i = 1, 2, .., n_s$$

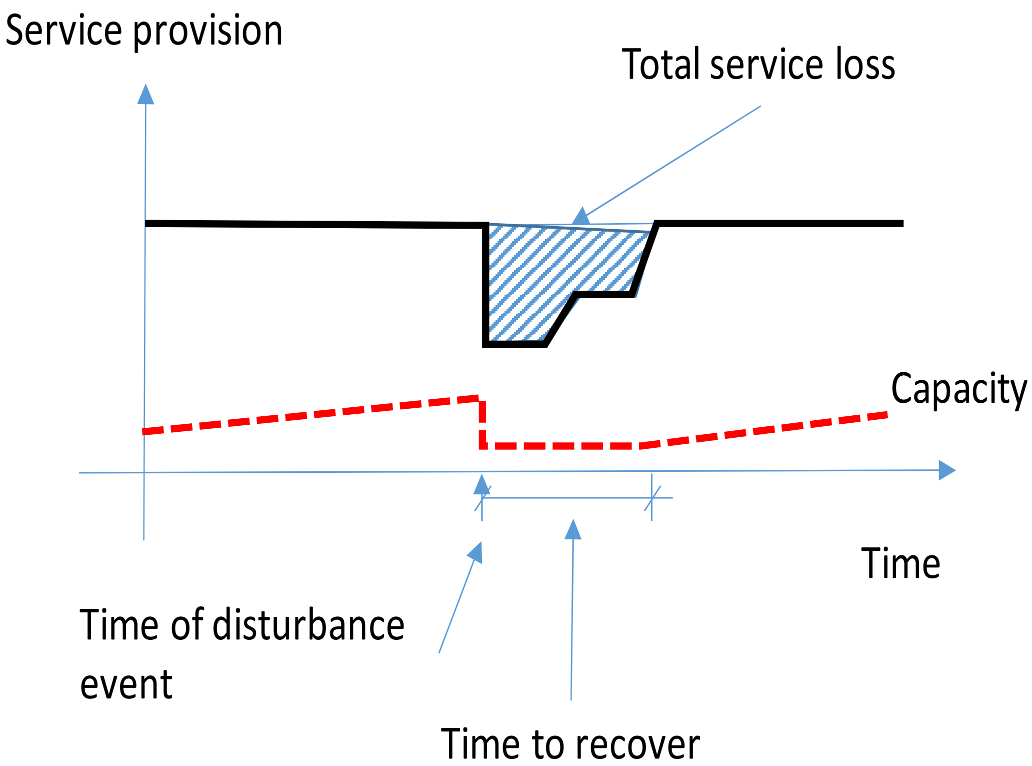
$$I_R(i) = \frac{c_D(i)}{c_T(i)}$$

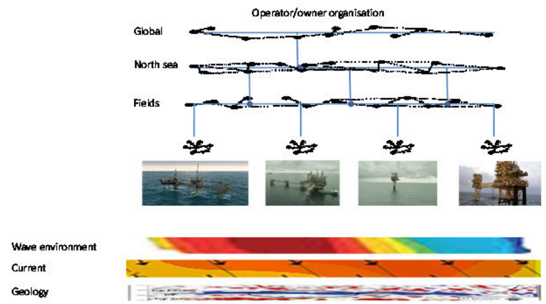
$$I_R(i) = \frac{c_{D,I}(i)}{c_{D,I}(i) + c_{D,P}(i)}$$

$$I_R(i) = \frac{c_{D,I}(i) + c_{D,P}(i)}{c_{D,I}(i) + c_{D,P}(i) + c_{ID}(i)}$$

Probabilistic System Representation

Probabilistic resilience modeling





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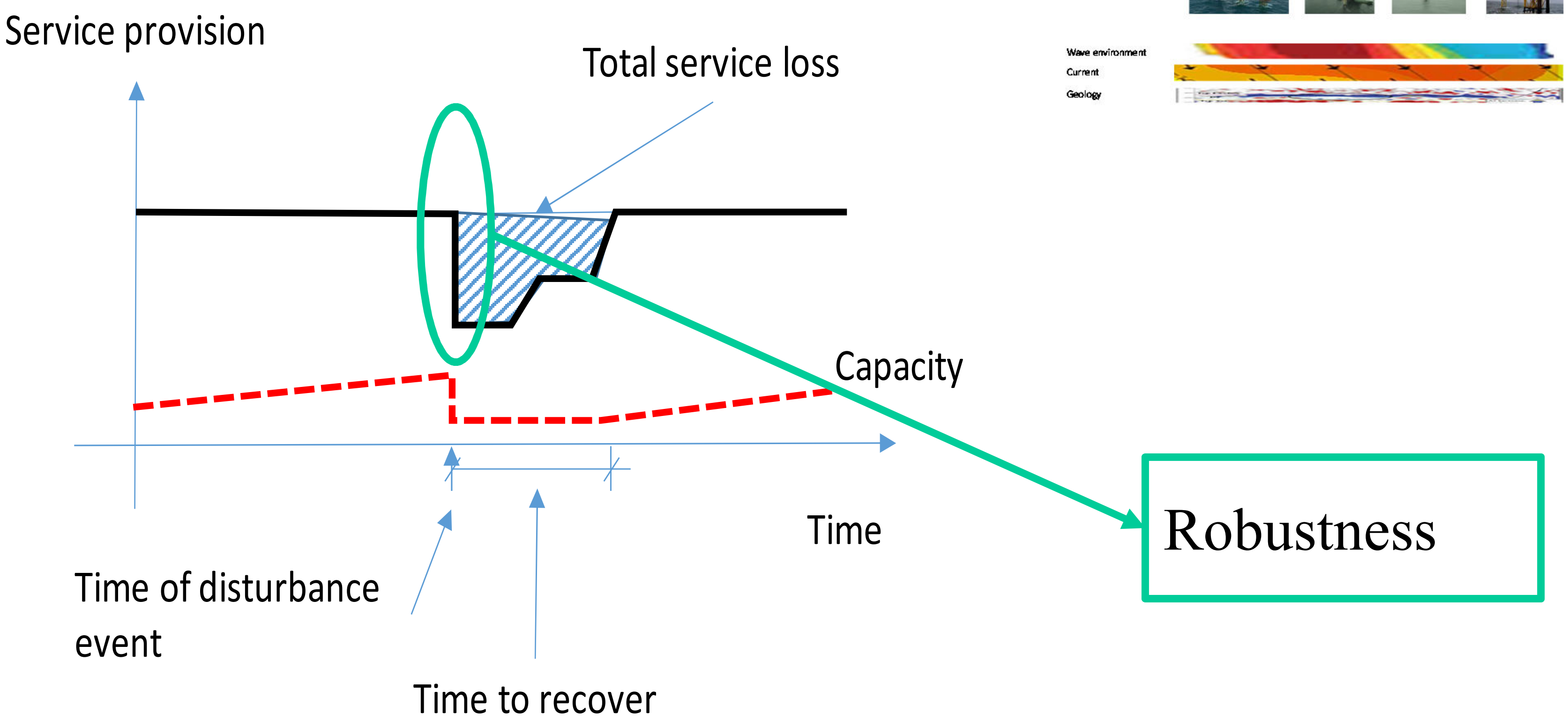
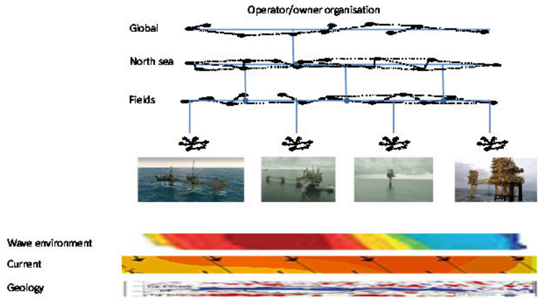
Probabilistic System Representation

Probabilistic resilience modeling





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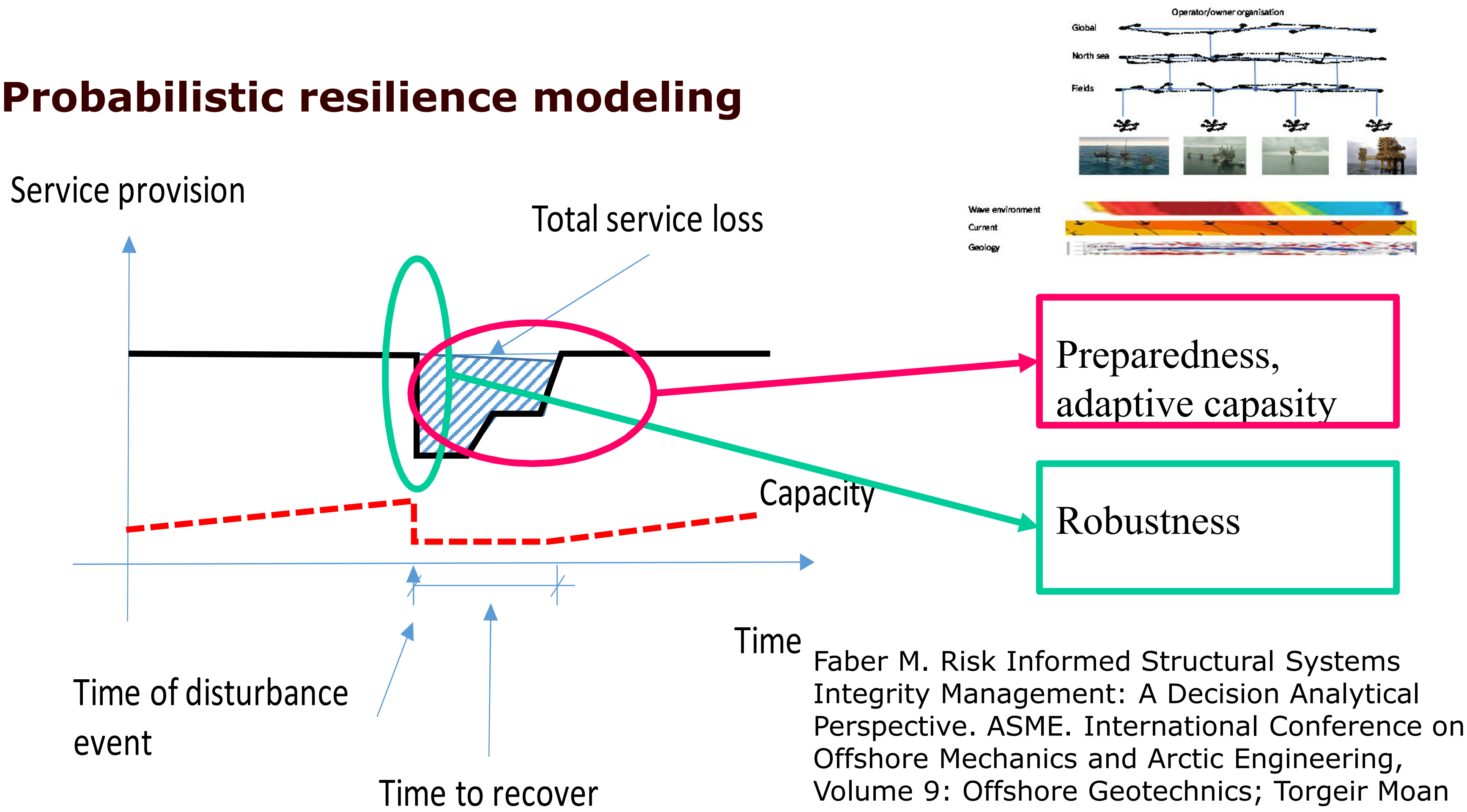
Probabilistic System Representation

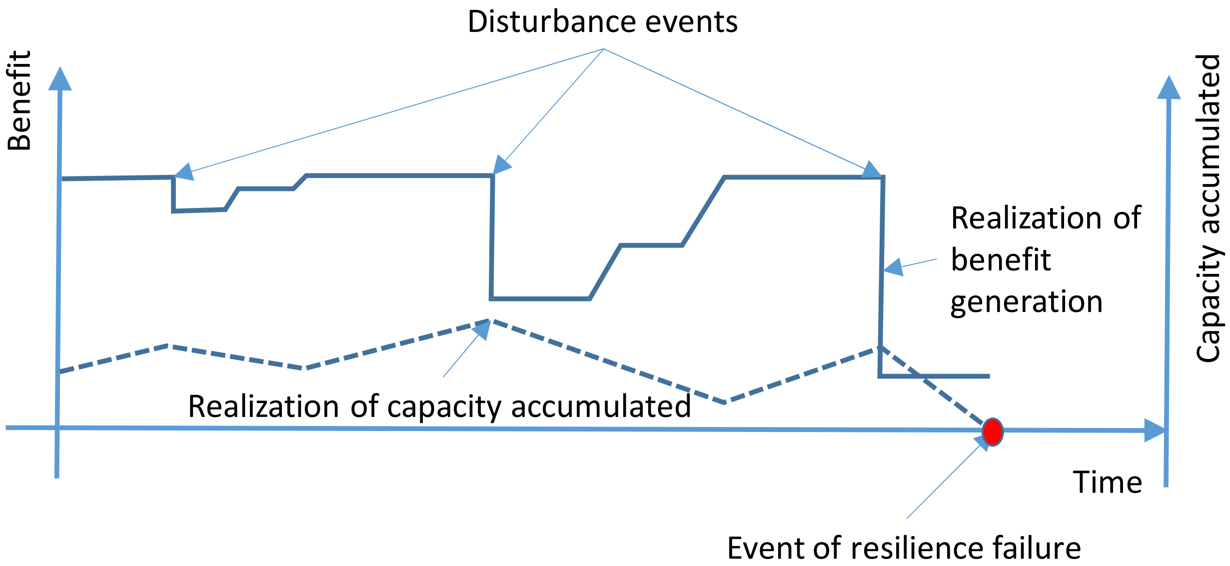
Probabilistic resilience modeling



Faber M. Risk Informed Structural Systems Integrity Management: A Decision Analytical Perspective. ASME. International Conference on Offshore Mechanics and Arctic Engineering, Volume 9: Offshore Geotechnics; Torgeir Moan Honoring Symposium ():V009T12A040. doi:10.1115/OMAE2017-62715.

Probabilistic System Representation

Resilience modeling



$$f_f(t) = \lim_{\Delta t \to 0} \frac{P(\{R(\tau) > S(\tau) \forall \tau \in [0,t[\} \cap \{R(t+\Delta t) \le S(t+\Delta t)\})}{\Delta t}$$

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Probabilistic System Representation

Consequences to health, environment and economy

Impacts to health and safety are addressed through the relative utility function comprised by the Life Quality Index (LQI) (Nathwani et al, 1997)

Impacts to the environment are addressed through:
- Quantitative Life Cycle Analysis (substances/energy) (Hauschild, 2015)

Impacts to the economy are addressed through:
- Monetary benefits (production functions)
- Monetary losses (production functions)

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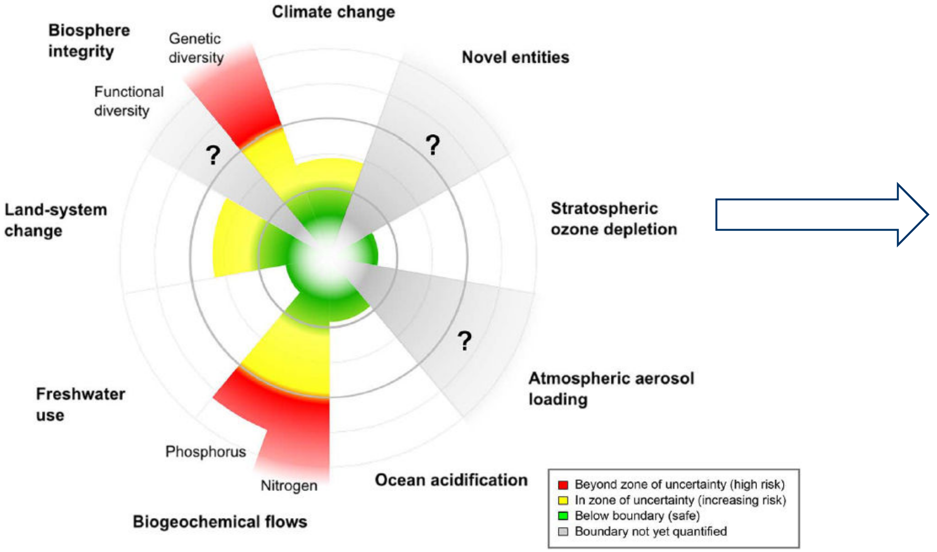
Probabilistic System Representation

Sustainability modeling

Global Planetary Boundaries provide a means for allocating capacities to different societal activities



Local /national and sector wise allocation of capacities

- **- Built environment**
- **- Energy production and distribution**
- **- Food production**
- **- Transportation**
- **- .....**
- **- ....**
- **- ...**
- **- ..**

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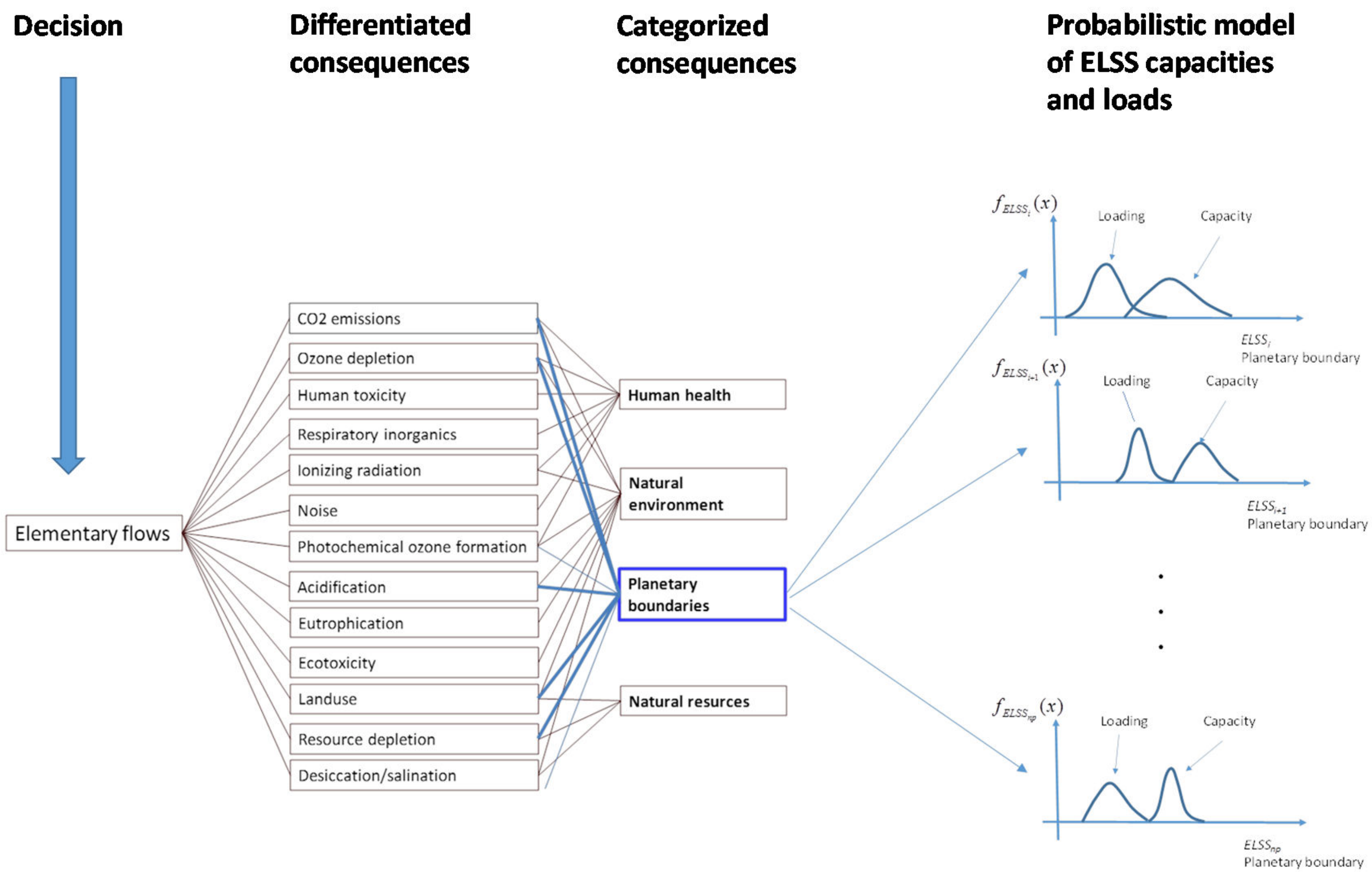
Probabilistic System Representation



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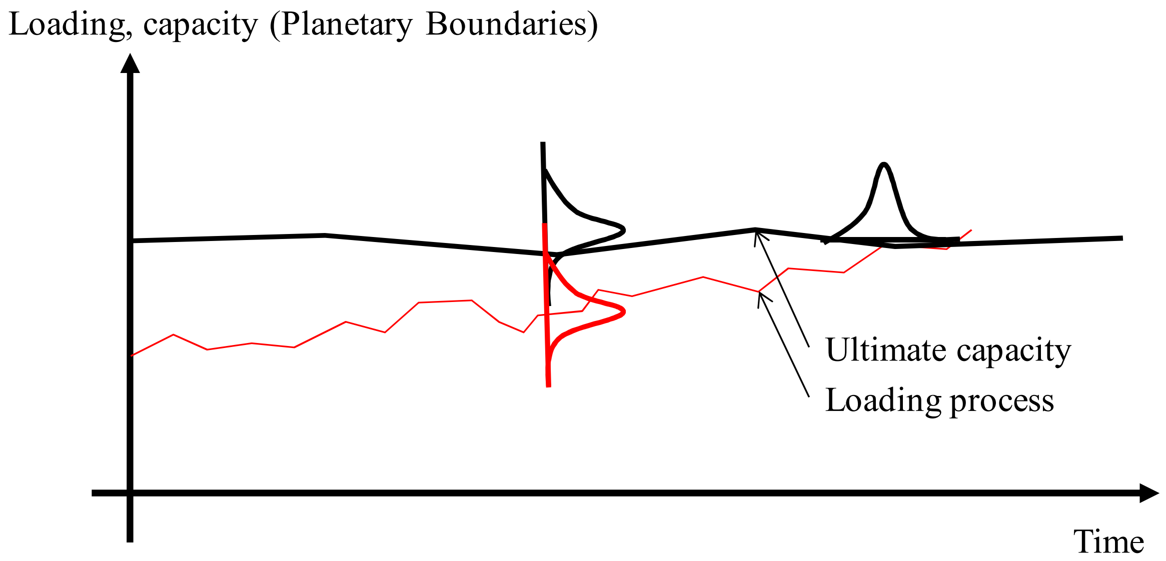
Probabilistic System Representation

Sustainability modeling

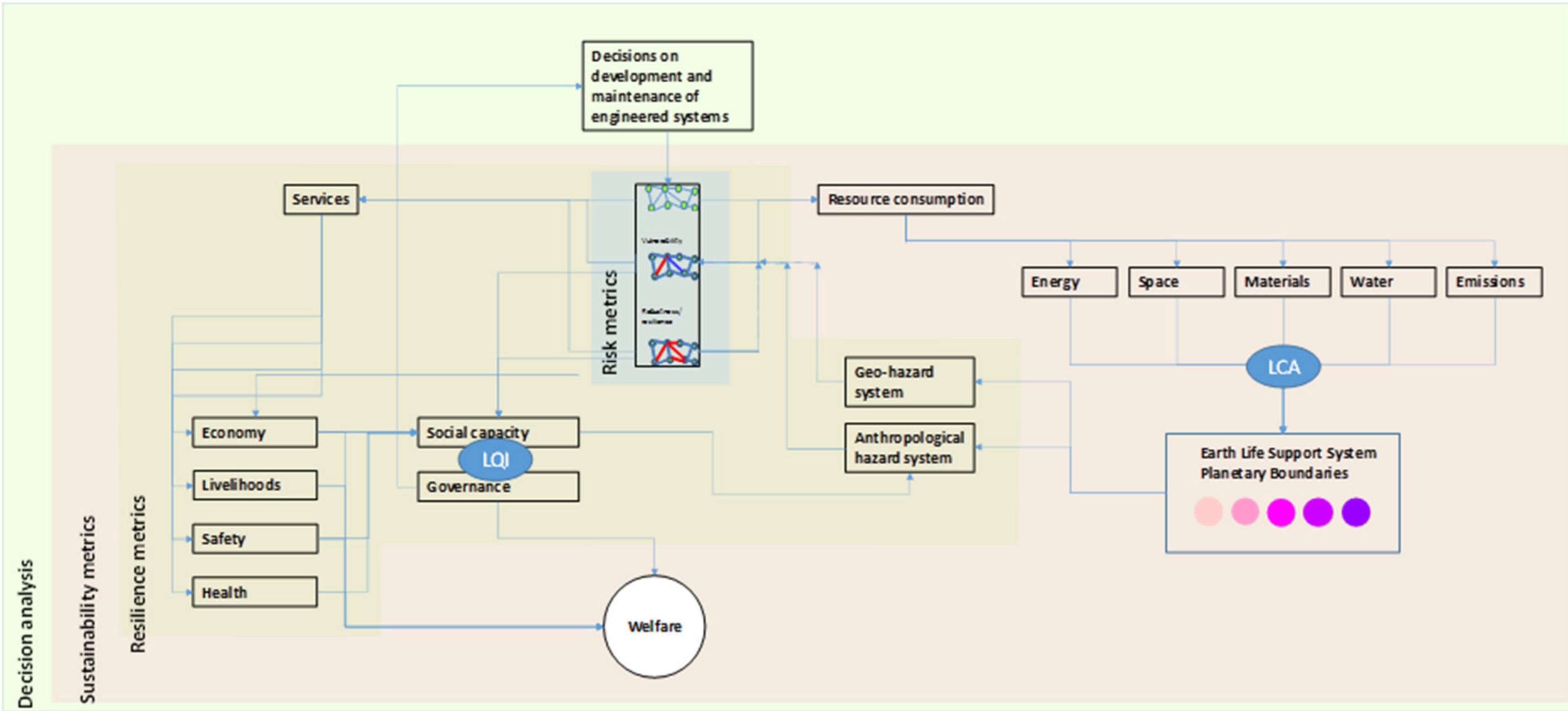
For given sector, geographical area or project sustainability failure is expressed in terms of exceedance of Planetary Boundaries



$$f_f(t) = \lim_{\Delta t \to 0} \frac{P(\{R(\tau) > S(\tau) \forall \tau \in [0,t[\} \cap \{R(t+\Delta t) \leq S(t+\Delta t)\})}{\Delta t}$$

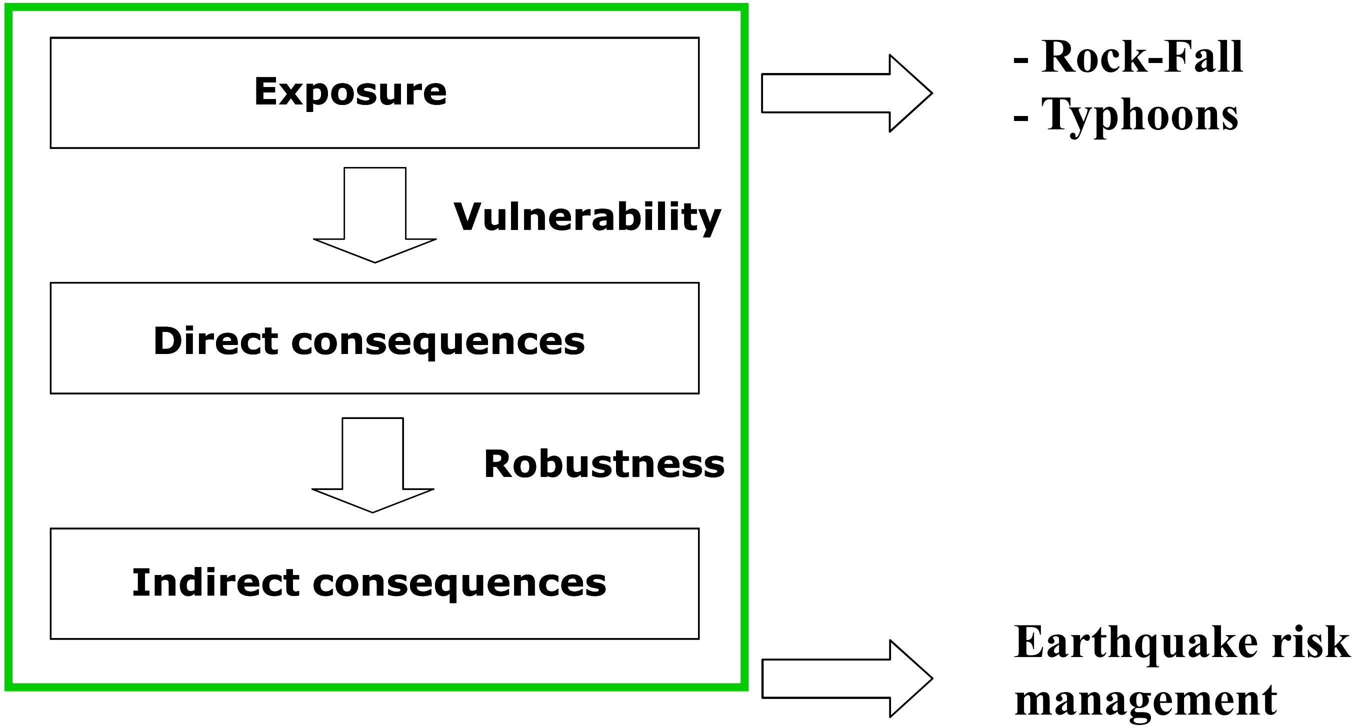
Probabilistic System Representation

Overall framework



Example Illustrations

Application of modeling concept



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Exposure Modeling

Exposure analysis in regard to rock-fall

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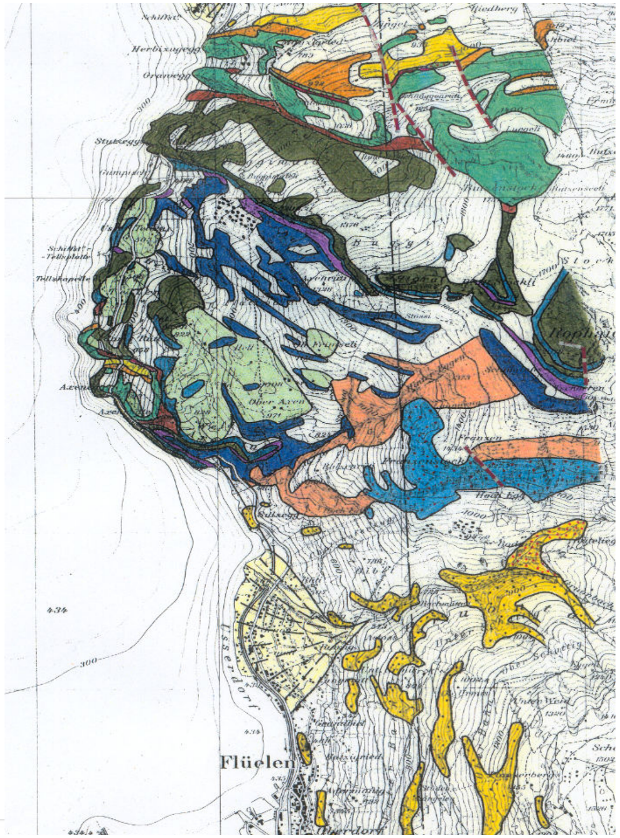
Exposure Modeling

Exposure analysis in regard to rock-fall



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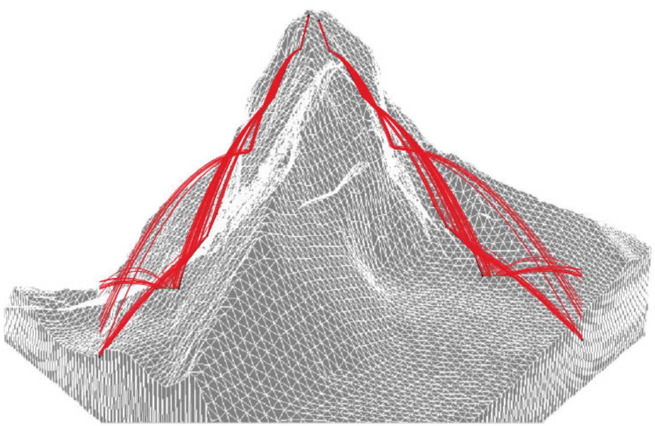
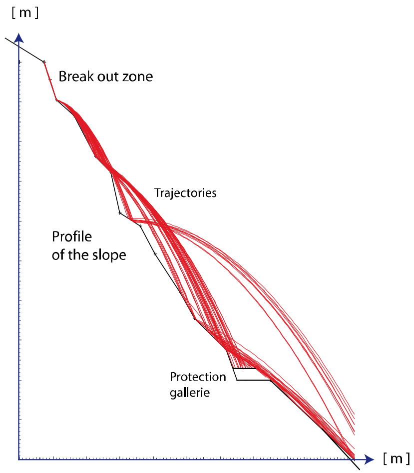
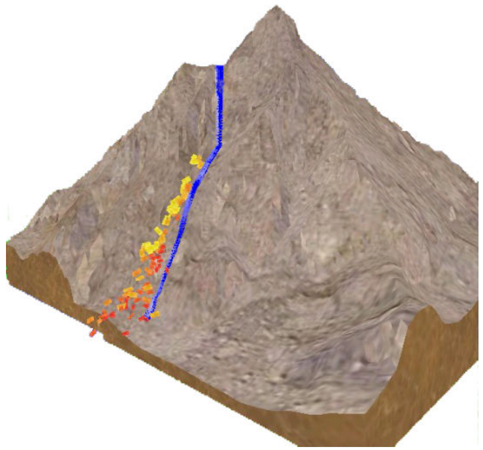
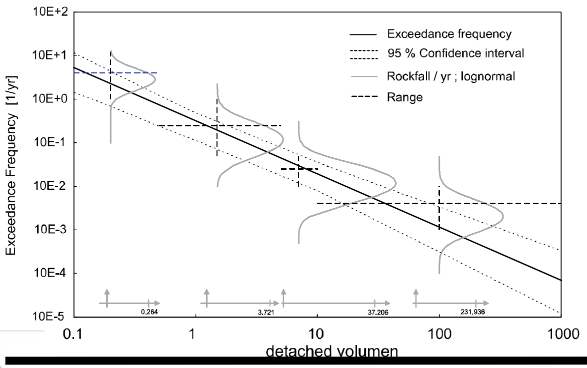
Exposure Modeling

Exposure analysis in regard to rock-fall









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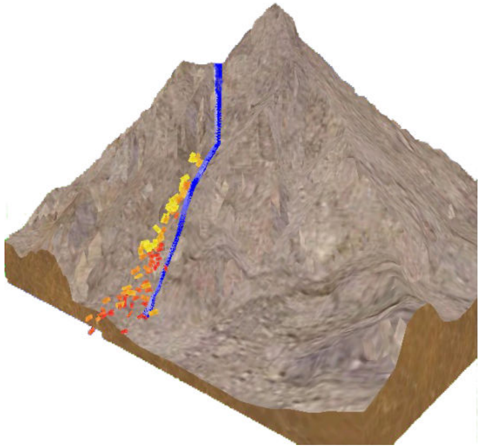
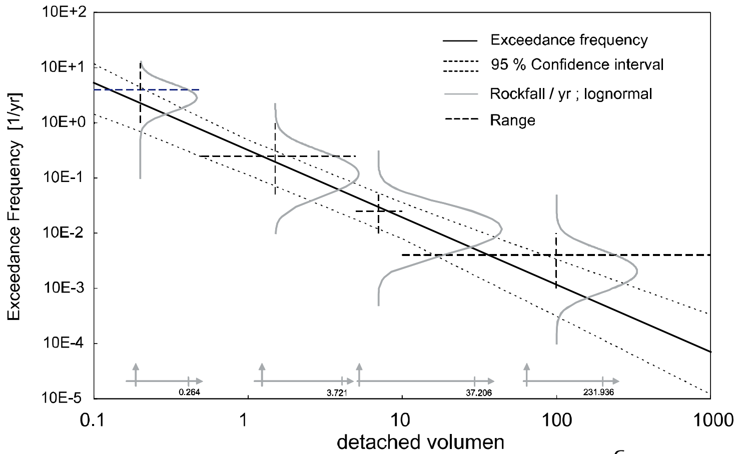
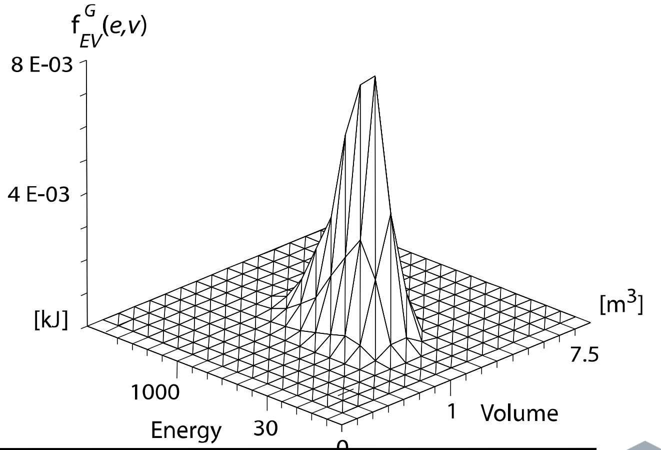
Exposure Modeling

Exposure analysis in regard to rock-fall





Detachment modeling



Fall modeling

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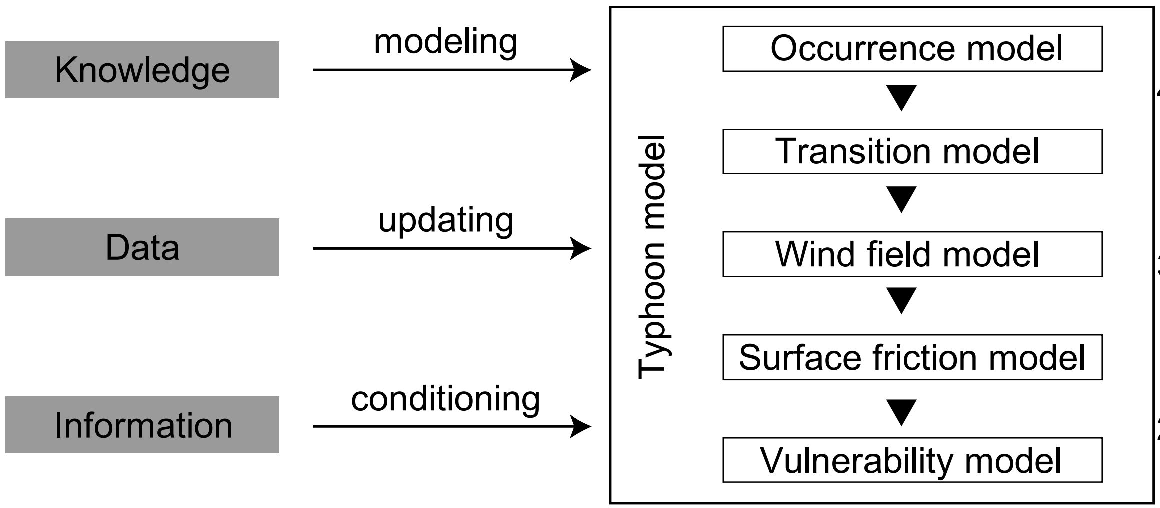
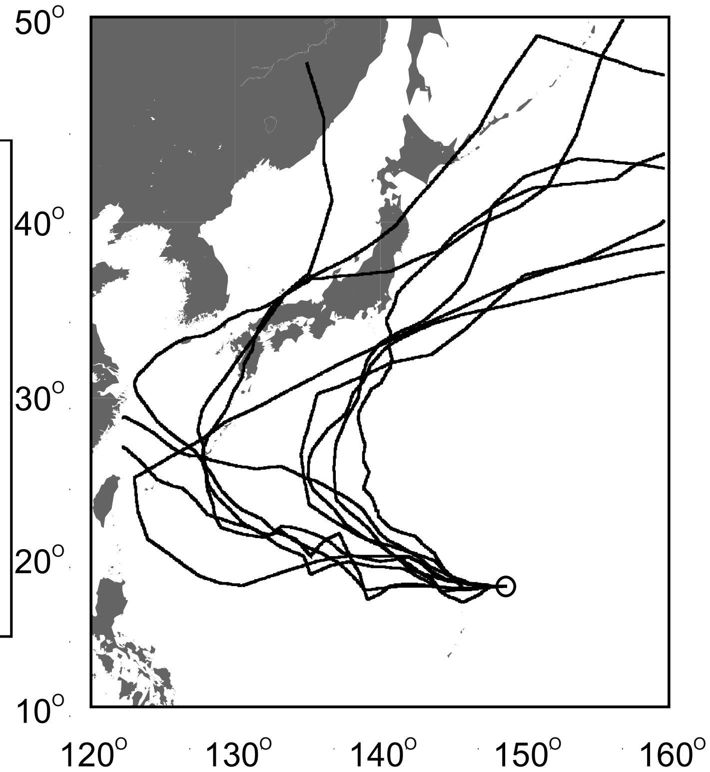
Typhoon Exposure Modeling

Representing the Event of Typhoons

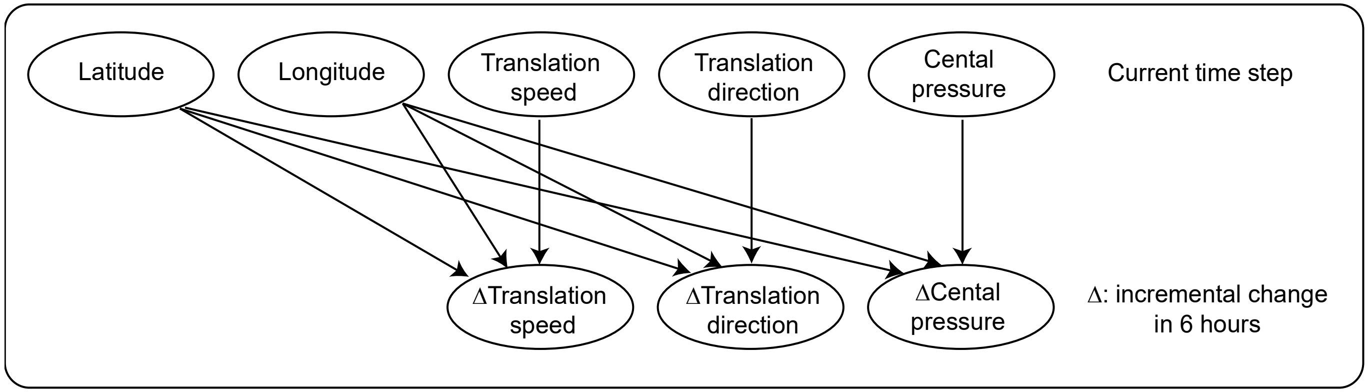




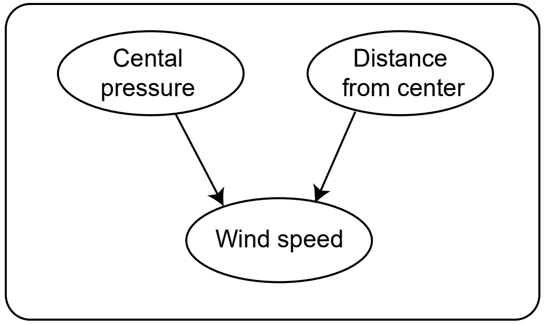
Typhoon Exposure Modeling

Representing the Event of Typhoons

Transition model



Wind field model



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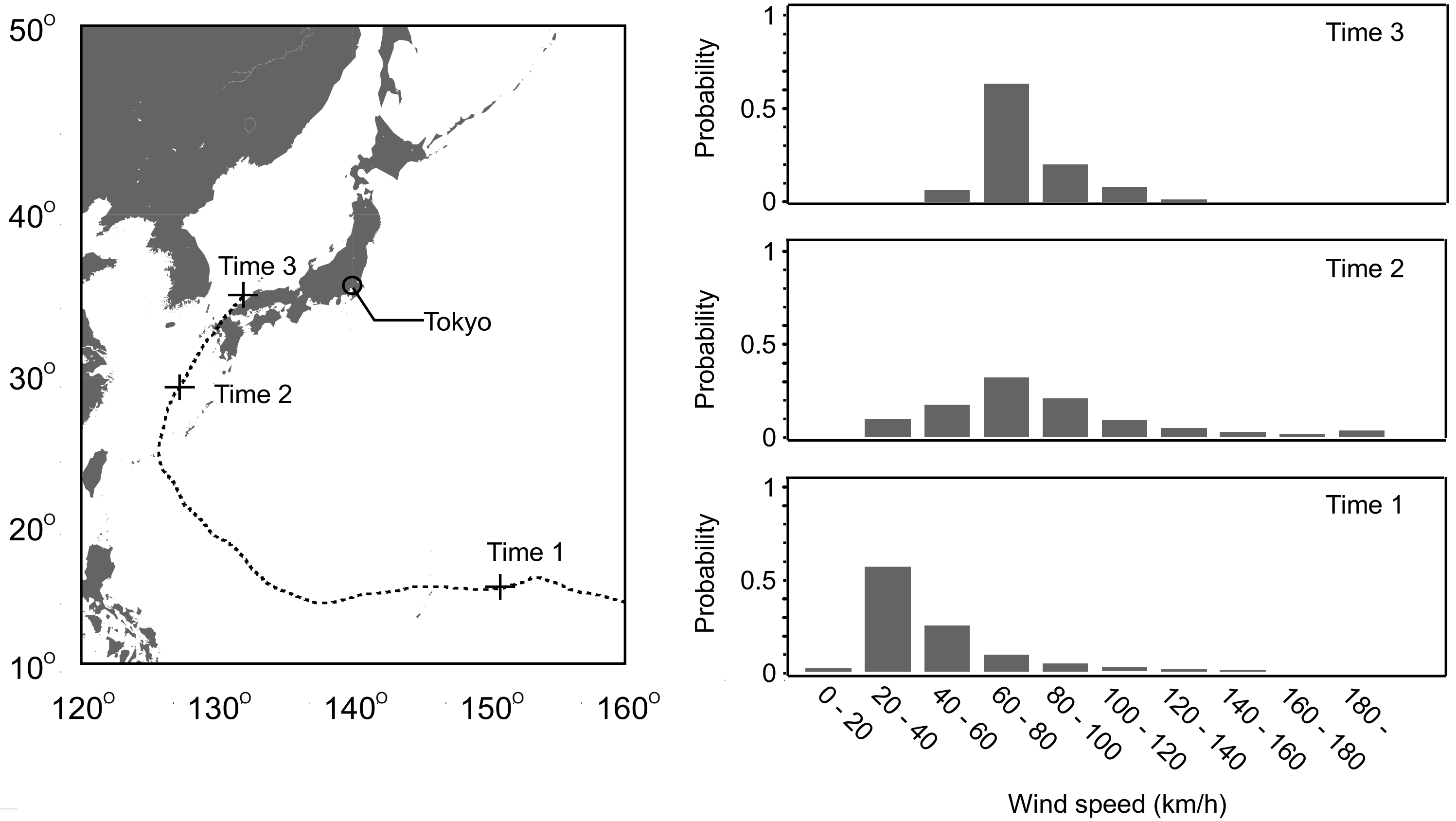
Typhoon Exposure Modeling

Representing the Event of Typhoons



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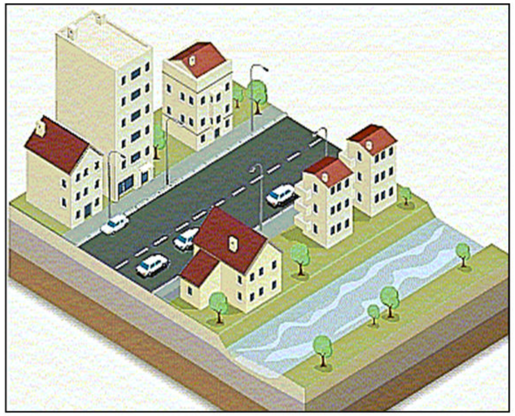
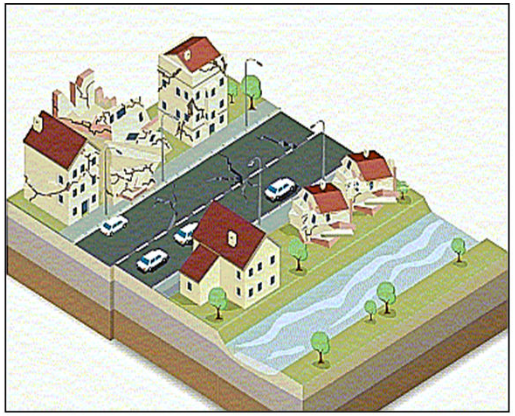
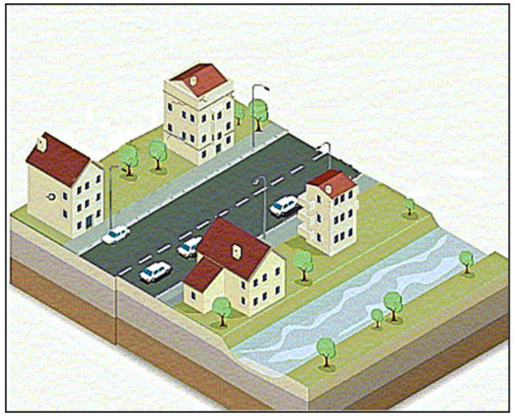
Management of Risks due to Earthquakes

Large scale earthquake risk management







Before

Optimal allocation of available resources for risk reduction

- retrofitting
- rebuilding

in regard to possible earthquakes

During

Damage monitoring/control

Emergency help and rescue

Aftershock hazard assessment

Identification of the seismic event

After

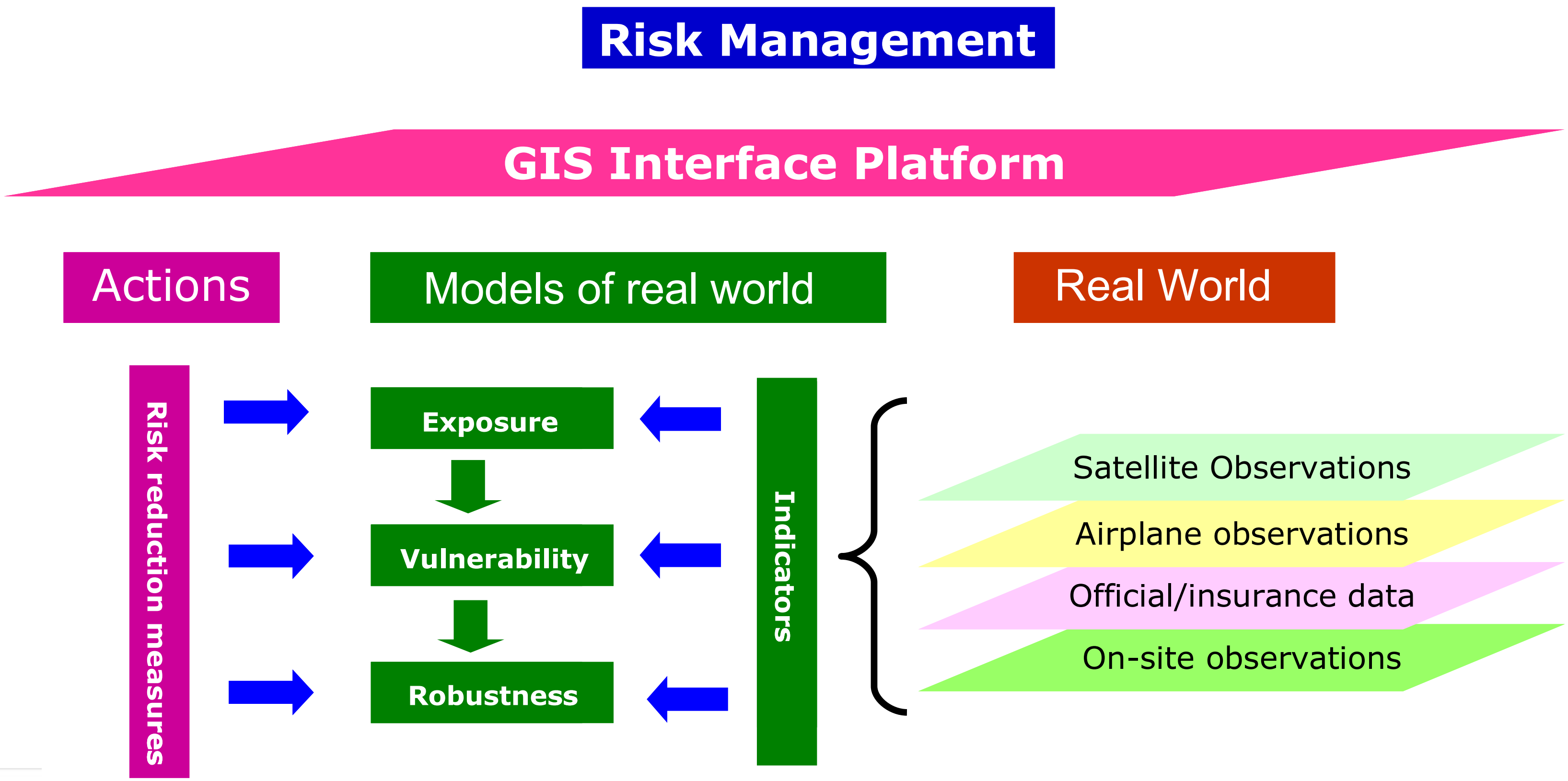
Rehabilitation of infrastructure functionality

Condition assessment and updating

Optimal allocation of resources for retrofitting and rebuilding

Management of Risks due to Earthquakes

Risk assessment for large portfolios



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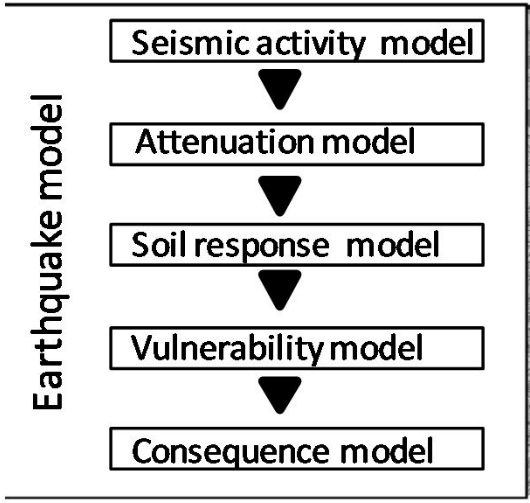
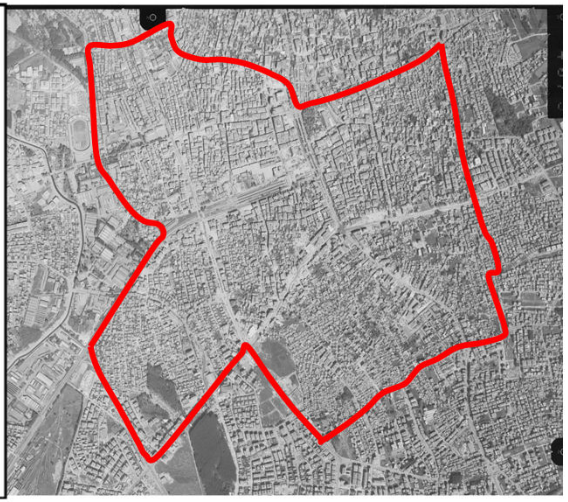
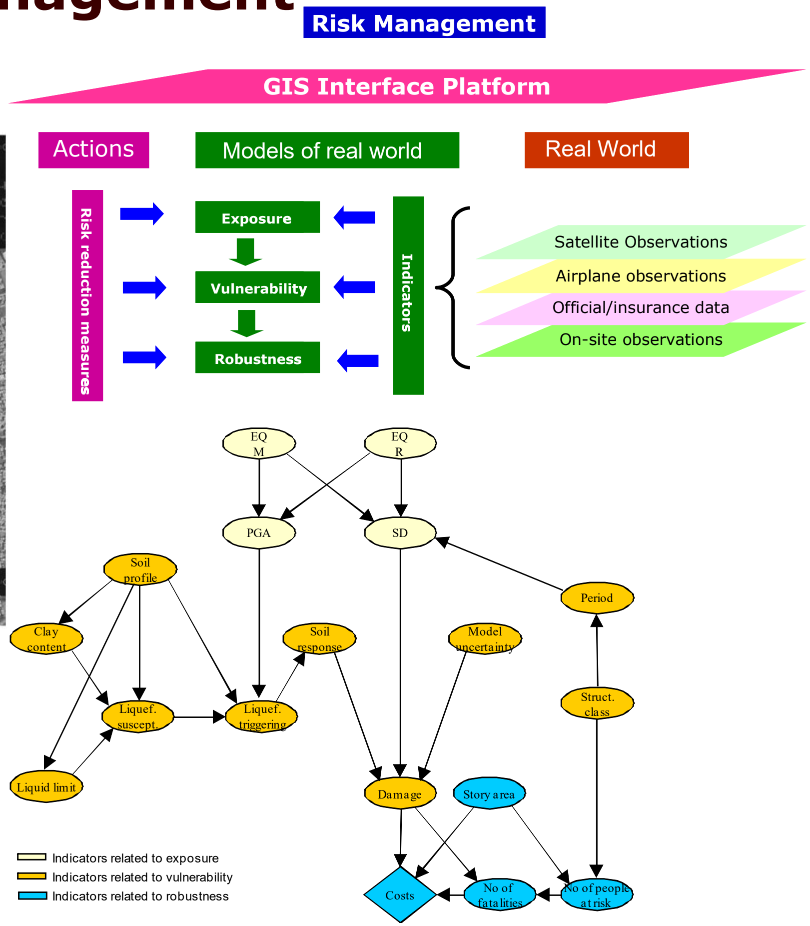
Management of Risks due to Earthquakes

Large scale earthquake risk management







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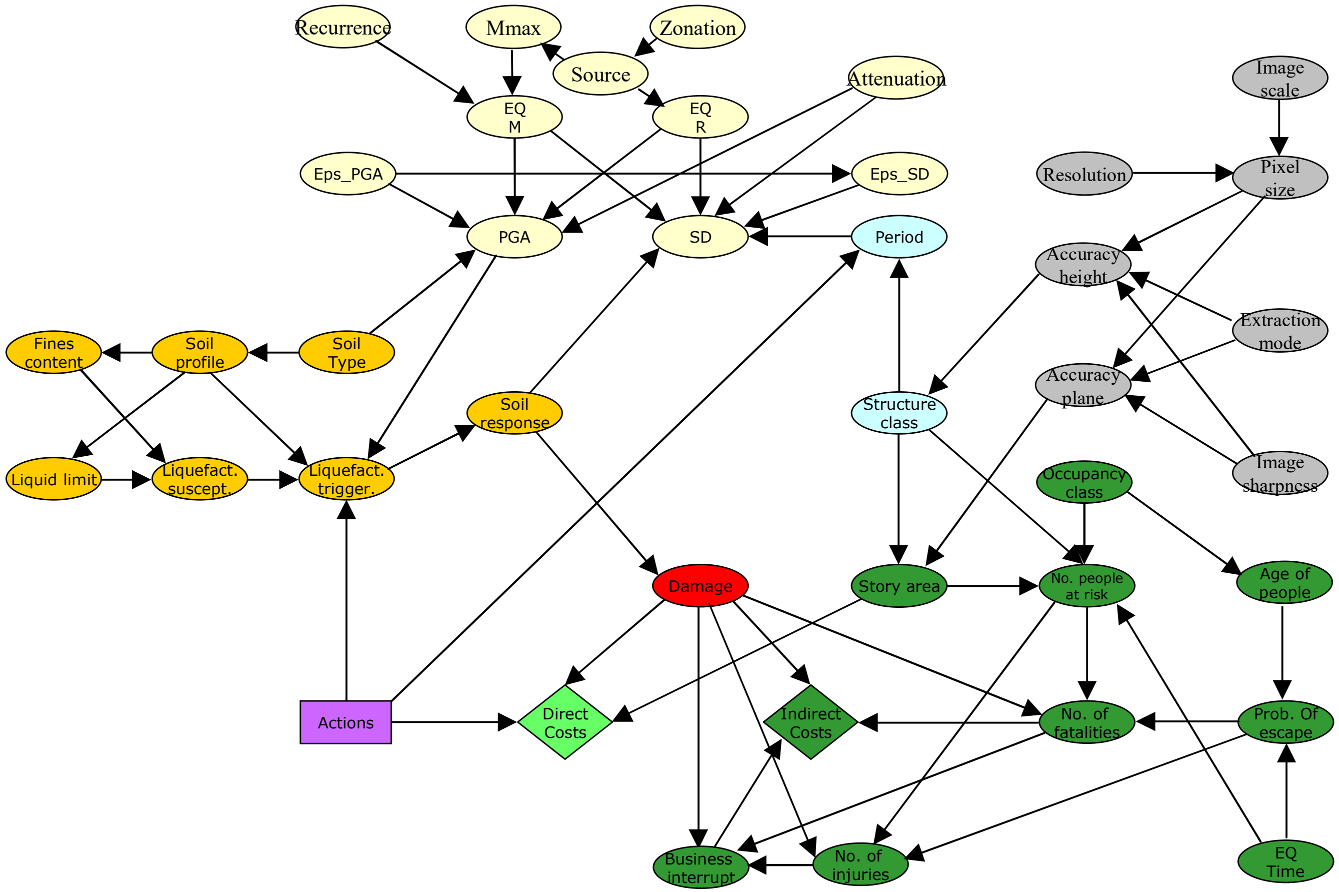
Recent Developments in Systems Modeling

Large scale earthquake risk management



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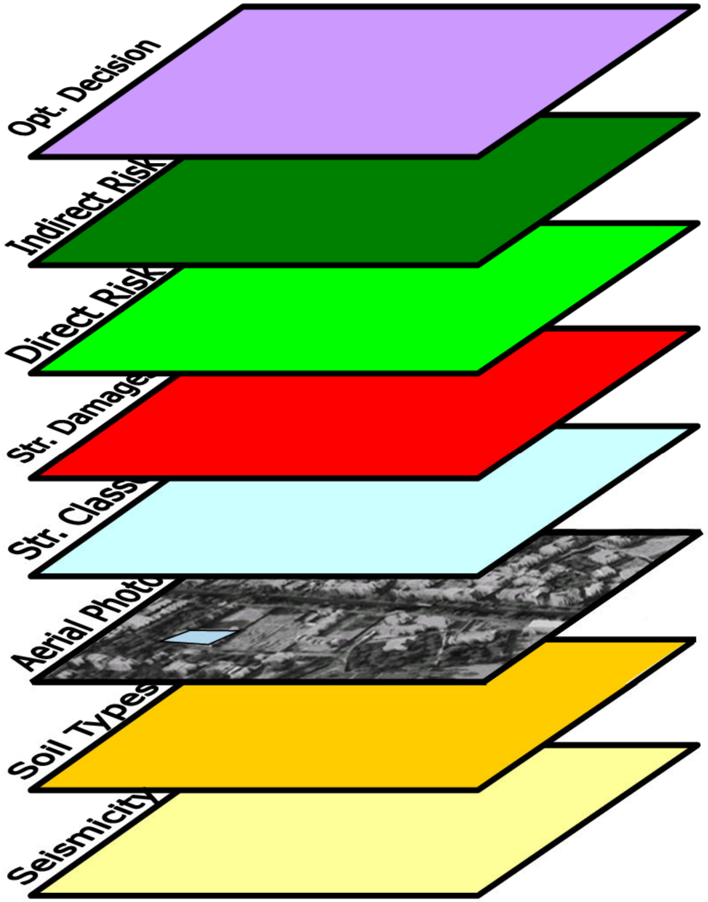
Recent Developments in Systems Modeling

Large scale earthquake risk management



Before: - retrofitting of buildings
- improvement of soil
- information collection

During: - emergency management

After: - condition assessment

- Occupancy class
- Business interruption
- Fatalities
- Injuries
- Story area, etc.
- Age of people at risk
- Probability of escape
- Earthquake occurrence time

- Rebuilding costs
- Retrofitting costs
- Building content cost, etc.

- Structure type
- Number of stories
- Design code

- Image scale
- Image resolution
- Extraction mode
- Image sharpness

- Soil type
- Soil profile
- Fines content, liquid limit
- Unit weight, water content, SPT

- Magnitude
- Distance
- Peak ground acceleration
- Spectral displacement
- Seismic souce model
- Attenuation model
- Reccurrence Model

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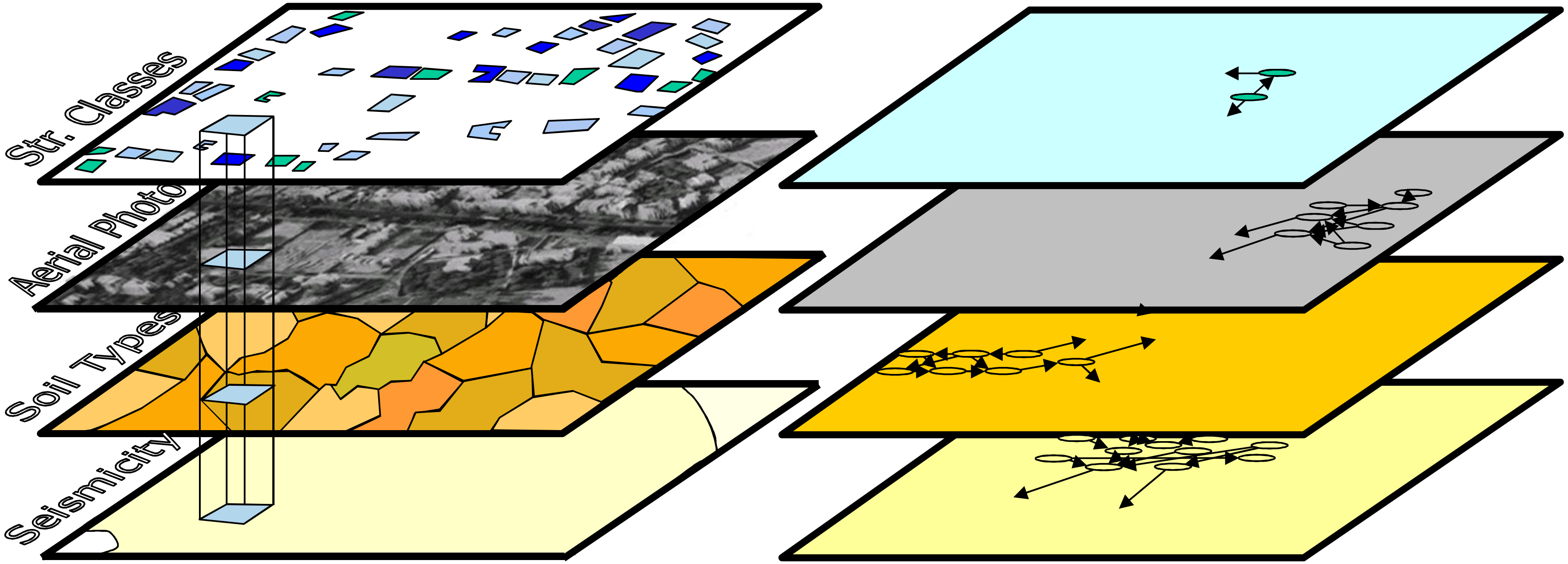
Recent Developments in Systems Modeling

Large scale earthquake risk management



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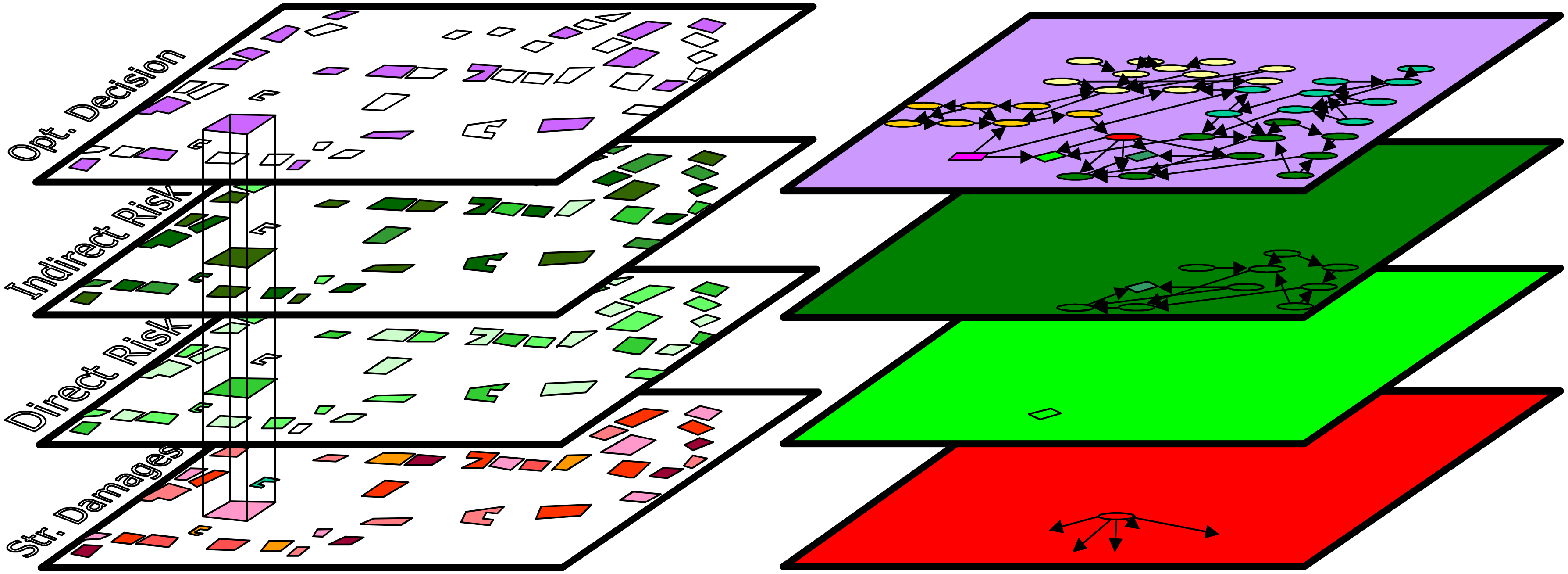
Recent Developments in Systems Modeling

Large scale earthquake risk management



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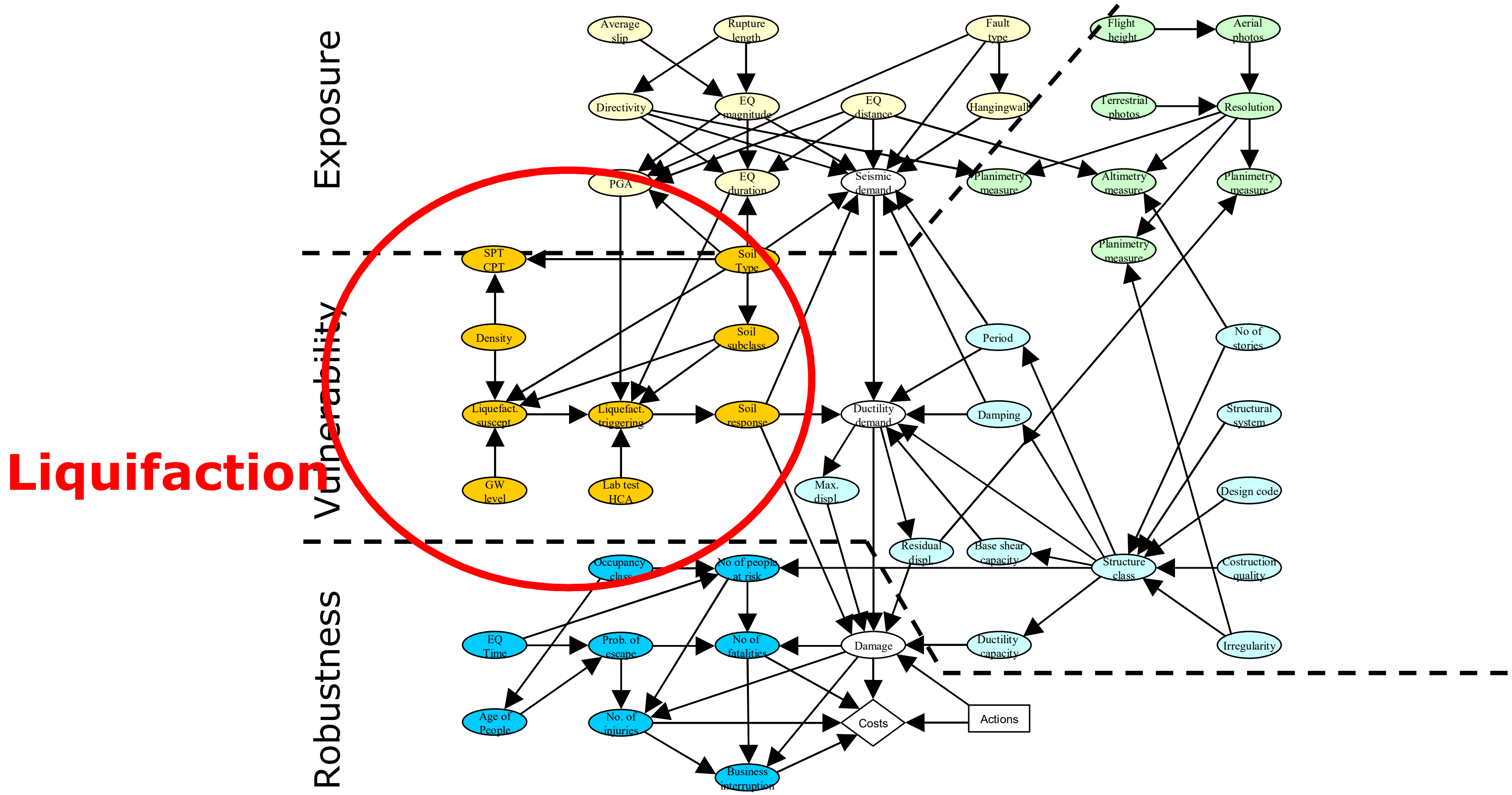
Recent Developments in Systems Modeling

Large scale earthquake risk management



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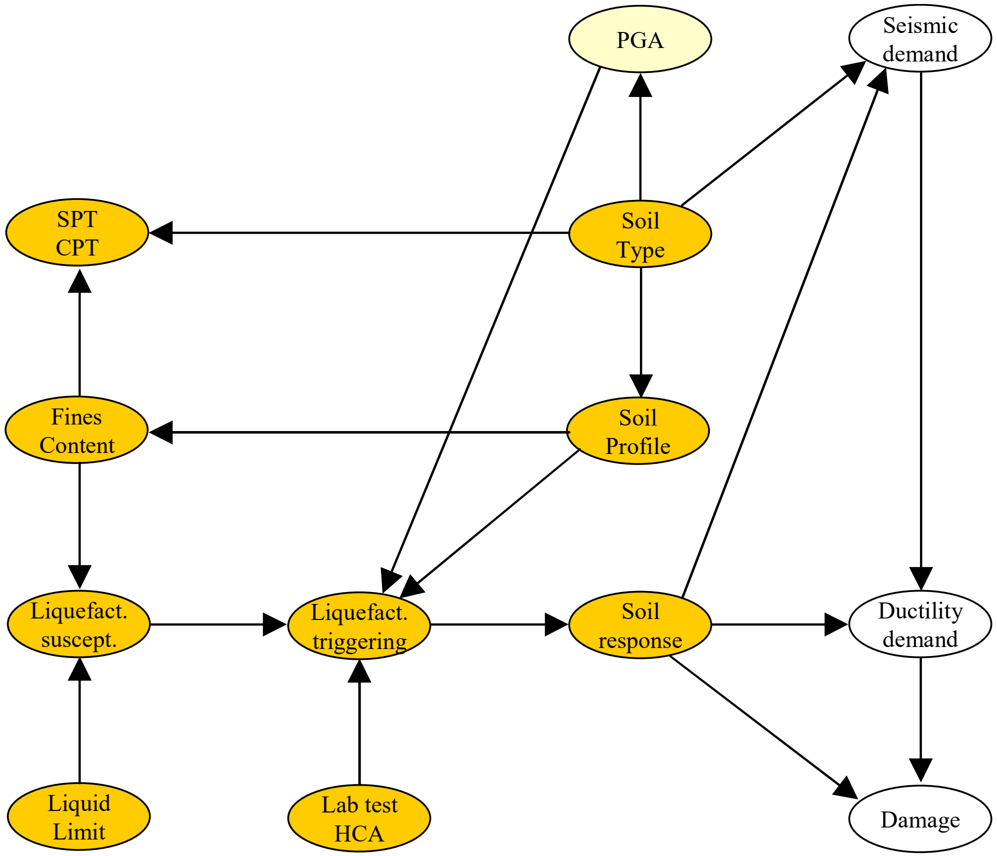
Recent Developments in Systems Modeling

Large scale earthquake risk management

Condition indicators for liquefaction susceptibility of silty and sandy soils



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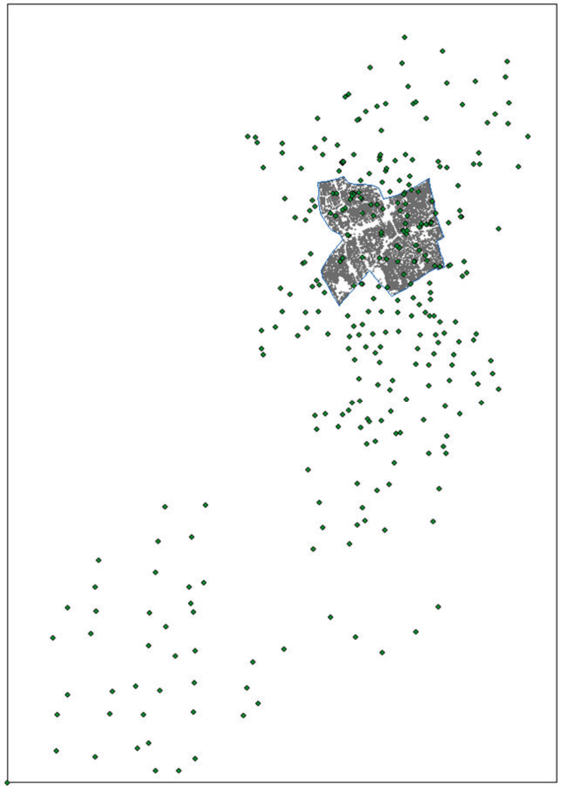
Recent Developments in Systems Modeling

Large scale earthquake risk management

Vulnerability in regard to liquifaction



Locations of buildings and soil measurements

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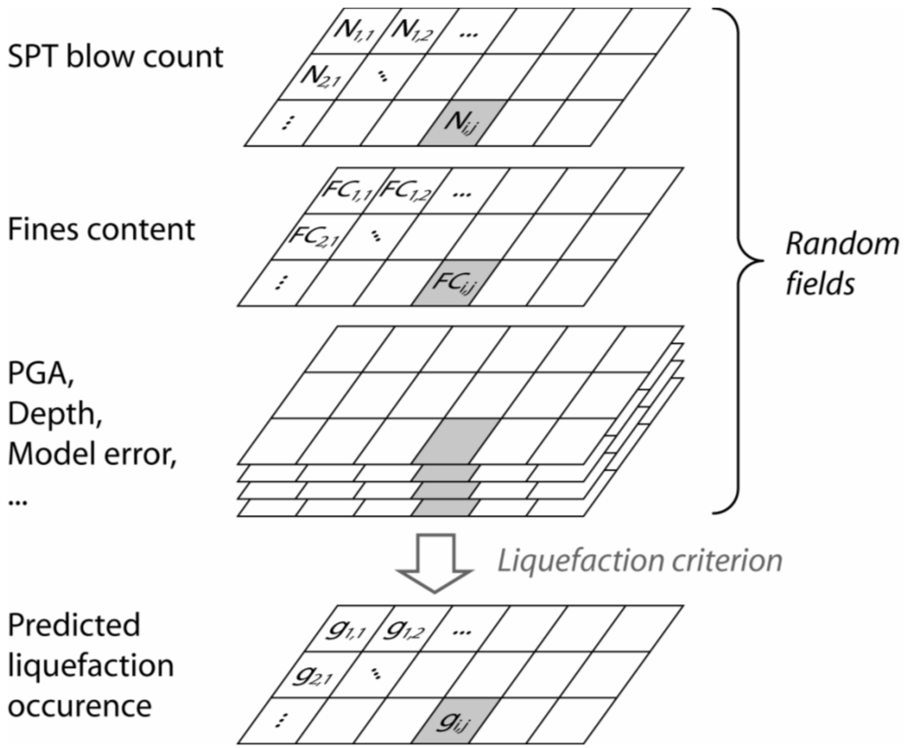
Recent Developments in Systems Modeling

Large scale earthquake risk management

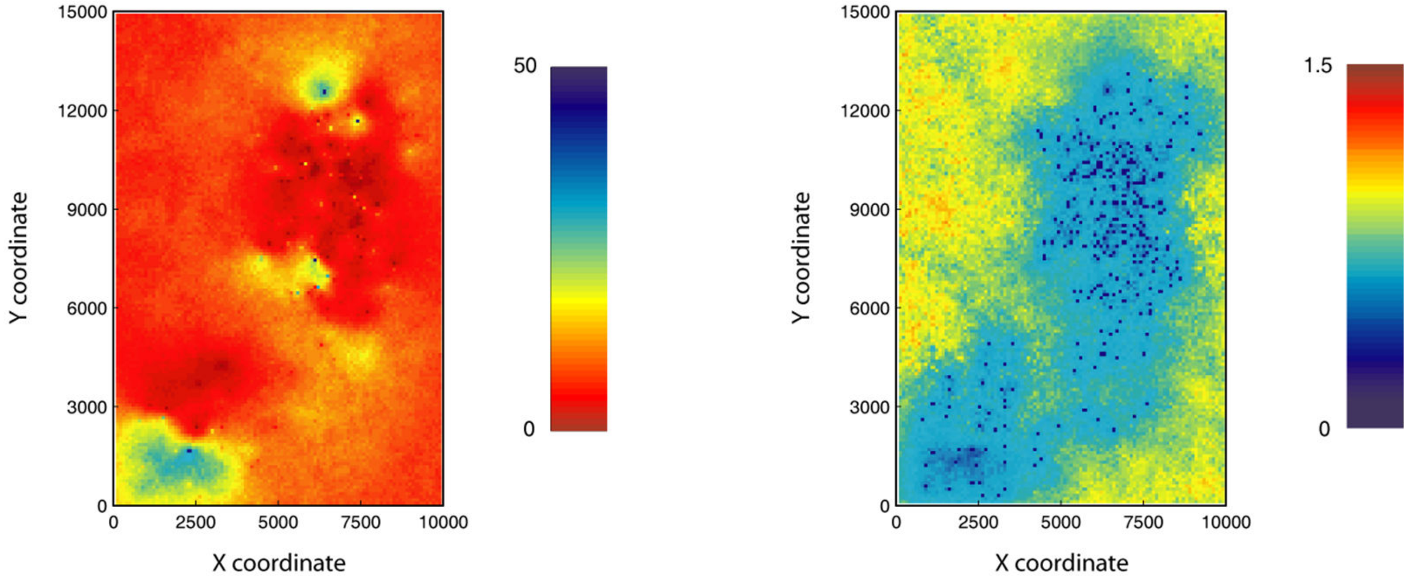
**Vulnerability
in regard to
liquifaction**



Recent Developments in Systems Modeling

Large scale earthquake risk management

Mean and coefficient of variation of conditional Standard Penetration Test (SPT) blowcounts $(N_1)_{60}$ simulations



$(N_1)_{60}$ is the SPT blow count normalized to an overburden pressure of approximately 100 kPa and a hammer energy ratio of 60%.

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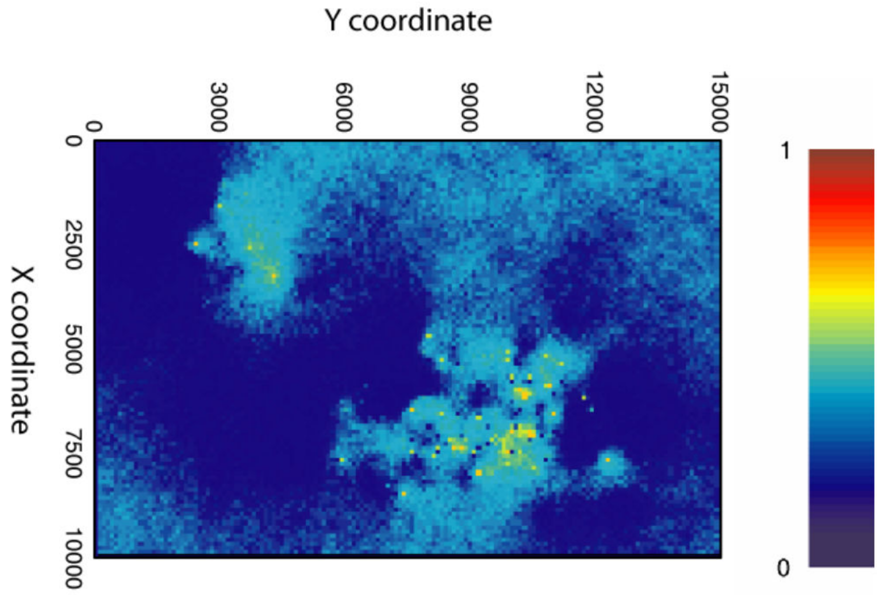
Recent Developments in Systems Modeling

Large scale earthquake risk management

Probability of liquefaction at the study site,
given a M=7.5 earthquake causing a PGA of 0.3g



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Recent Developments in Systems Modeling

Large scale earthquake risk management

Distribution of damage for a M=7.5 earthquake

Damage State

- Fully Operational
- Operational
- Life Safety
- Near Collapse
- Collapse

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Recent Developments in Systems Modeling

Large scale earthquake risk management

Total risks for a M=7.5 earthquake

Total Risk [$]

- 0
- 0 – 200'000
- 200'000 – 400'000
- 400'000 – 600'000
- 600'000 – 800'000

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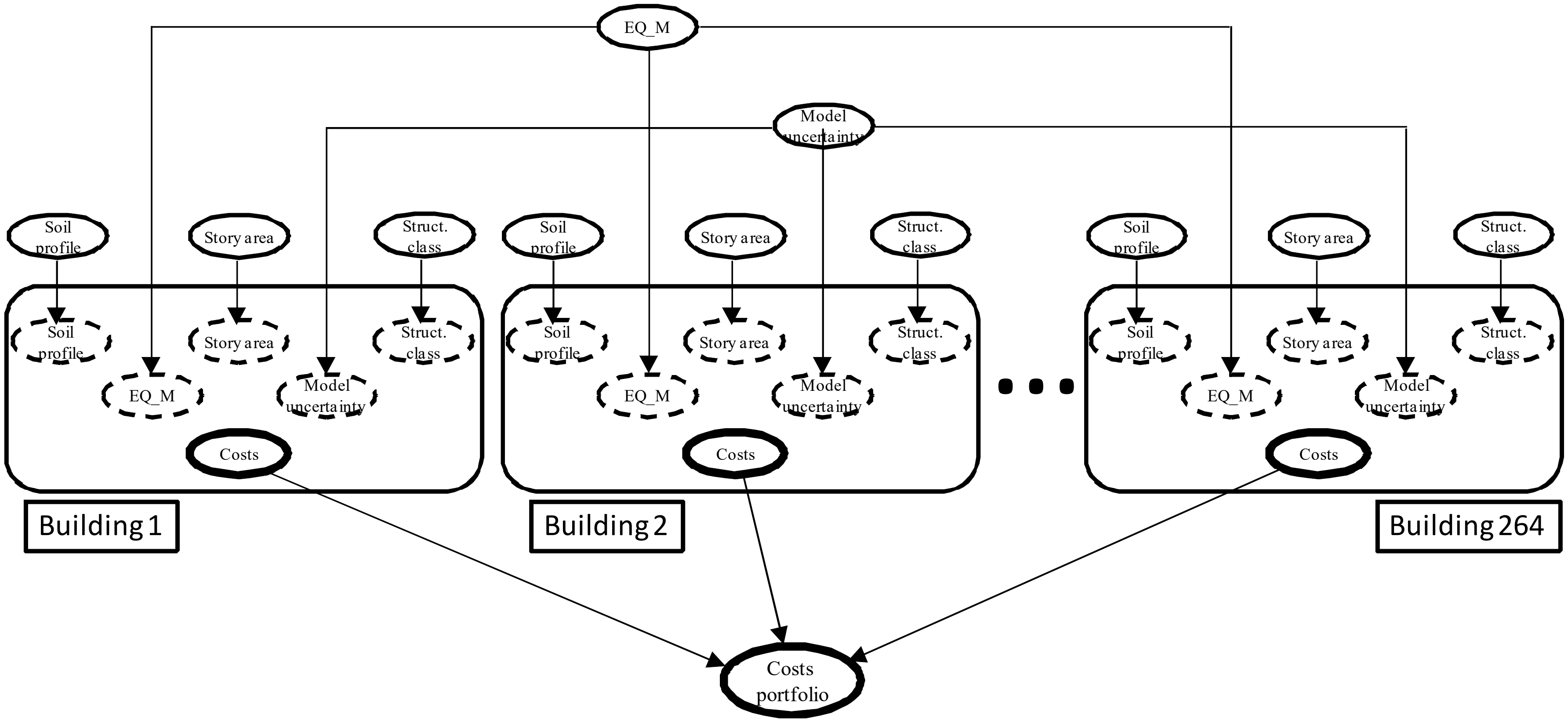
Management of Risks due to Earthquakes

Risk assessment for large portfolios



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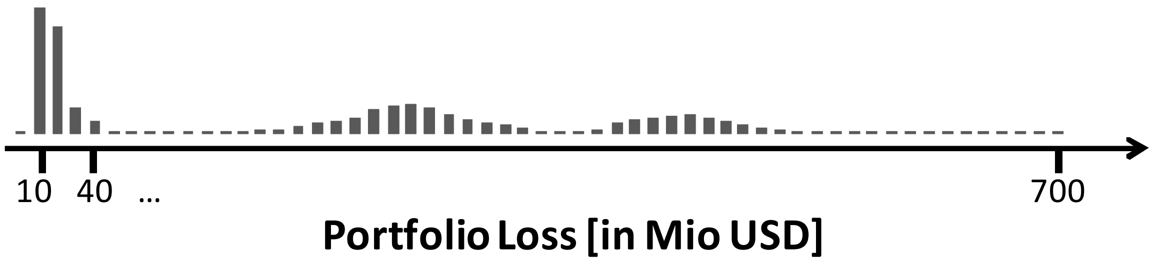
Management of Risks due to Earthquakes

Risk assessment for large portfolios

Without dependency

E[Costs]=25 Mio USD

With dependency



E[Costs]=25 Mio USD

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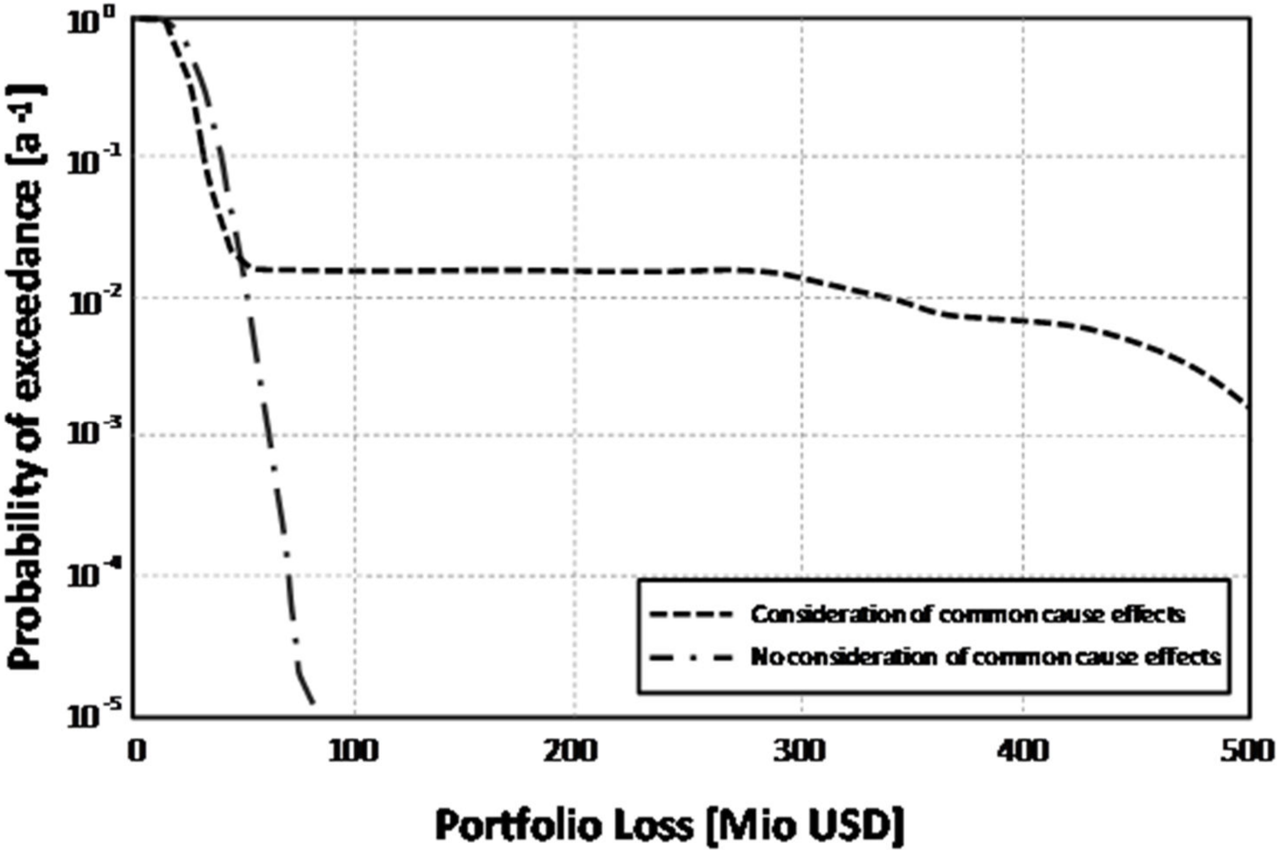
Management of Risks due to Earthquakes

Risk assessment for large portfolios



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Concluding Remarks

- **Modern risk assessment frameworks and tools greatly enhance risk management**
- **Utilize generic risk modeling**
- **Facilitate updating of risks through indicators**
- **Can be applied for individually and jointly acting hazards**
- **Can be coupled with any (set) of models available which link exposure events to effects of climatic change**

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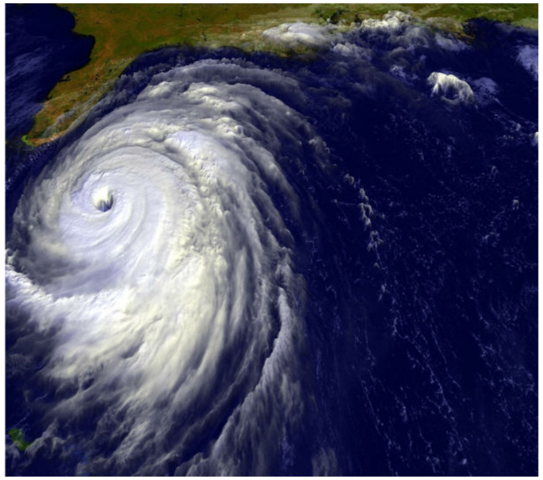
Concluding Remarks

- **We still need to improve modelling and best practices in risk management of natural hazards to establish the right focus on how to:**
  - reduce risks
  - increase resilience
  - achieve sustainability

- **Efforts must be directed on standardization of:**
  - modeling approaches
  - assessment criteria

- **Industry 4.0 must be utilized to facilitate:**
  - open platforms for sharing models/data/tools
  - real-time observations/monitoring/advise



K-FORCE Lectures
Banja Luka, Bosnia Herzegovina
December 13, 2018

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Thanks for your attention ☺

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www.r3sbe.civil.aau.dk

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Resilience
Sustainability
Built
Environment