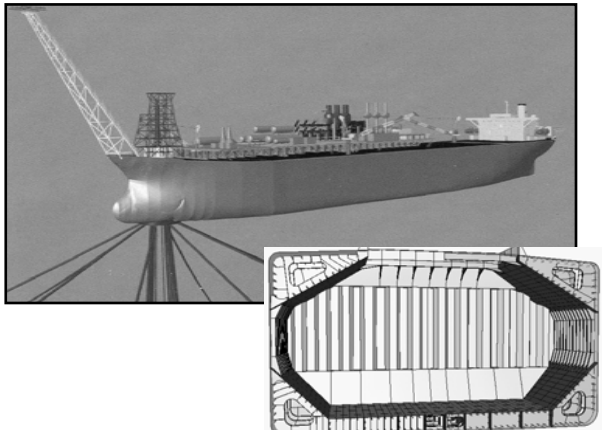
Optimal Reliability of Components of Complex Systems Using Hierarchical System Models



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Background

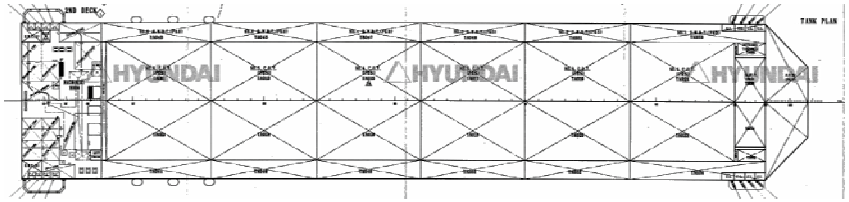
Engineered systems such as:

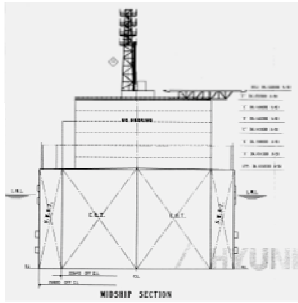
- electricity/water distribution systems
- structural systems

are complex in the sense that:

- components are functionally/geographically interrelated
- different levels of analyses provided by different experts are required.

Ship hull structure is an example:





- components/(sub-)structures are interrelated:
  - joints
  - plates
  - tanks
- different levels of analyses are required such as:
  - yielding, fracture and corrosion of materials
  - structural analysis
  - consequence analysis.

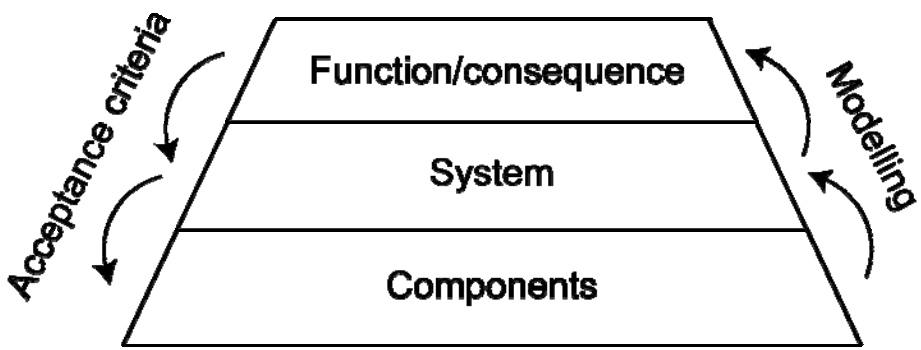
Objective

To develop a framework for optimization of engineered systems.

- What are effectively designed are *components*.
- Acceptance criteria are often given for *system performance* and
- *system performance* is our direct concern.

Objective

The bridge between component and system performance needs to be developed.



Clues

The proposed framework relies on the typical characteristics that

- individual components are standardized
- components are hierarchically interrelated

and takes basis in the fact that system performance depends on

- way of interrelation between components
- reliability of components.

Approach

- Modelling of complex systems by Bayesian probabilistic Networks
- Consideration of a-priori given acceptance criteria for system performance
- Setting up an optimization problem

Bayesian probabilistic network:

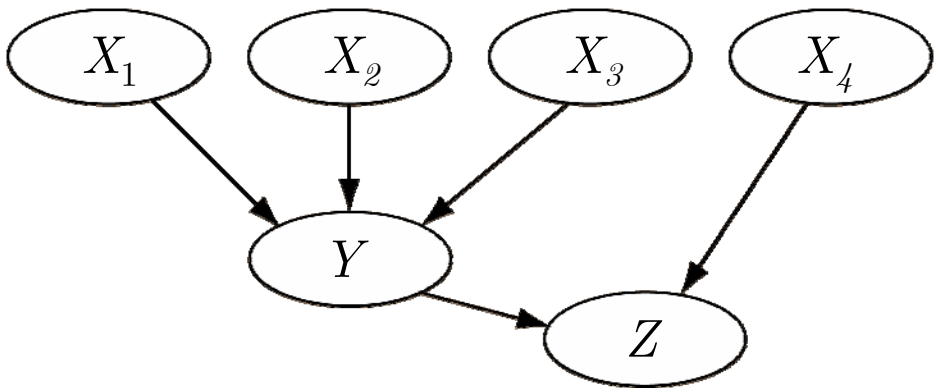
- is a graphical representation of probabilistic structure of variables by nodes and arrows
- is quantitatively characterized by conditional probability tables
- can provide e.g. expected value, conditional probability

Object-oriented Bayesian probabilistic network:

- is useful when a structure has many identical (sub-) structures/components.

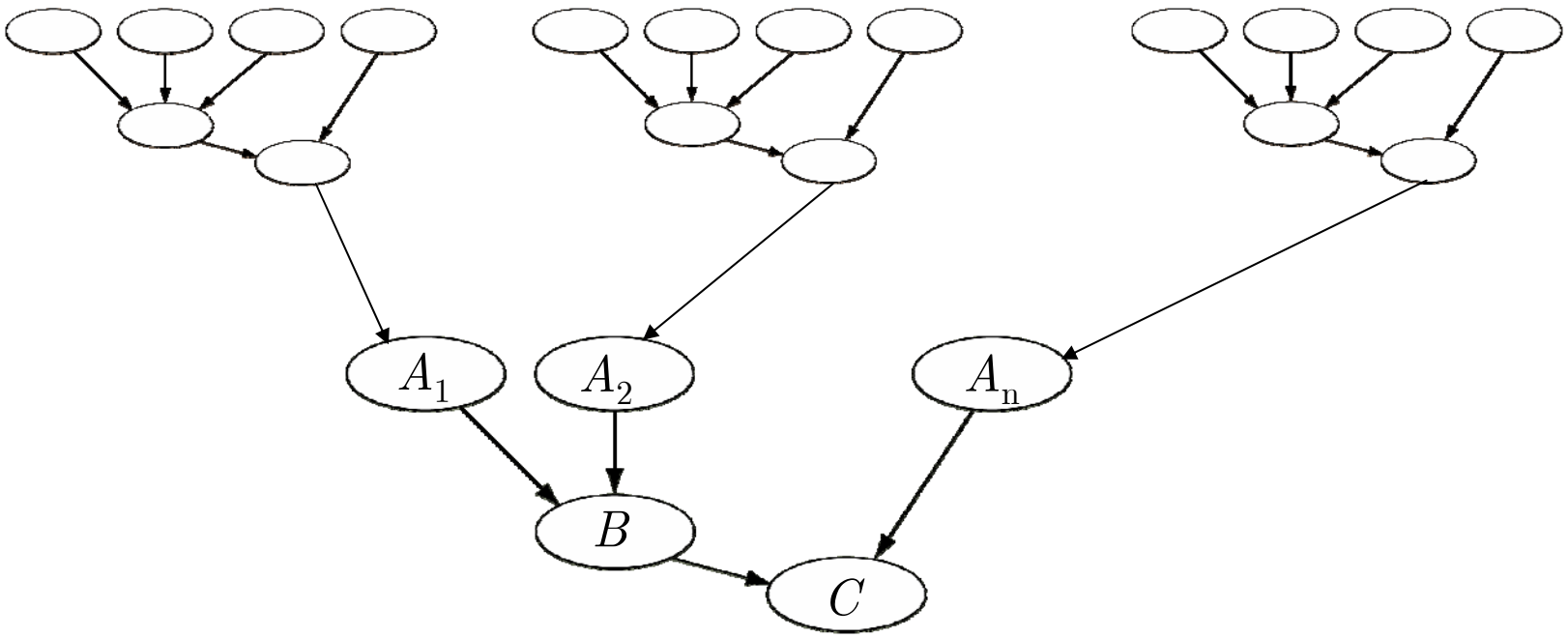
Hierarchical modeling by use of Bayesian probabilistic network

- Component level



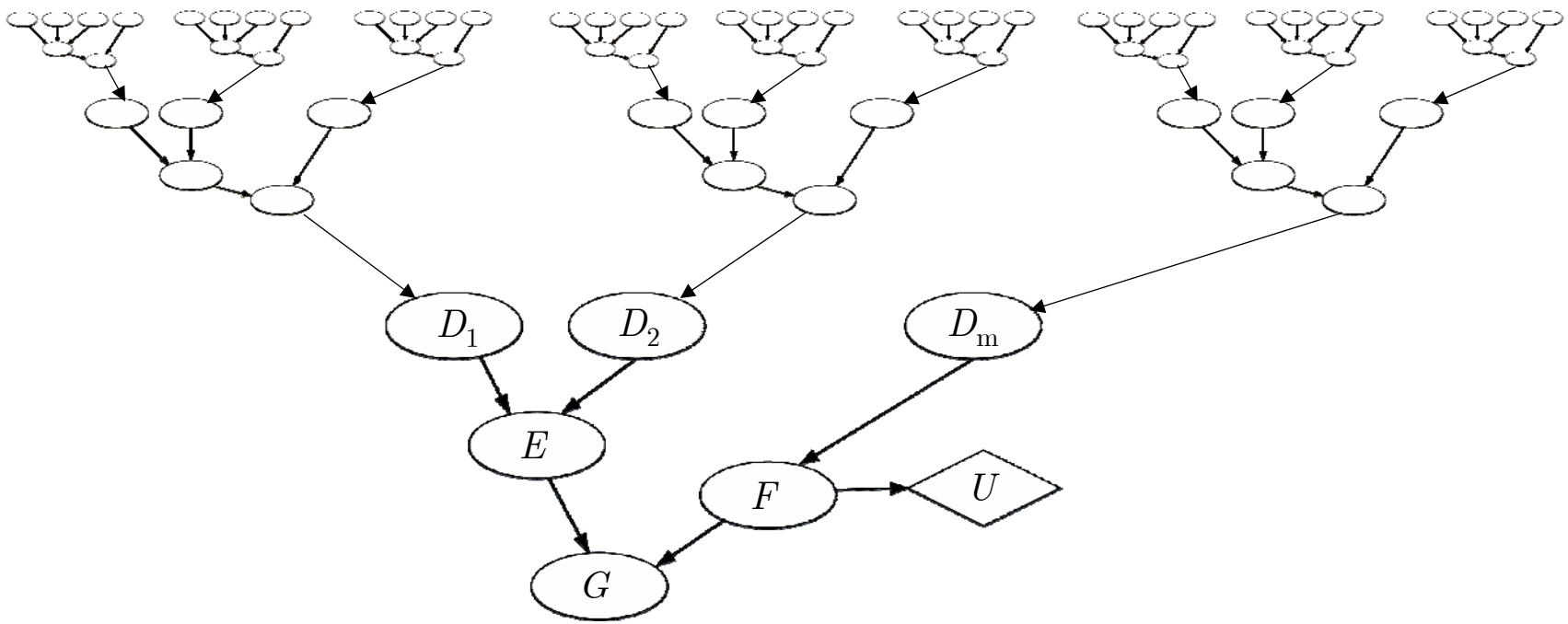
Hierarchical modeling by use of Bayesian probabilistic network

- Sub-structure level

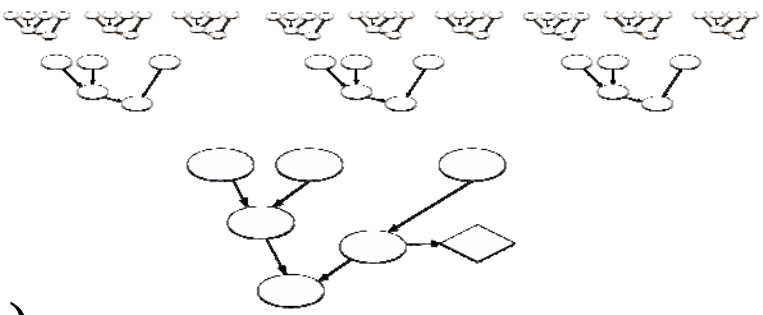


Hierarchical modeling by use of Bayesian probabilistic network

- Structure level



On Bayesian probabilistic networks:



expected total cost is written as:

$$u = f(x_1, x_2, ..., x_N)$$

where x_i is design variable for components, e.g. component reliability.

acceptance criteria for system performance are written as:

$$g_j(x_1, x_2, ..., x_N) \leq c_j$$

Optimization of component reliability can be reduced to be a standard constrained optimization problem:

Minimize $$u = f(x_1, x_2, ..., x_N)$$

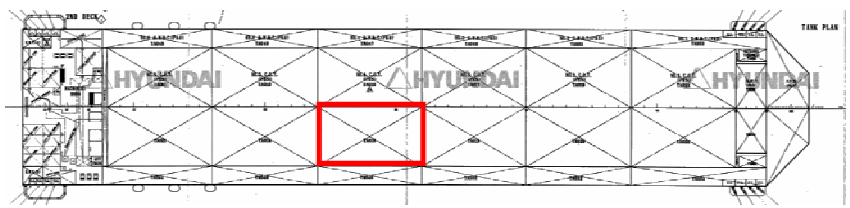
such that $$g_j(x_1, x_2, ..., x_N) \leq c_j \quad ,(j = 1, 2, ..., M)$$

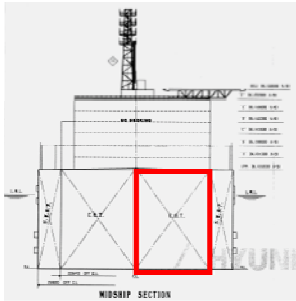
→ solving the optimization problem with commonly available techniques, e.g. Microsoft Excel and Hugin.

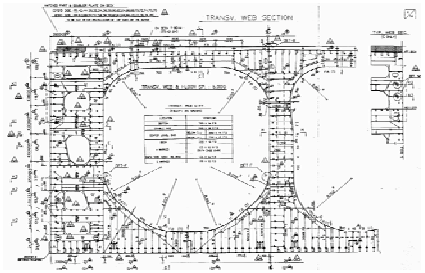
Optimization of reliability of welded joints in ship hull structure

Acceptance criterion: probability of failure of ship hull < 10^{-3}/yr

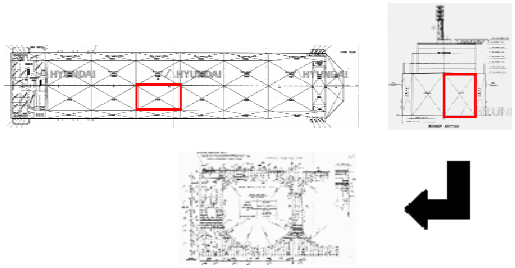
Objective function : expected total cost

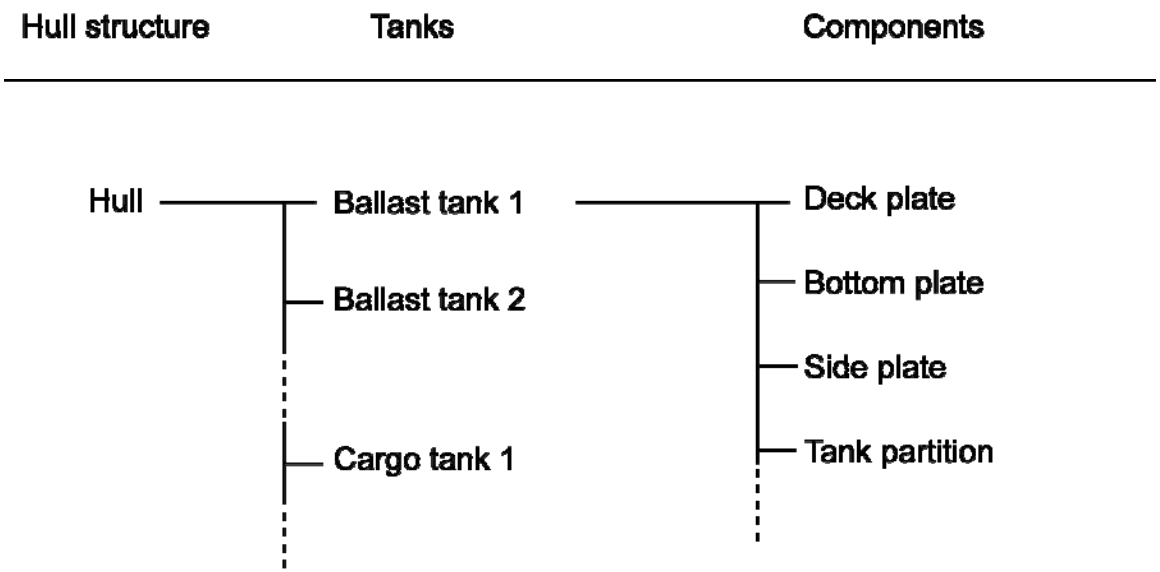




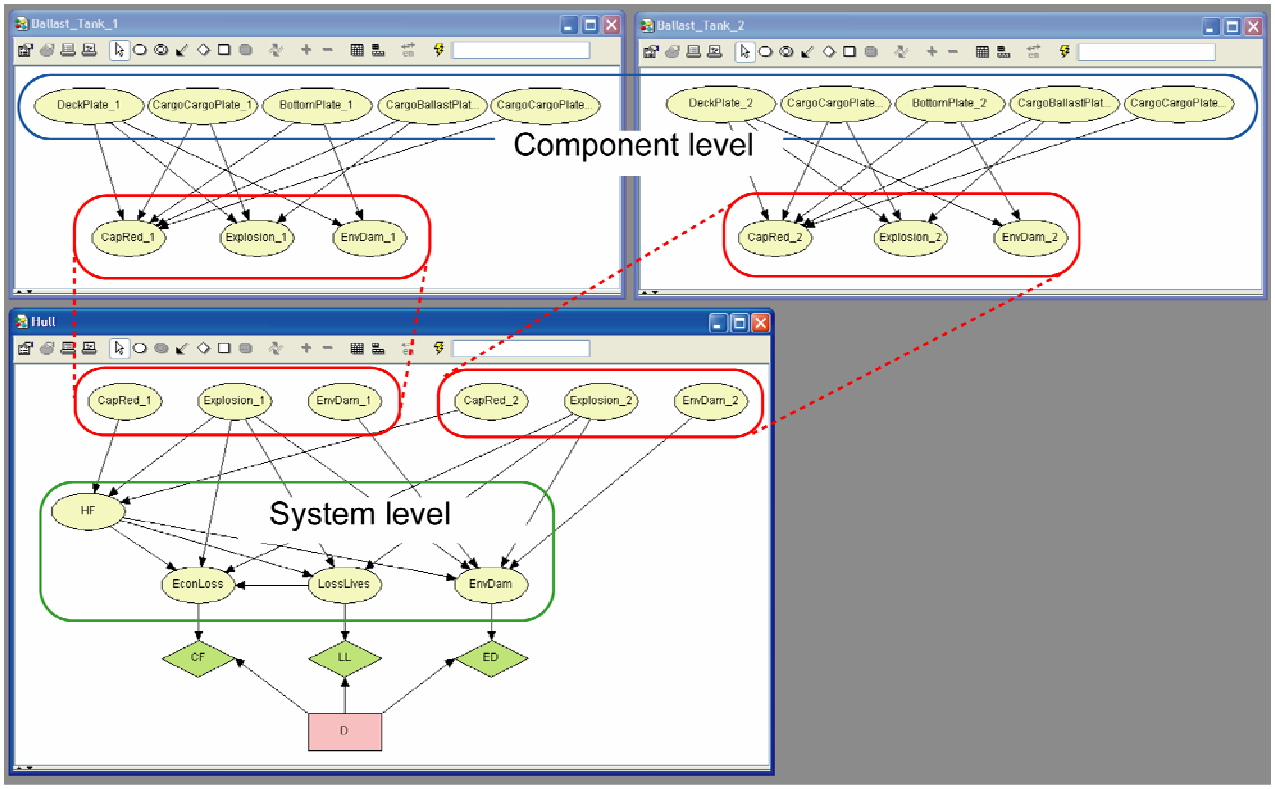


Hierarchical structure of the ship hull:

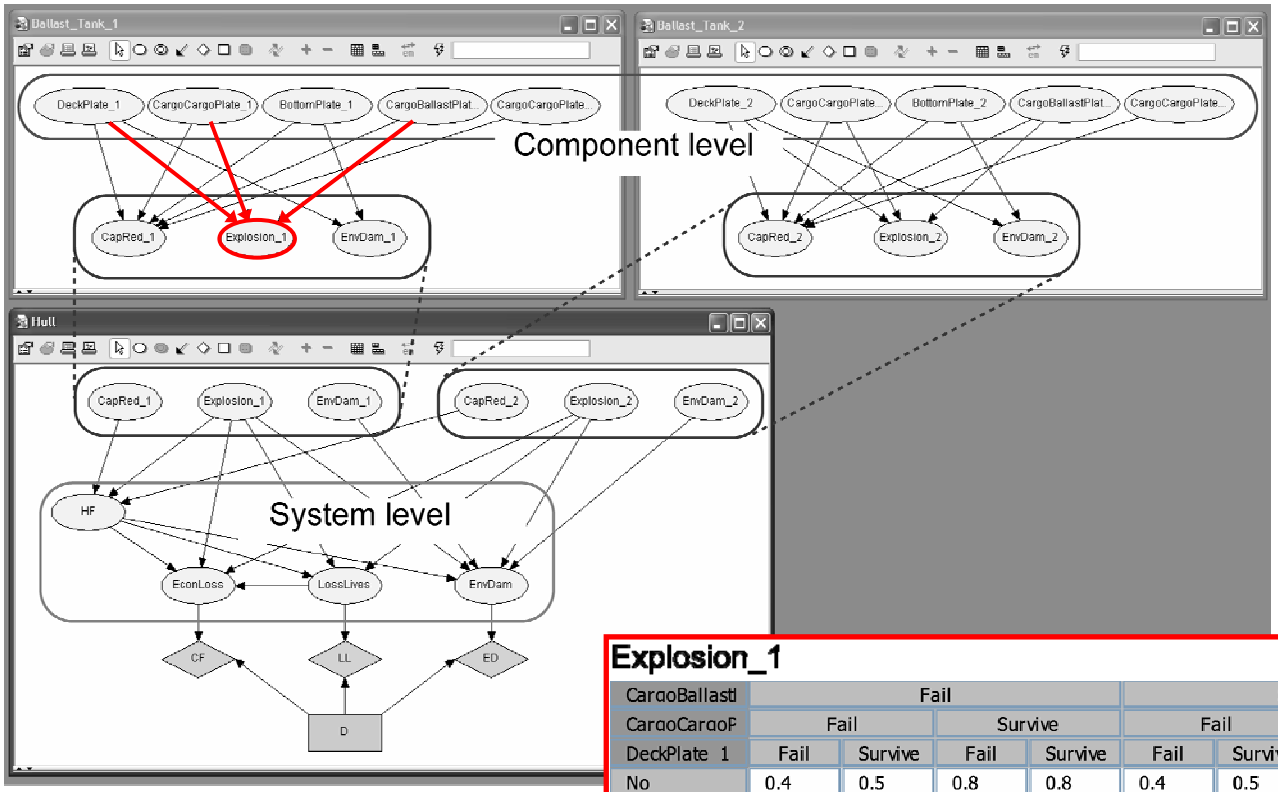




Corresponding BPN's:



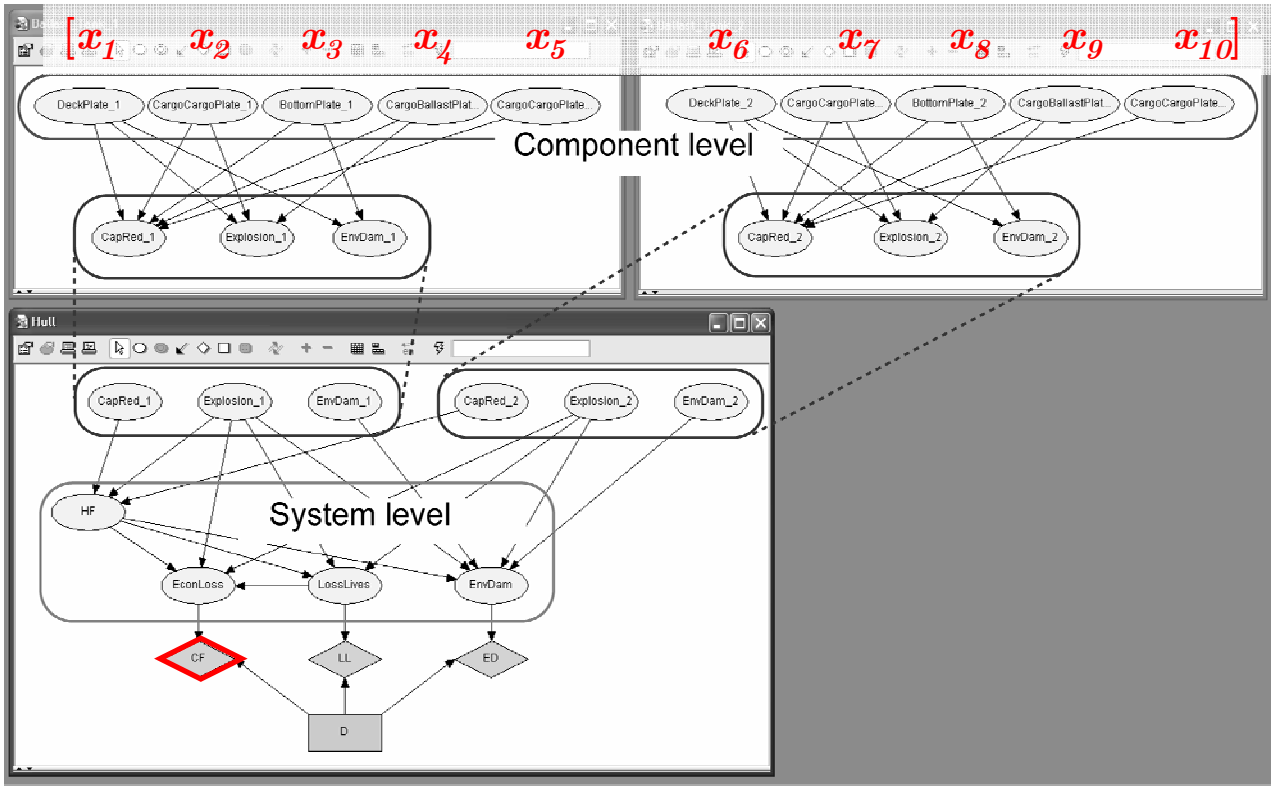
Conditional probability table



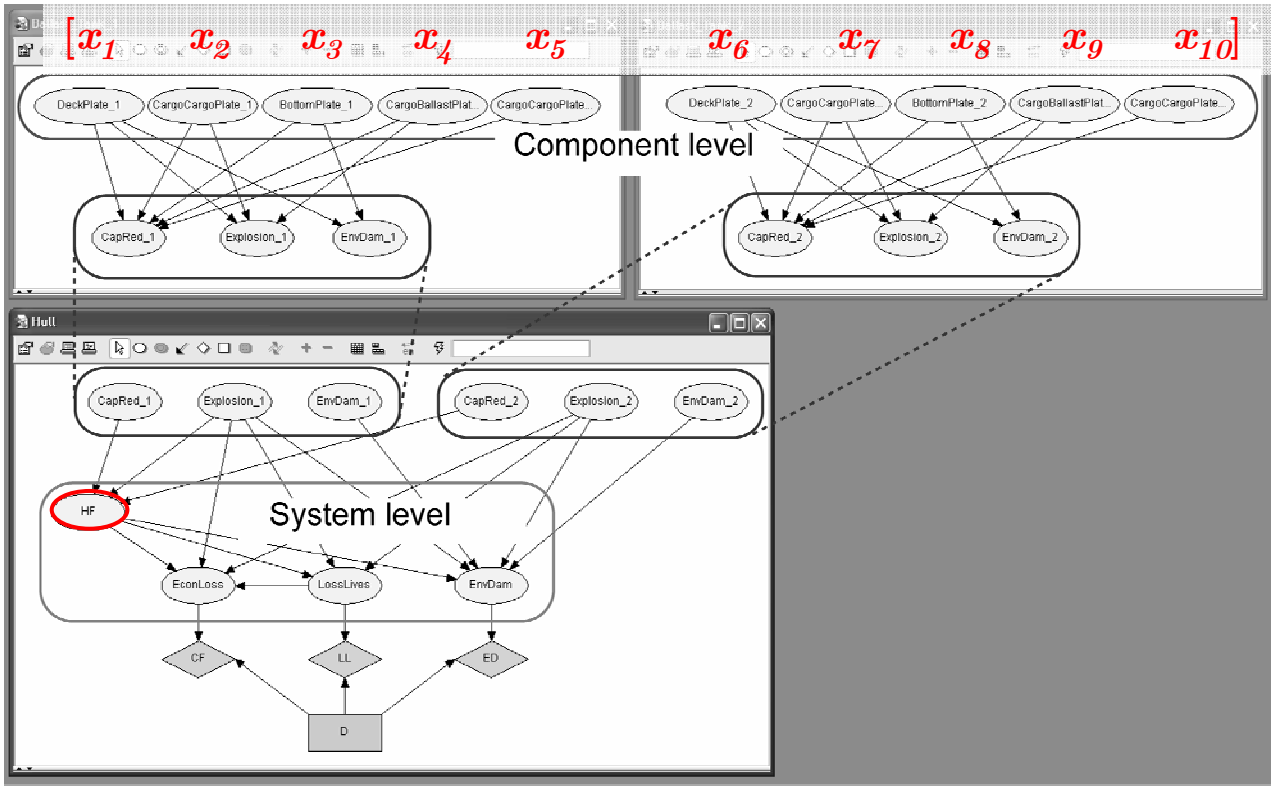
Explosion_1

CargoBallastl	Fail				Survive			
CargoCargoP	Fail		Survive		Fail		Survive	
DeckPlate_1	Fail	Survive	Fail	Survive	Fail	Survive	Fail	Survive
No	0.4	0.5	0.8	0.8	0.4	0.5	0.6	1
Minor	0.5	0.45	0.1	0.19	0.55	0.49	0.35	0
Major	0.1	0.05	0.1	0.01	0.05	0.01	0.05	0

Objective function: $u = f(x_1, x_2, \ldots, x_{10})$

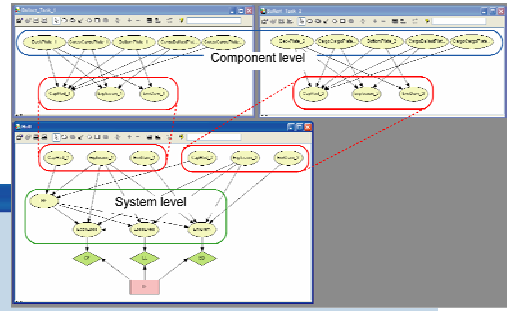


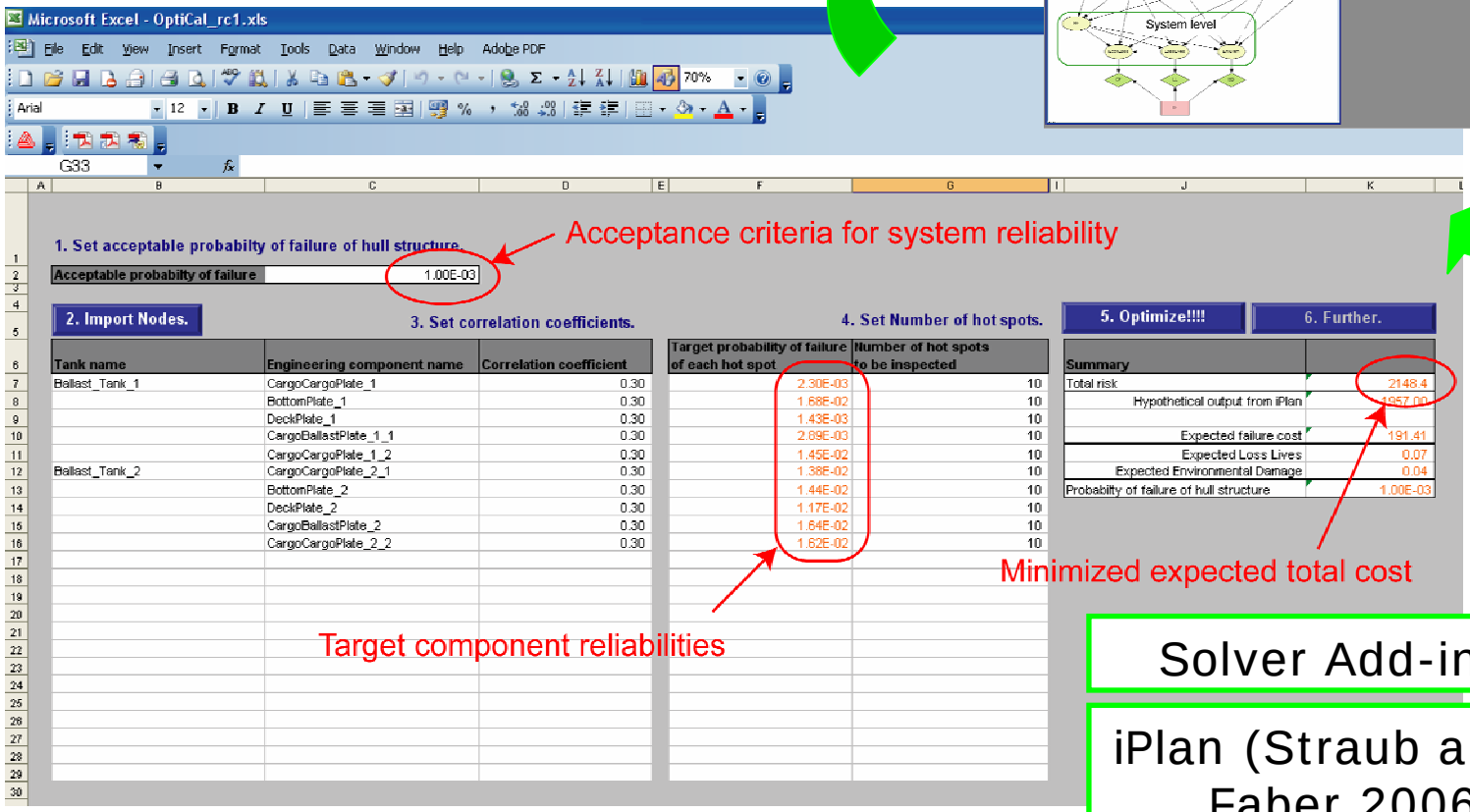
Constraints: $g(x_1, x_2, ..., x_{10}) \leq c$



Excel platform

ActiveX





Solver Add-in

iPlan (Straub and Faber 2006)

- Use of BPN

  Engineered system can be hierarchically modelled by use of BPN and especially by object-oriented BPN.

- Standard constrained optimization

  - Objective function: expected total cost
  - Constraints: acceptance criteria for system performance
  - Variables: component reliability

- Use of commonly available techniques/algorithms

  For example, Hugin and Microsoft Excel.