Managing Technical Risks
Matrisk

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From Risk Analysis to Decision Support

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R^3+SBE

Risk
Reliabiliy
Resilience
Sustainability
Built
Environment

Managing Technical Risks
Matrisk

Contents

- Background and Motivation
- Risk – the Metric
- Systems Modelling – the JCSS Framework
- Information Management
- Decision Analysis for Risk Management
- Digital Twins and Virtual Labs
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Motivation

Why risk informed decision support?

Societal activities are increasingly associated with significant potential consequences in terms of health implications, financial losses and damages to the qualities of the environment.

Need and demand for efficiency, transparency and accountability in industry and public governance.

There is a move from prescriptive regulation to performance based regulation.

Risk – the Metric

Risk and Bayesian decision analysis

Risk is a characteristic of an decision *a* relating to all possible events n_E which may follow as a result of the decision

The risk contribution R_{E_i} from the event E_i is defined through the product between the

event probability P_{E_i}

and

the consequences of the event C_{E_i}

The risk associated with a given decision *a*, R_a is thus

$$R_a = \sum_{i=1}^{n_E} R_{E_i} = \sum_{i=1}^{n_E} P_{E_i} \cdot C_{E_i}$$

Risk – the Metric

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Expected value of consequences

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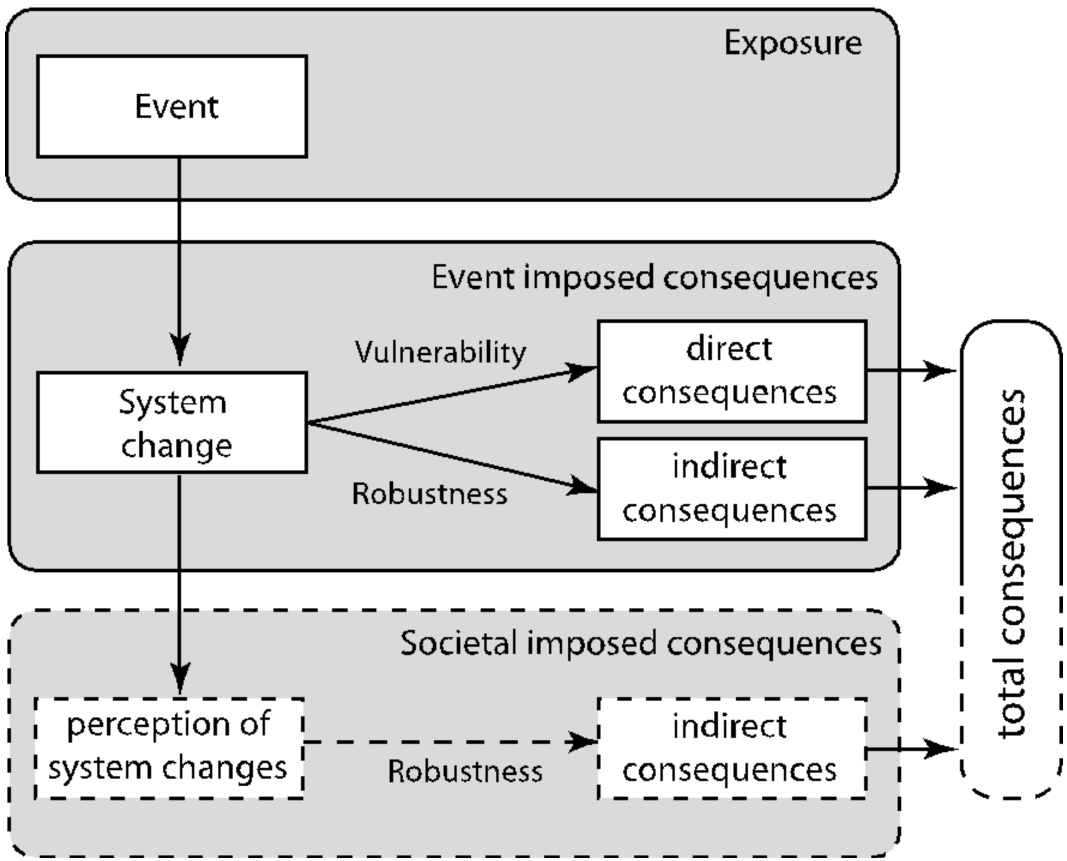
Systems Modelling – the JCSS Framework

How are consequences generated?



Systems Modelling – the JCSS Framework

Structural safety and information management

Models of real world

Decisions

Real world

Exposures/loads

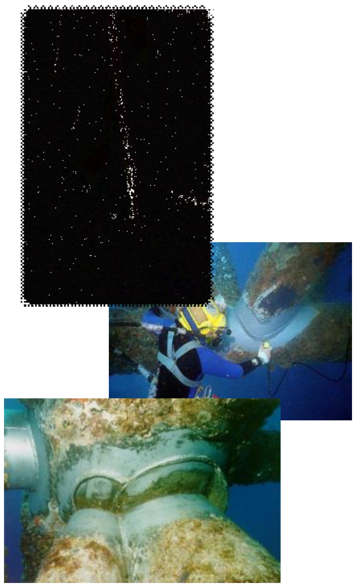
Site investigations
Load control
Environment control
….
Materials
Component design
….
System concept
Maintenance/monitoring
Evacuation strategy
…

Observations/measurements

Vulnerability / direct con.

Robustness / indirect con.

Safety, risk and life-cycle costs



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Systems Modelling – the JCSS Framework

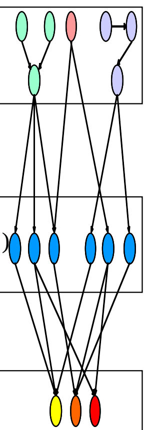
Structural safety and information management

Models of real world

$p(\mathbf{EX})$

$$R_D = \sum_{k=1}^{n_{EXP}} \sum_{l=1}^{n_{CSTA}} p(\mathbf{C}_l | EX_k) c_D(\mathbf{C}_l) p(EX_k)$$

$$R_{ID} = \sum_{k=1}^{n_{EXP}} \sum_{l=1}^{n_{CSTA}} \sum_{m=1}^{n_{SSTA}} c_{ID}(S_m, c_D(\mathbf{C}_l)) \times p(S_m | \mathbf{C}_l, EX_k) p(\mathbf{C}_l | EX_k) p(EX_k)$$



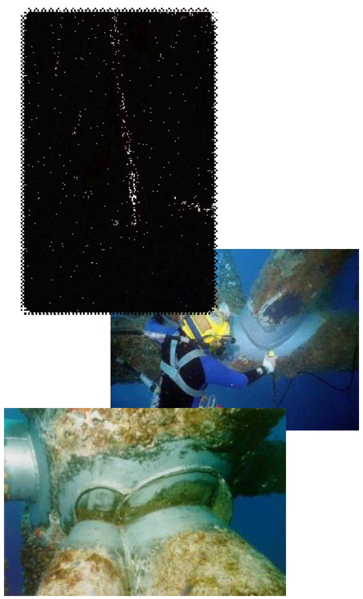
JCSS, Probabilistic Model Code

Decisions

Site investigations
Load control
Environment control
….
Materials
Component design
….
System concept
Maintenance/monitoring
Evacuation strategy
…

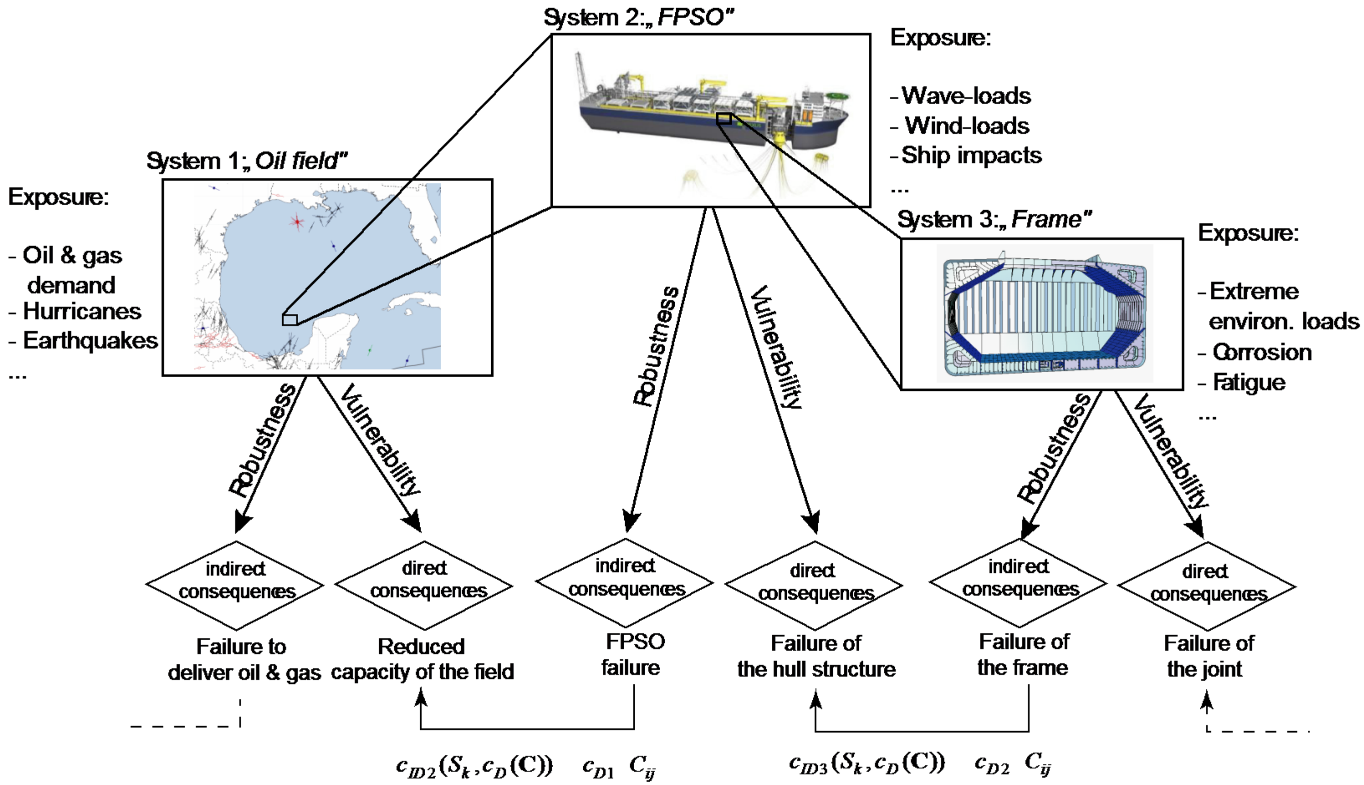
Likelihoods

Real world



Systems Modelling – the JCSS Framework

Scale – dependent on considered decision alternatives



Systems Modelling – the JCSS Framework

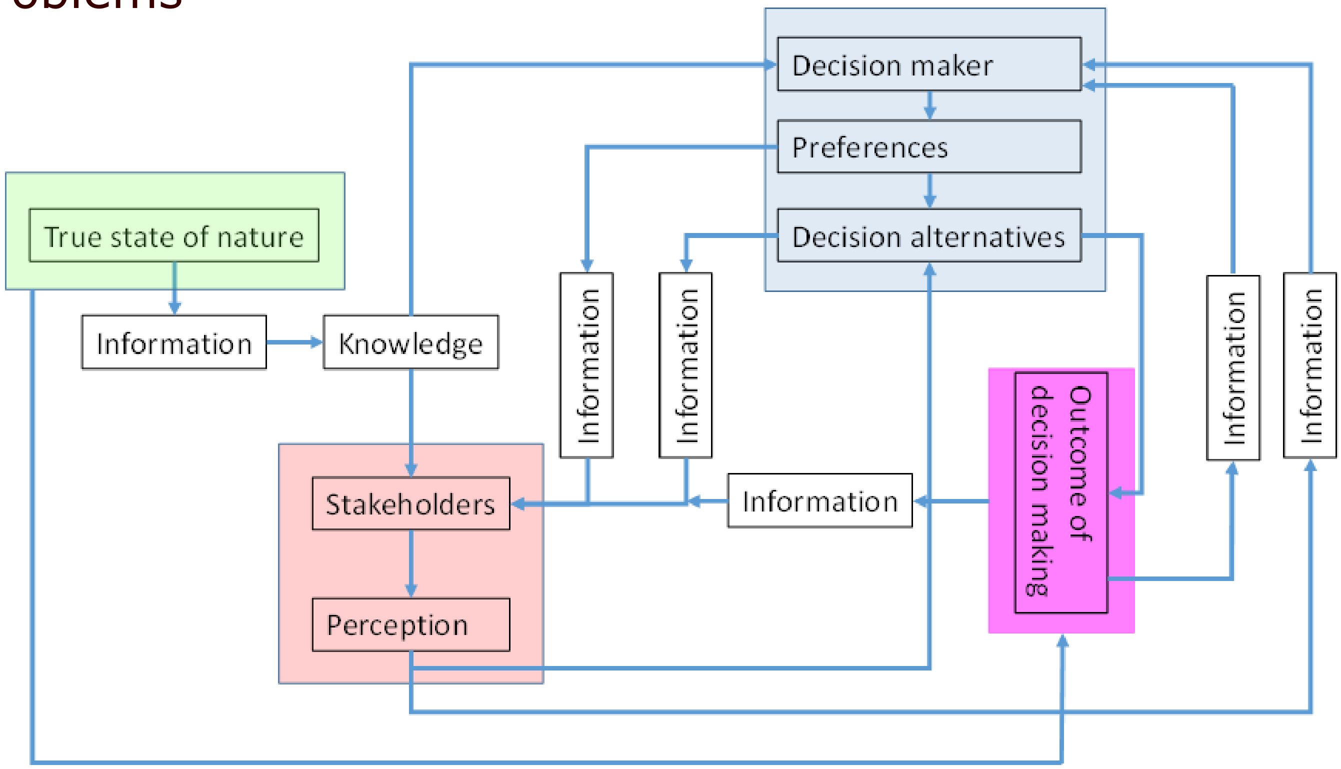
All we know about systems may be expressed in terms of information

We apply probability theory to represent information in our models (aleatory and epistemic uncertainties)

Information Management

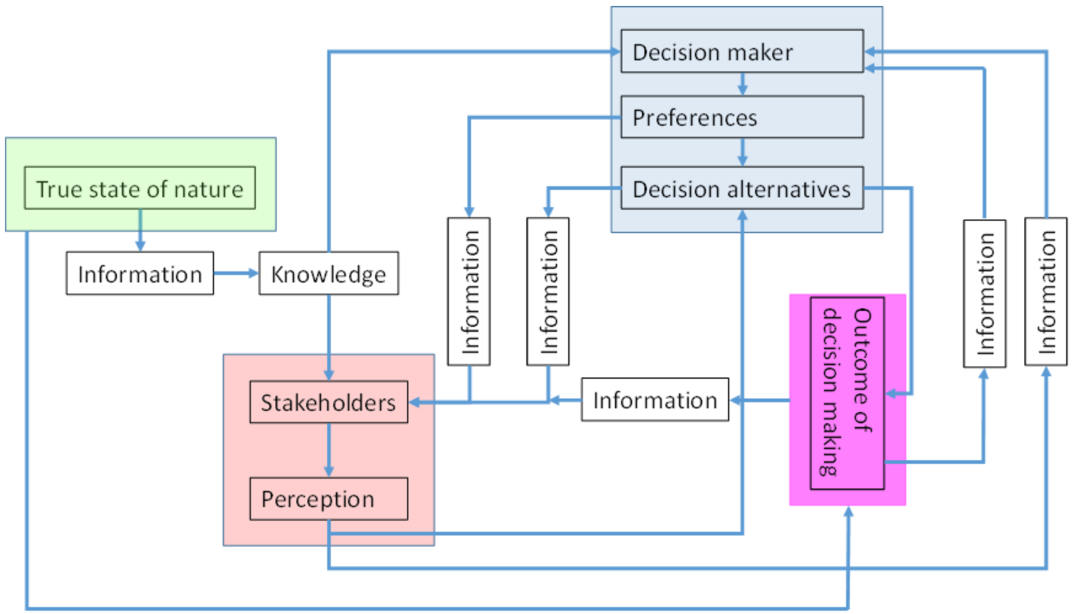
Problem framing

Information and knowledge influence all aspects of decision problems



Information Management

Issues in information management



Cases of "broken information"

Information is:
- delayed
- disrupted
- relevant and precise.
- relevant but imprecise.
- relevant but incorrect
- irrelevant

Information Management

Approach – systems and information

Appreciating possible competing systems.

Accounting for all relevant scenarios.

Including possible adverse consequences originating from information.

Focus on how management of information might contribute to achieving objectives – options for buying information facilitating for adaptation.

Information Management

System representation

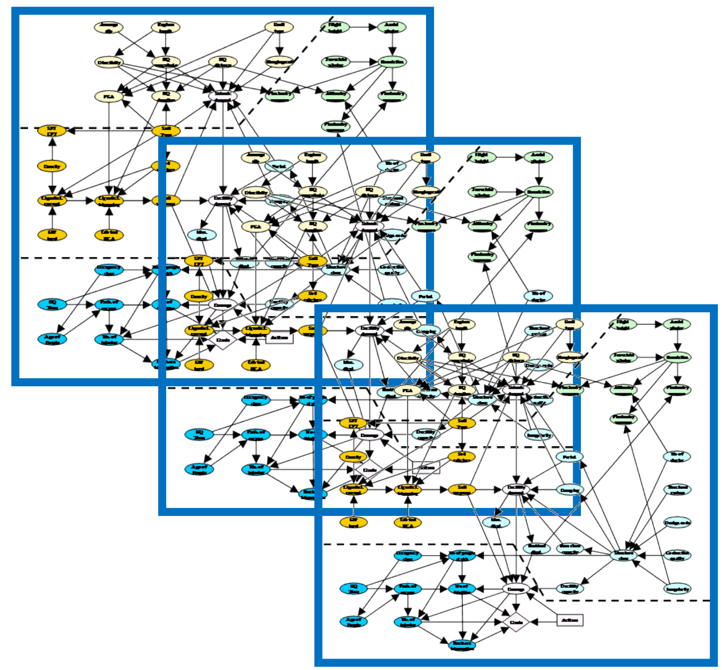
System model $\mathbf{M}(\mathbf{a}) = (\Sigma(\mathbf{a}), \mathrm{C}(\mathbf{a}), \mathbf{X}(\mathbf{a}))^{\mathrm{T}}$

Graph model $\Sigma(\mathbf{a})$

Constituents model $\mathrm{C}(\mathbf{a})$

Probabilistic model $\mathbf{X}(\mathbf{a})$

Decision alternatives $\mathbf{a}$



Information Management

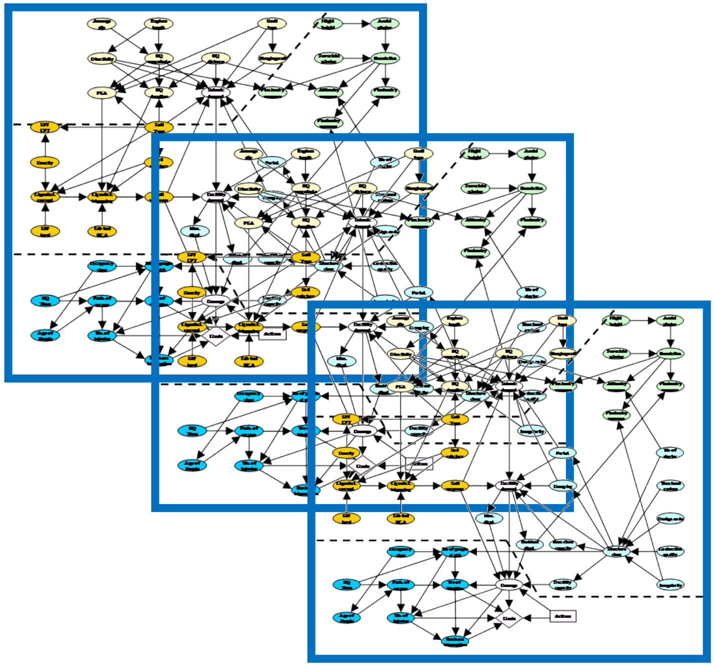
System representation

$$\mathbf{M}(\mathbf{a}) = (\Sigma(\mathbf{a}), \mathrm{C}(\mathbf{a}), \mathbf{X}(\mathbf{a}))^{\mathrm{T}}$$

- System models may be established using "bottom-up" approaches as in structural engineering or by "top-down" approaches as in data-mining

- Potentially a combination of the two approaches would be adequate

- Bayesian Networks lend themselves for system modelling in either case



Information Management

Systems representation

Top-down models – or data driven modelling approaches are usually assumed to be better that bottom-up models – ”data cannot lie”.

It is overseen that data-driven models depend entirely on the data-bases, ”experiment” plans and algorithms they take basis in – all of which are choices – and thus subjective – in the same manner as bottom-up models

Decision Analysis for Risk Management

Three situations of decision making

Before events

Strategic management
- Service life perspective
- Preventive measures

During events

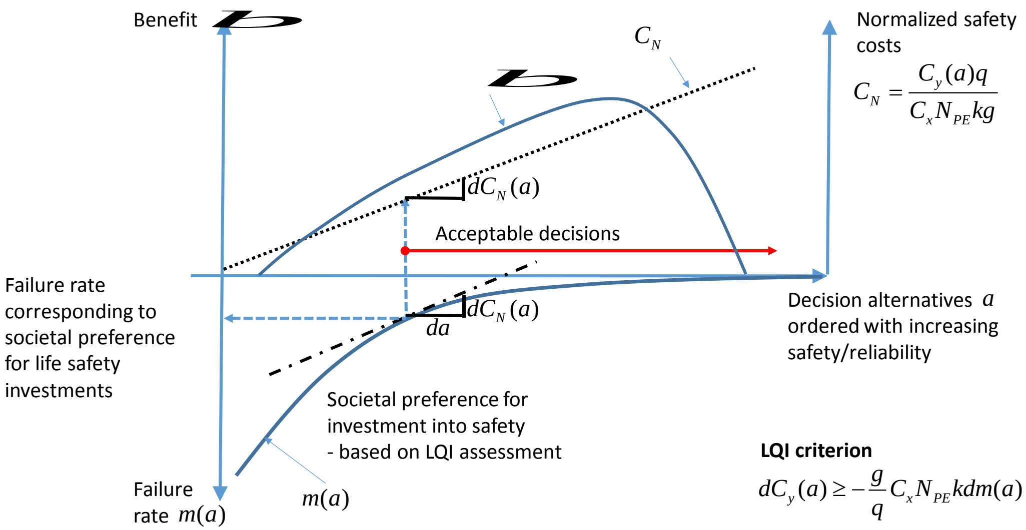
Tactical management
- Actual situation
- Loss reduction measures

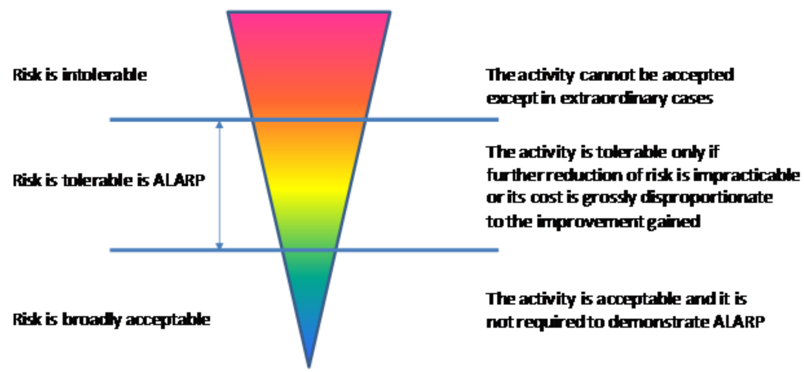
After events

Adaptation management
- Knowledge updating
- Strategic management

Decision Analysis for Risk Management

Decision ranking





ALARP assessment based on the LQI concept

$$\frac{dg}{g} + \frac{1}{q}\frac{d\ell}{\ell} \geq 0$$

Decision Analysis for Risk Management

Three types of decision analyses

1) Decision analyses based on the available knowledge
   Prior decision analysis

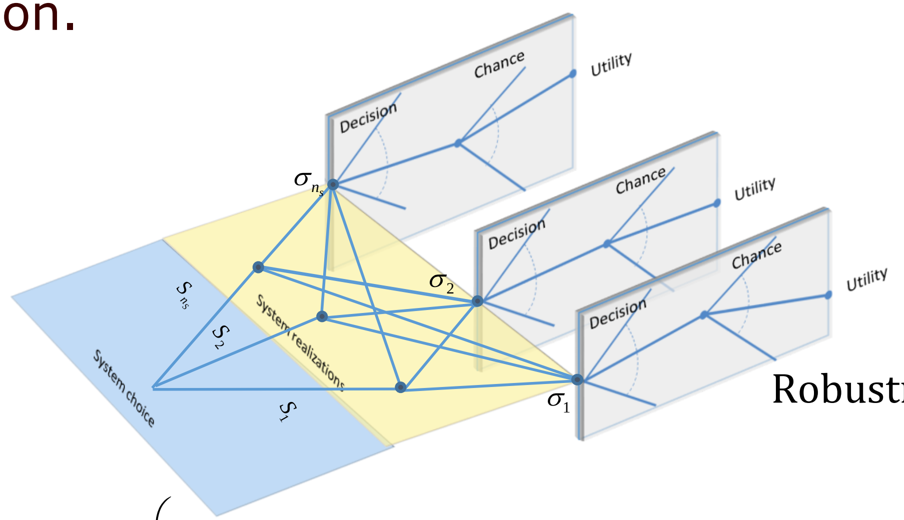
2) Decision analyses based on updated knowledge
   Posterior decision analysis

3) Decision analysis based on planned updated knowledge
   Pre-posterior decision analysis

Decision Analysis for Risk Management

Decision optimization

Bayesian decision analysis as framework for managing information.



$$\text{Robustness} = \frac{E'_{\mathbf{X}|s}(U(a^*,\mathbf{X}))}{E'_{\Sigma\backslash s}\left(E'_{X|\{\Sigma\backslash s\}}(U(a^*,X))\right)}$$

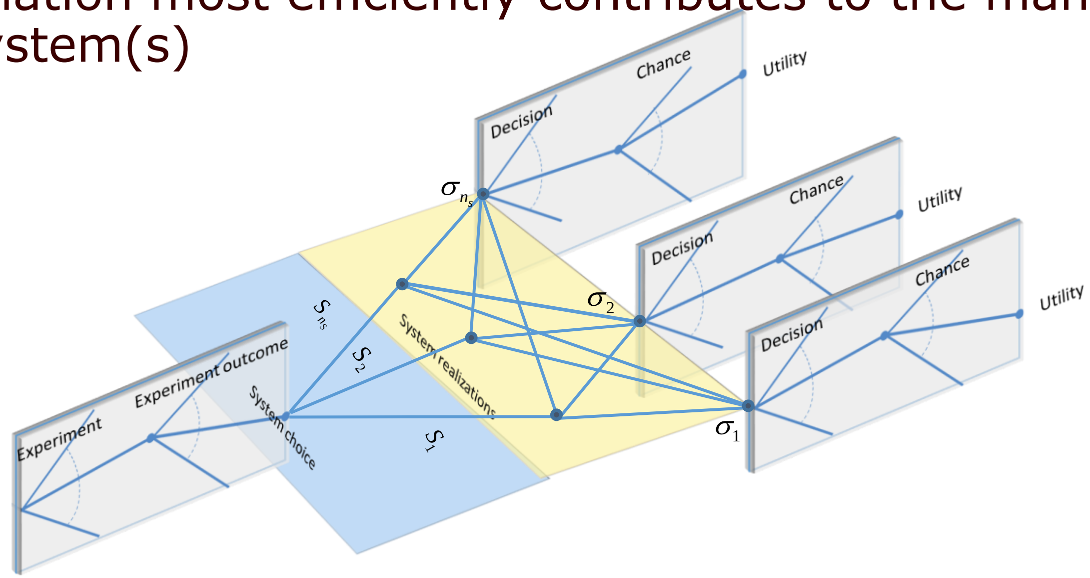
$$(s^*,a^*) = \max_s\left(P'(\Sigma = s)\max_a\left(E'_{\mathbf{X}|a}\left[U(a,\mathbf{X})\right]\right) + E'_{\Sigma\backslash s}\left[E'_{\mathbf{X}|\{\Sigma\backslash s\}}\left[U(a^*,\mathbf{X})\right]\right]\right)$$

When new information is available prior probability assignments may be updated and the importance of the different possible systems will change – as well as the probability assignments within the different possible systems

Decision Analysis for Risk Management

Decision optimization

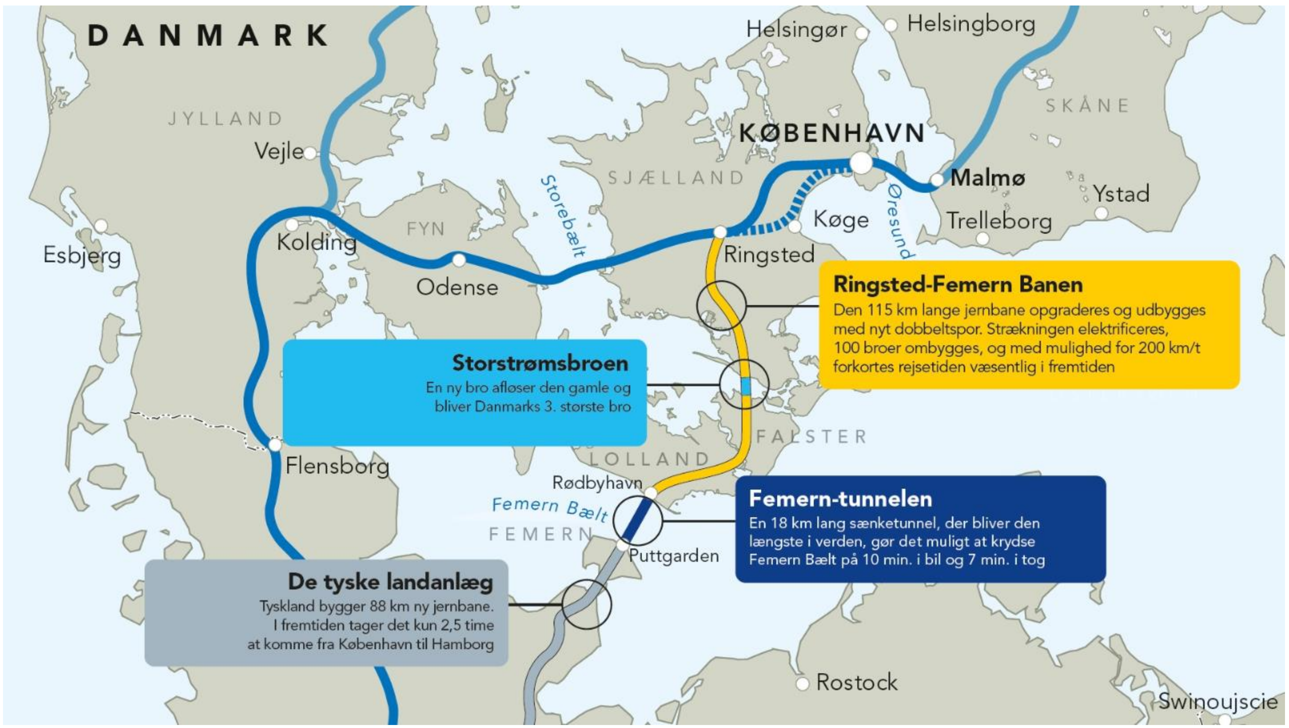
Pre-posterior decision analyses to identify how additional information most efficiently contributes to the management of the system(s)



$$(e^*, s^*, a^*) = \max_e E'_{\mathbf{Z}}\left[\max_s\left(P''(\Sigma = s|\mathbf{z})\max_a\left(E''_{\mathbf{X}|a}\left[U(a,\mathbf{X})\right]\right) + E''_{\Sigma\setminus s}\left[E''_{\mathbf{X}|\{\Sigma\setminus s\}}\left[U(a^*,\mathbf{X})\right]\right]\right)\right]$$

Digital Twin and Virtual Labs

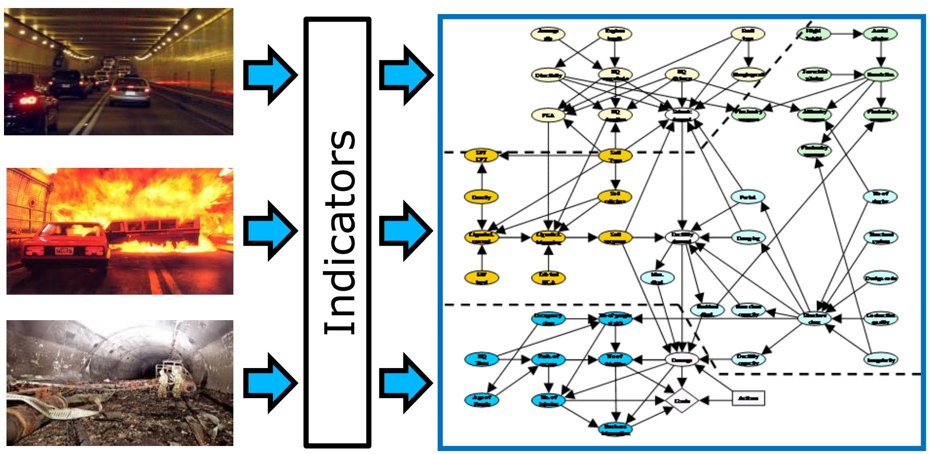
FEMERN SAFETYLAB PROJECT



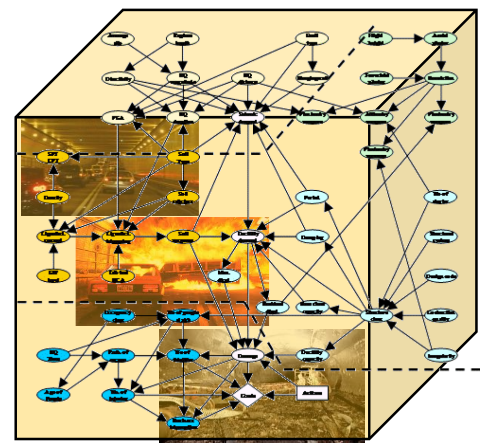
Digital Twin and Virtual Labs

System

Context



Virtual Lab



Digital Twin and Virtual Labs

FEMERN SAFETYLAB PROJECT

- **Femern SafetyLab project** is a consortium led by Dansk Brand- og Sikringsteknisk Institute (DBI).
- The **main objective** of the project is directed on the development of two technologies: ***SafetyLab*** and ***Emergency-cockpit***.

DBI BRAND OG SIKRING

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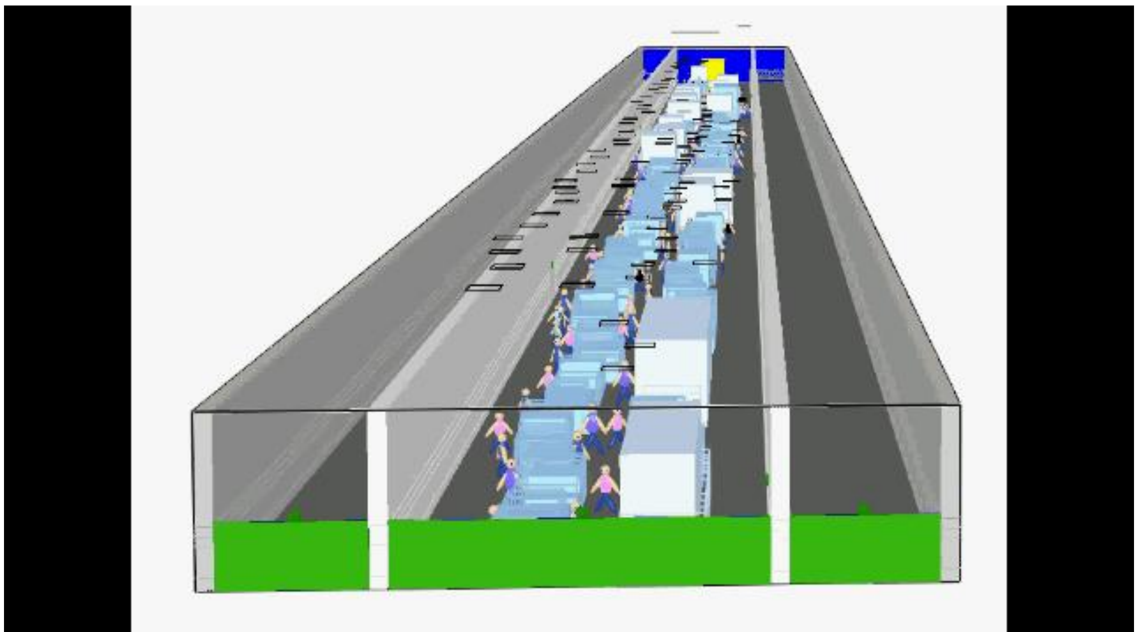
RAMBØLL

FemernBelt.net
Innovationsnetværk Femern Bælt

Digital Twin and Virtual Labs

FEMERN SAFETYLAB PROJECT



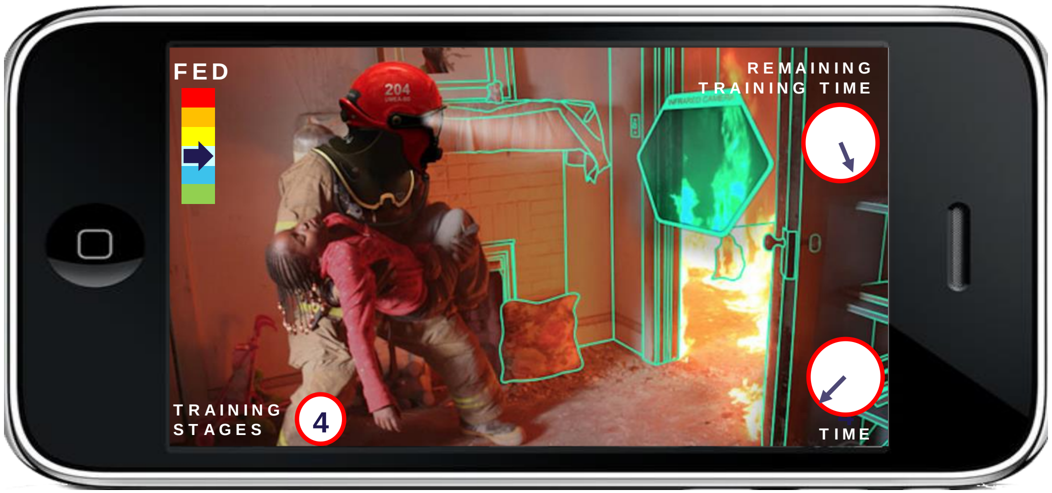
SafetyLab is a Virtual Lab – testing environment to support

- innovation in the design and implementation of new fire safety technology
- identify and optimize strategies for tactical safety management

DBI BRAND OG SIKRING · ALEXANDRA INSTITUTTET · RAMBØLL · FemernBelt.net Innovationsnetværk Femern Bælt

Digital Twin and Virtual Labs

FEMERN SAFETYLAB PROJECT



Emergency-cockpit is a VR and AR environment built around SateyLab such to facilitate:

- interaction with fire scenarios for training of fire rescue managers and personnel
- Identification and optimization of rescue strategies
- information/training of users

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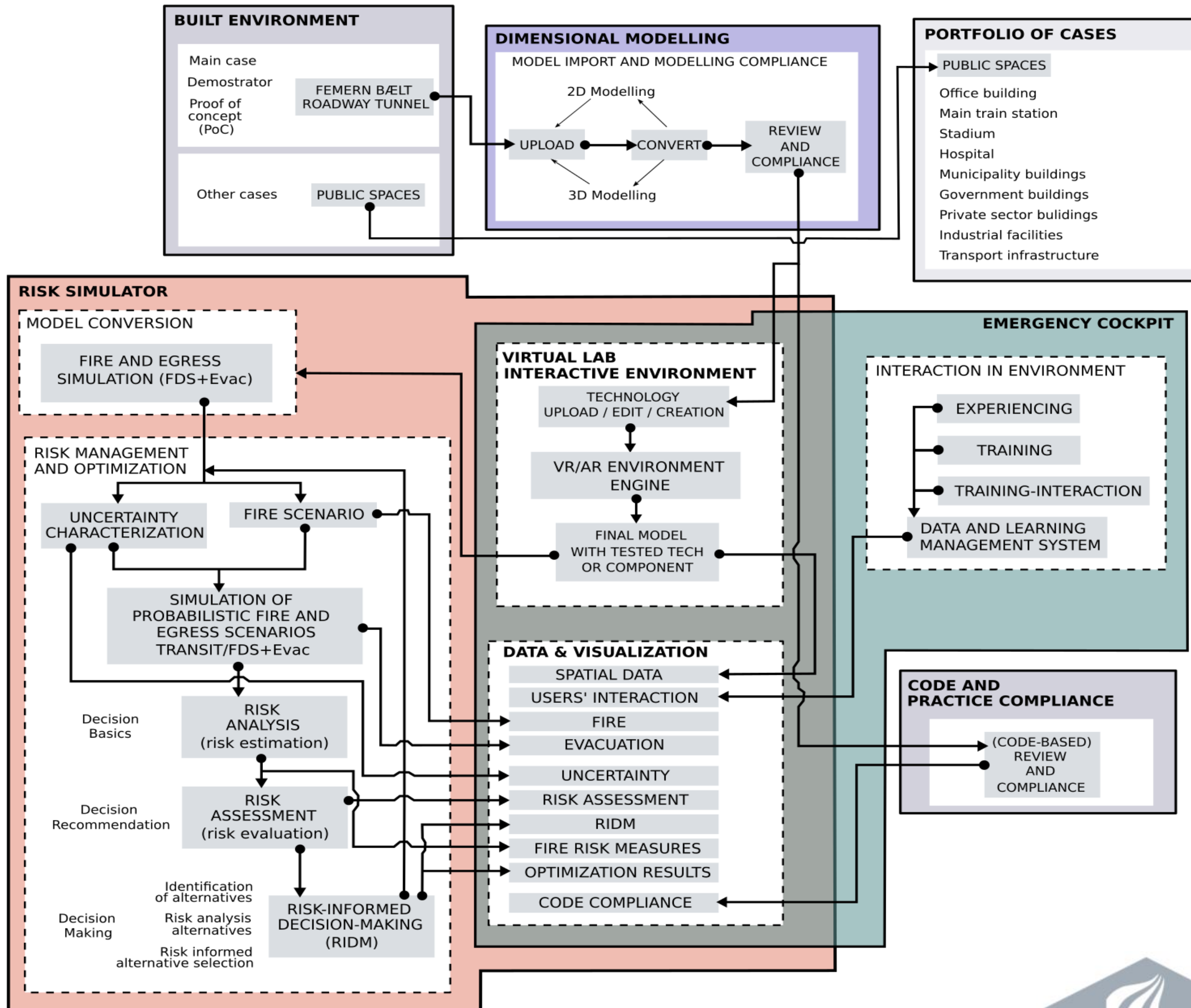
Design concept for the "Virtual Lab"



Outlook

Probabilistic system representations, decision analysis together with the LQI rationale, greatly enhances decision making on efficient safety management of the built environment

Still much work to be done to enhance systems modeling
- utilizing Bayesian Probabilistic Nets (bottom-up/top-down)
- accounting for interdependencies between systems
- linking probabilistic system models with monitoring information

Digital Twins – interfaced with VR/AR technology provide a whole new platform in support of system design, operation and maintenance as well in tactical loss reduction.

Collaborative research has strong merits in pushing developments in the direction where they are relevant and have the largest impact

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Thanks for your attention ☺

Let collaborate !

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