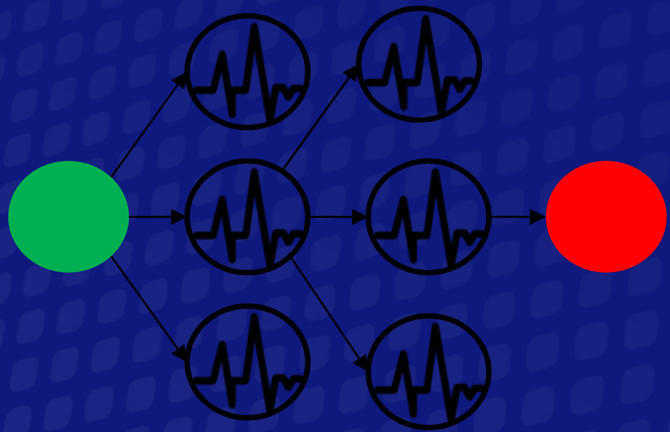
Seeking Rare Events in a Simulated System using Risk Distances



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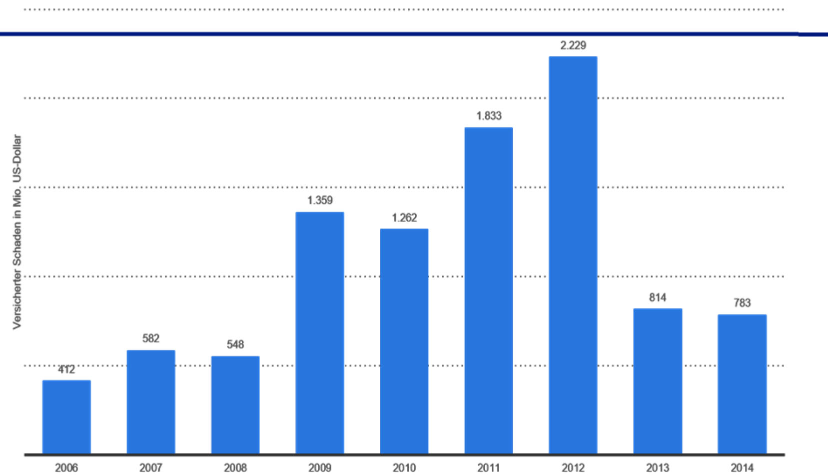
Motivation and Problem Definition

- Accidents are part of the maritime domain
  - Despite high safety standards
- Worldwide insurance losses very high
  - 2014: 783 million US dollars
- Dangers of the maritime domain occur in many forms
- Some dangers of the maritime domain are often neglected - in risk analysis
  - Reason: Appearance very rare
- Investigation too time-consuming and therefore very cost-intensive



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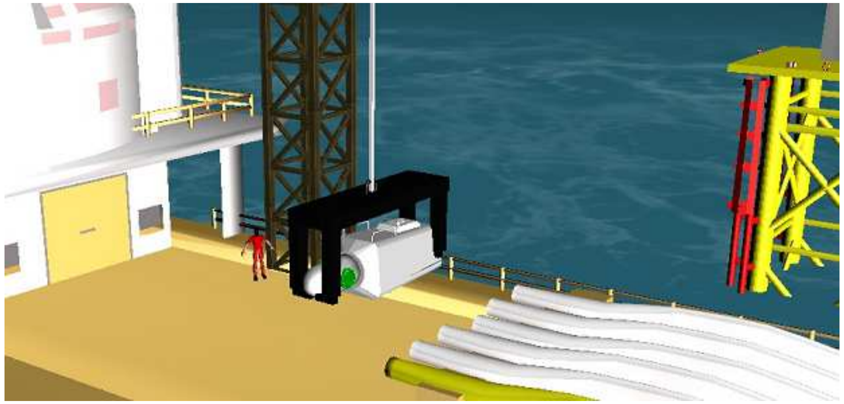
Agenda

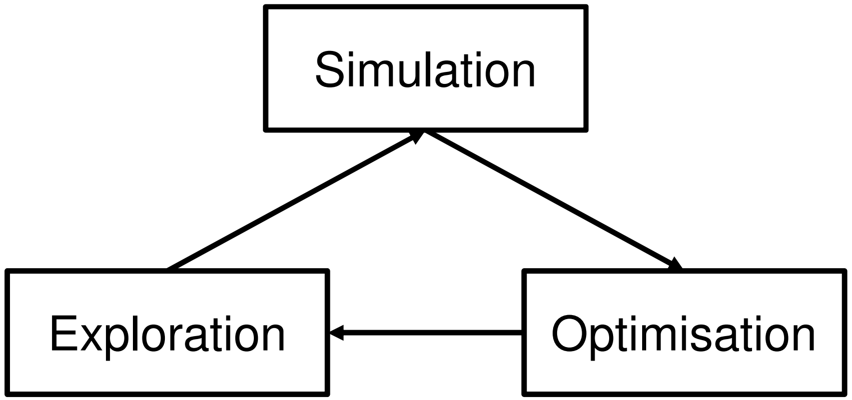
- Motivation and problem definition
- **Approach**
- Methodology for determining risk distances in simulations
- Validation
- Conclusion and outlook

Solution approach for simulative risk analysis
Simulation

Consideration of
- physical connections,
- environmental factors,
- and human behavior

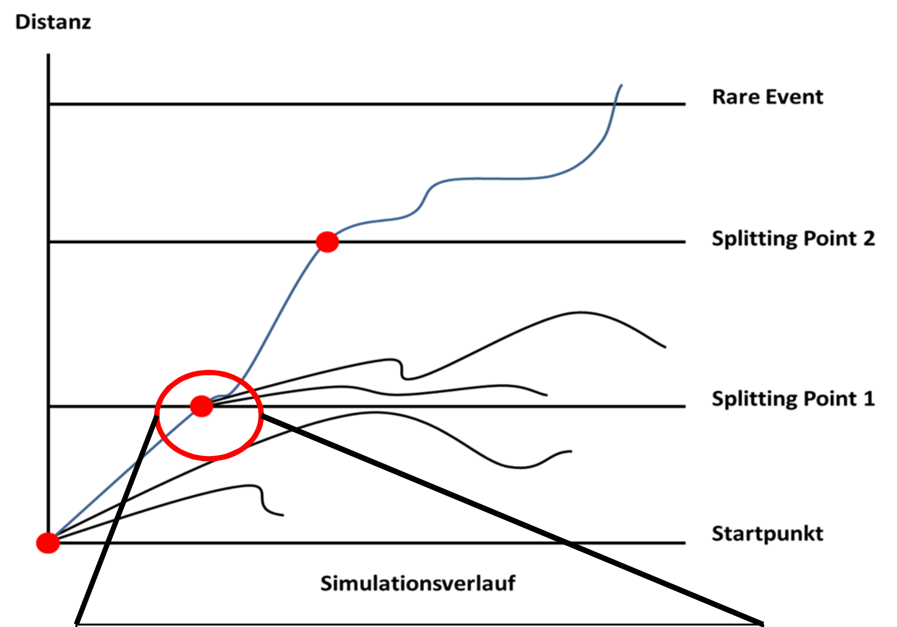


Naive simulation very time-consuming
- Continuous Space
- Consideration of non-deterministic behavior
- A lot of time can pass before a rare risky situation occurs



Solution approach for simulative risk analysis
Rare Event Simulation

- Rare Event Simulation
  - Methods for reducing the number of simulation runs
- Import Splitting
  - Iterative approximation of rare events
  - Discarding of less promising trajectories



Question:
- How can such a Splitting Point be described?
- How is it determined?

SHAHABUDDIN, PERWEZ: Rare Event Simulation in Stochastic Models. In: *Proceedings of the 27th Conference on Winter Simulation, WSC '95*. Washington, DC, USA : IEEE Computer Society, 1995 — ISBN 0-7803-3018-8, S. 178–185

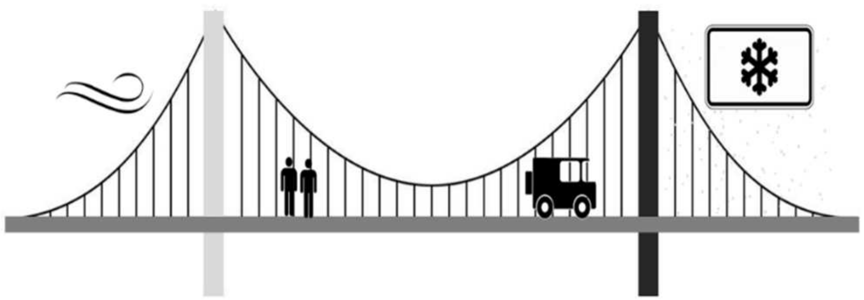
JEGOUREL, CYRILLE ; LEGAY, AXEL ; SEDWARDS, SEAN: Importance splitting for statistical model checking rare properties. In: *Computer Aided Verification* : Springer, 2013, S. 576–591

JUNEJA, SANDEEP ; SHAHABUDDIN, PERWEZ: Rare-event simulation techniques: an introduction and recent advances. In: *Handbooks in operations research and management science* Bd. 13 (2006), S. 291–350

Solution approach for simulative risk analysis

Semi-probabilistic safety concept

- Evaluation of building structures
- Evaluation criteria are used to determine the ultimate limit state of the bearing capacity
- Various actions are evaluated in terms of their relevance
- transfer to risk distance functions:
  - Combination of several partial risks
  - Each sub-risk defines limit states



KLUG, YVETTE: *Lastannahmen nach neuen Normen: Grundlagen, Erläuterungen, Praxisbeispiele ; Einwirkungen auf Tragwerke aus: Eigen- und Nutzlasten, Wind- und Schneelasten, Erdbebenlasten*, 2007 — ISBN 978-3-89932-130-2

DIN EN 1990/NA Nationaler Anhang - National festgelegte Parameter - Eurocode: Grundlagen der Tragwerksplanung. Bd. DIN EN 1990/NA, Ausgabe 2010–12, 2012

Scientific questions

1. How can the distance to high-risk situations in the runs be defined and determined?

2. How can the distances determined be used to speed up risky situations?

Basic conditions and requirements

Requirements for the approach

- Correlated risk occurrence and risk distance
- Use of risk distances as a basis for simulation control
- Support of Black-Box simulators

Requirements for the (co-) simulations

- Observability of the (co-) simulation
- Controllability of the (co-) simulation
- Calculability of the distance to risk

Solution Approach

Methodology for the simulative analysis of risks in simulations

Based on:

Importation Splitting Technique
for conducting black box simulations of critical situations

Information Retrieval Technology
for a quick evaluation of two situations regarding their similarity

Distance functions
to evaluate situations in terms of their proximity to critical situations

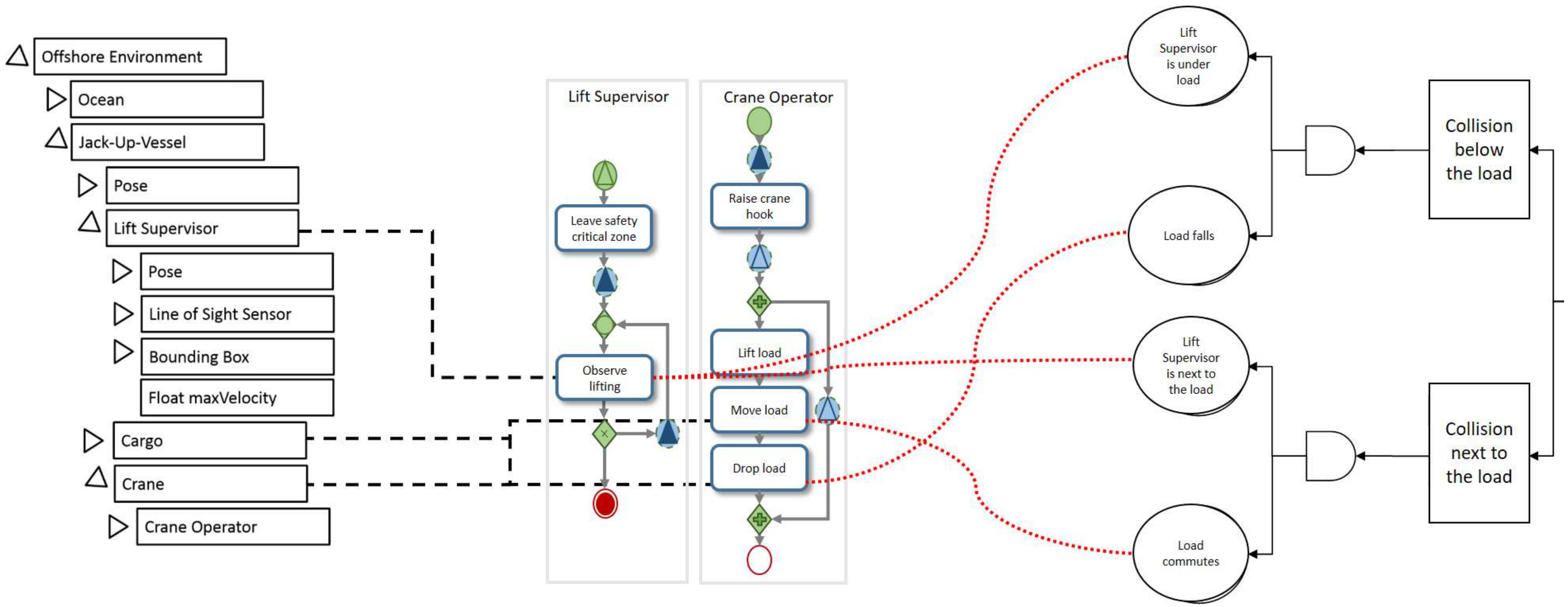
Semi-probabilistic security concept
to define the risk distance functions

Modeling of the system to be analyzed → Risik Distance description → Simulative Analysis

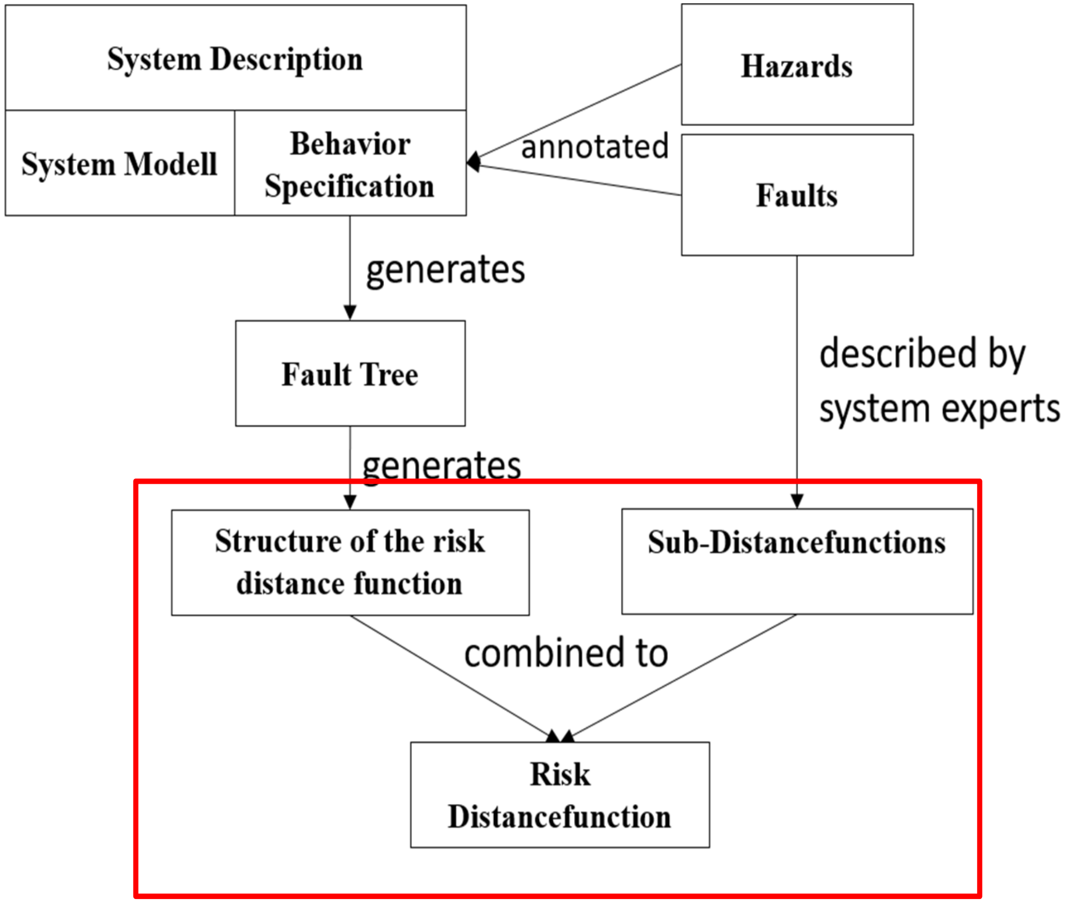
- Modeling of the system to be analyzed
  - System, behavior and hazard description
- Risik Distance description
  - Determined risk distance function
- Simulative Analysis
  - Description of the simulation process

Solution Approach
Preliminary Work

System Description **Behavior Specification** **Generated Fault Tree**



Solution Approach- Influences on the risk distance function



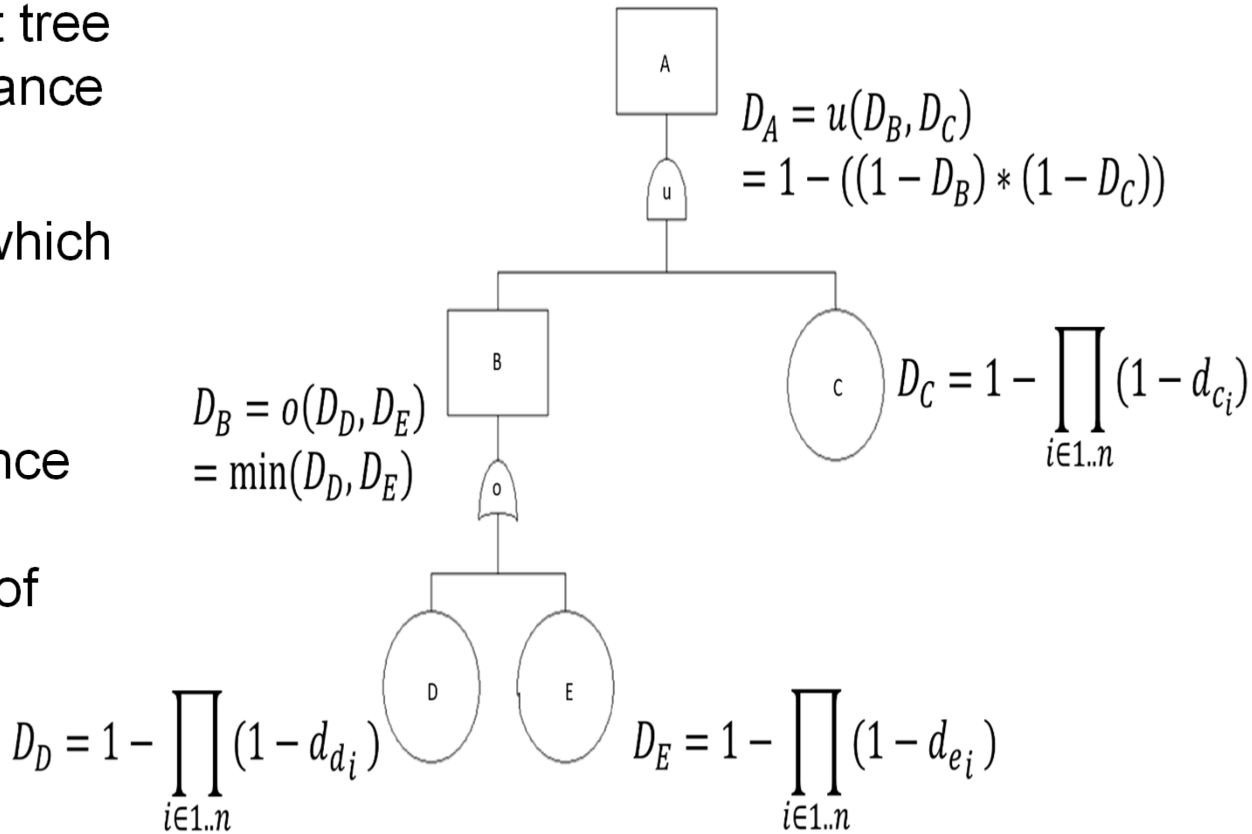
Use of the system and behavioral description including annotated hazards and causes to create the risk distance function

Solution Approach – *Structure of the risk distance function*

Relationship between fault tree and structure of a risk distance function

D^X is a distance function which describes the fault tree element X

d^Y describes the subdistance functions to be added to describe a leaf element Y of the fault tree.



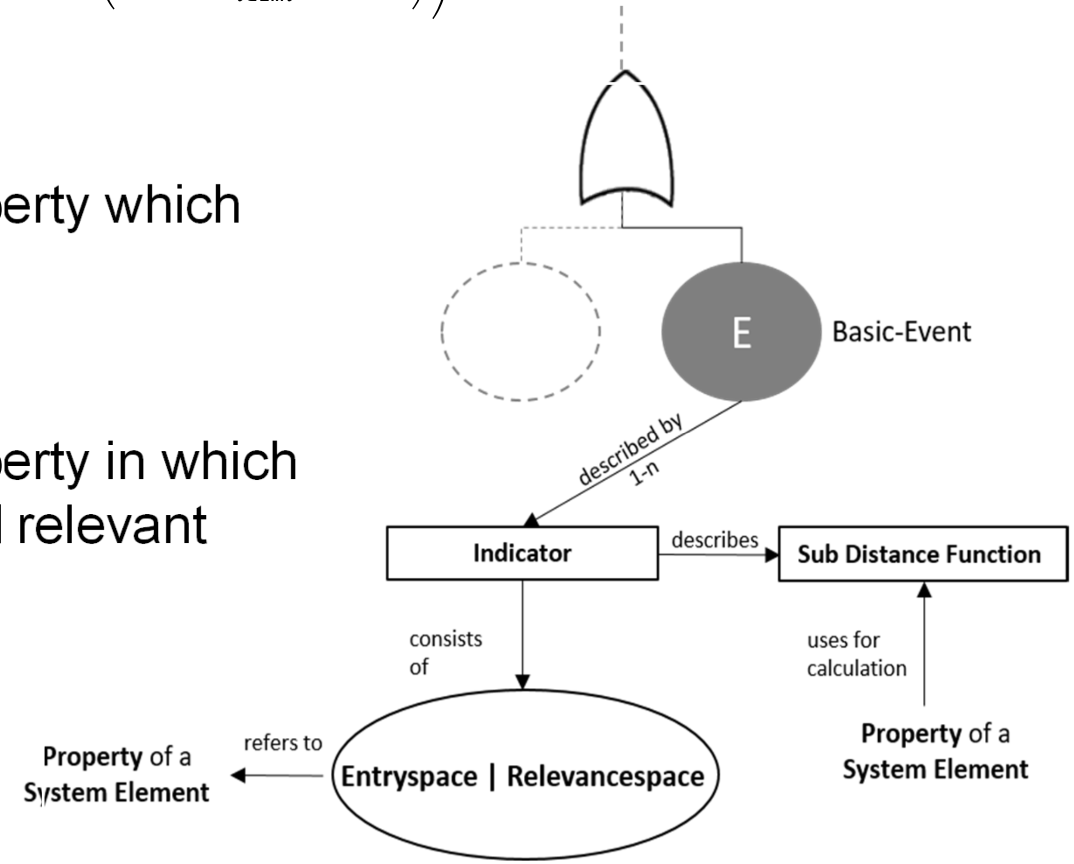
Solution Approach – *Description of sub-risks*

$$D^A = 1-\left(\left(1-\min\left(1-\prod_{i\in 1..n} 1-d_{d_i},\, 1-\prod_{i\in 1..n} 1-d_{e_i}\right)\right) * \left(1-\left(1-\prod_{i\in 1..n} 1-d_{c_i}\right)\right)\right)$$

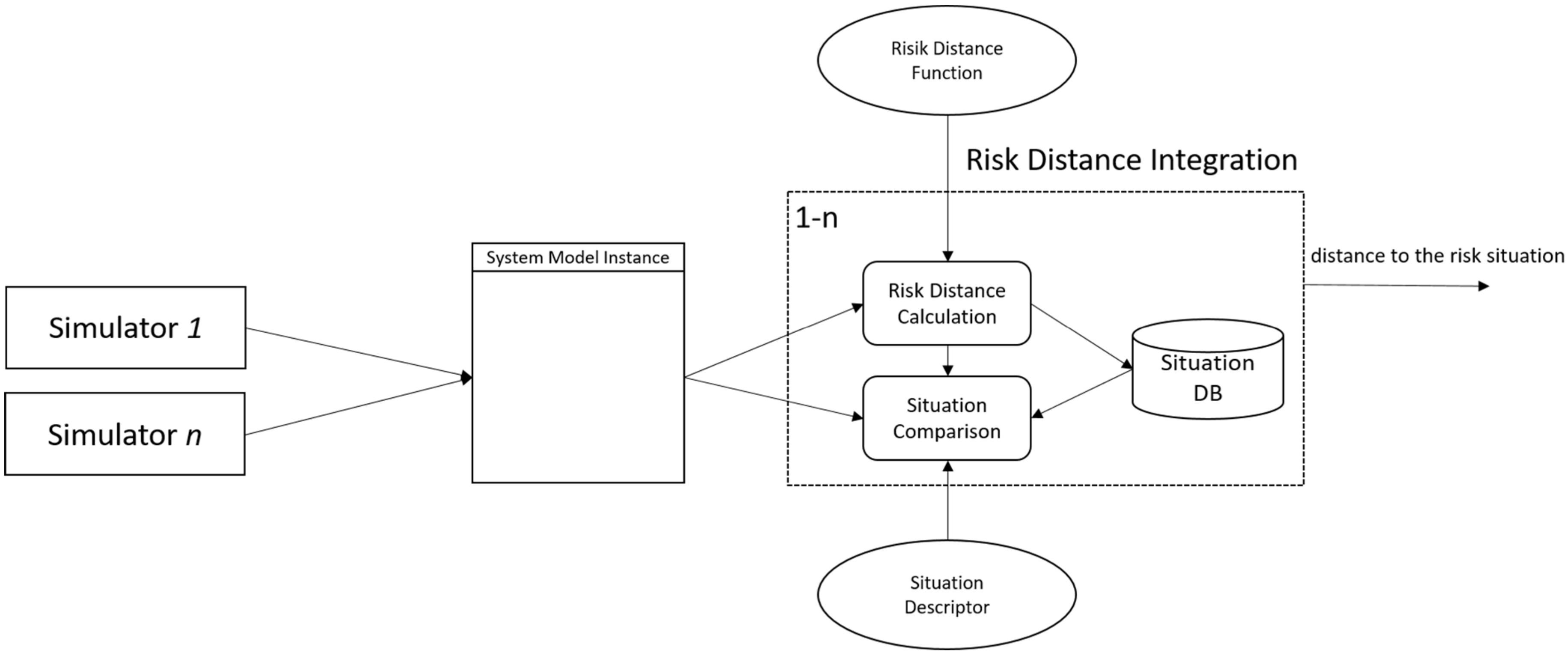
Entrance space:
Defines the value range of a property which favors the described cause

Relevance space:
Defines the value range of a property in which the proximity to risk is considered relevant

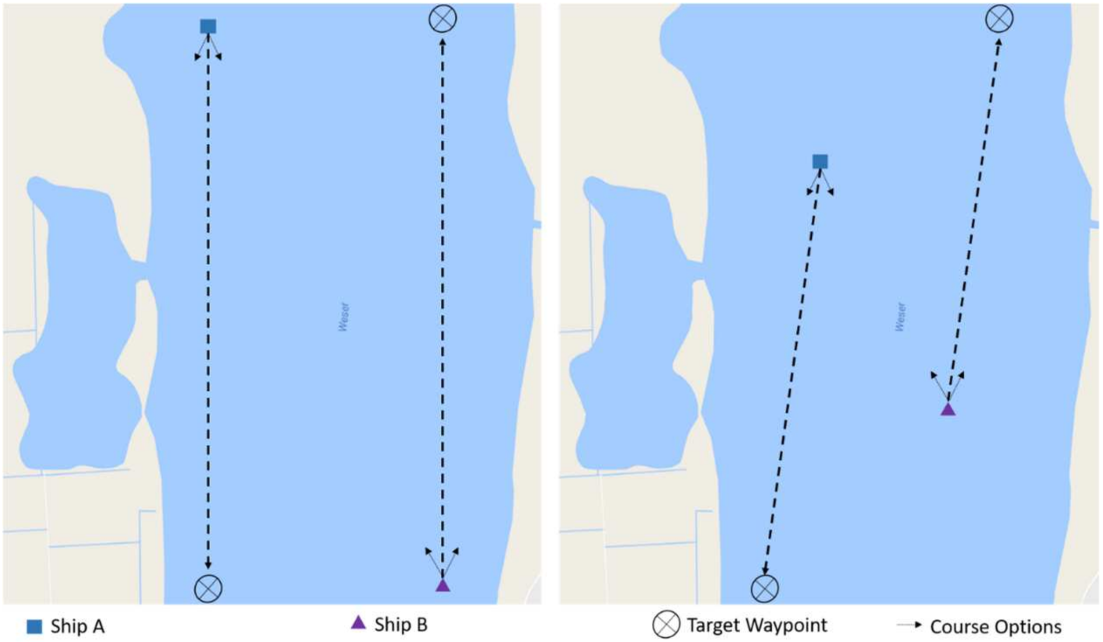
$$d_{D_i} = \begin{cases} 0, if\ \ X \geq E_{D_{min}}(Y) \wedge X \leq E_{D_{max}}(Y) \\ 1, if\ X \leq R_{D_{min}}(Y) \vee X \geq R_{D_{max}}(Y) \\ \min\left(\frac{\left(X - E_{D_{min}}(Y)\right)}{\left(R_{D_{min}}(Y) - E_{D_{min}}(Y)\right)}, \frac{\left(X + E_{D_{max}}(Y)\right)}{\left(R_{D_{max}}(Y) - E_{D_{max}}(Y)\right)}\right), else \end{cases}$$



Solution Approach- *Risk distance evaluation in a co-simulation environment*



Validation – *Scenario*

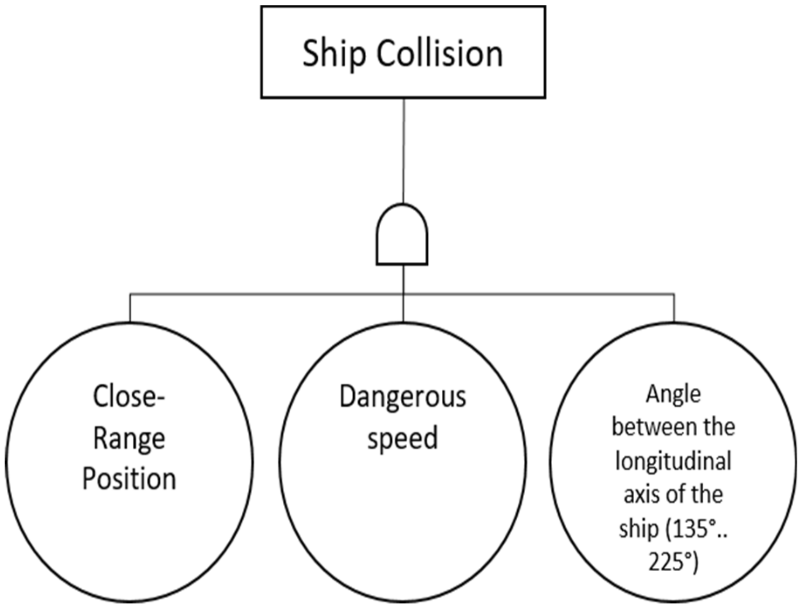


The two ships involved try to reach their destination. With a very low probability, the ships depart to the left or right of their course.
The event that was investigated in this evaluation was a collision between the two ships, which should be observed within this evaluation 100 times under the respective simulation settings.

Validation – *Simulation Settings*

- The simulation settings consisted of a naive and a guided simulation
- Three variants of how to determine the next splitting point
  - an adaptive method, which in each simulation step checks whether a lower risk distance evaluation has been achieved than before
  - and, secondly, a method, which has applied the splitting points at predetermined intervals (0.01 and 0.05)
- In all methods, except for the naive simulation, a new simulation run was started when a state with a new lower risk distance was reached in the case of the adaptive method or a new risk level in the case of the predefined intervals
- All simulation runs in which no collision occurred were counted as well as the real time measured up to the time of the occurrence of a collision. This operation was performed 100 times, with no parallel execution.

Validation-
Risk distance function



$$D_K = 1 - \left(\left(1 - \begin{cases} 0, if\ distance = 0m \\ 1, if\ distance \geq 4980m \\ \dfrac{distance}{4980m}, else \end{cases} \right) \times \left(1 - \begin{cases} 0, if\ speed \geq 12{,}5kn \\ 1, if\ speed \leq 10kn \\ \dfrac{(speed - 12{,}5kn)}{(10kn - 12{,}5kn)}, \quad else \end{cases} \right) \times \left(1 - \begin{cases} 0, if\ angle \geq 135° \wedge angle \leq 225° \\ 1, if\ angle \leq 100° \vee angle \geq 250° \\ \min\left(\dfrac{(angle - 135°)}{(100° - 135°)}, \dfrac{(angle + 225°)}{(250° - 225°)} \right), else \end{cases} \right) \right)$$

Simple Fault Tree for a frontal collision between two ships and the corresponding risk distance function

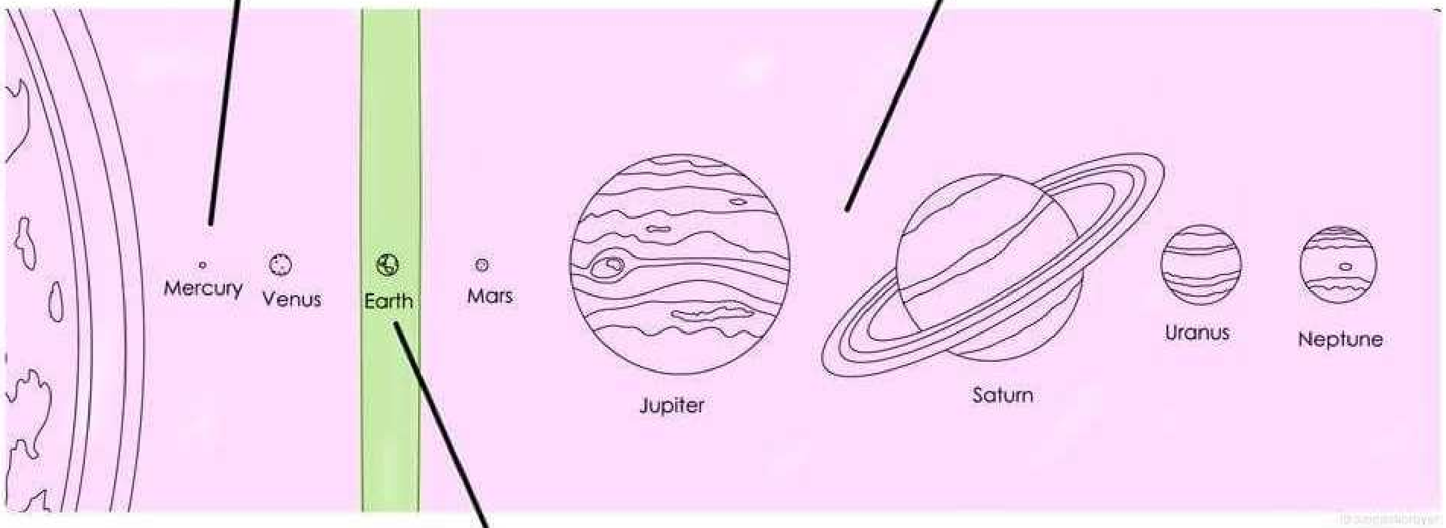
Validation – *Results*

	Naiv	RDF (Adaptive)	RDF (Distance 0,01)	RDF (Distance 0,05)
Total Duration (Milliseconds)	9176670	**92**	95	3.153
Mean (Counted Runs)	440766,19	**531,5**	595,51	53.749,3
Max (Counted Runs)	1.929.412	**1.074**	1.161	149.351
Min (Counted Runs)	8.254	**4**	6	6
Sum (Counted Runs)	44.076.619	**53.150**	59.551	5.374.930

Thank you for your attention

No risk for a ship collision

No risk for a ship collision



High risk of a ship collision