PROCESS SAFETY

Overview of the research activities and theses

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Research group members
Dr. Federica Ovidi
Mr. Lorenzo Rossi

Introduction to process safety

Process safety is defined* as the prevention and mitigation of process-related injuries and damage arising from process incidents involving fire, explosion and toxic release


Sannazzaro, 3 weeks ago


Deepwater Horizon, 2010

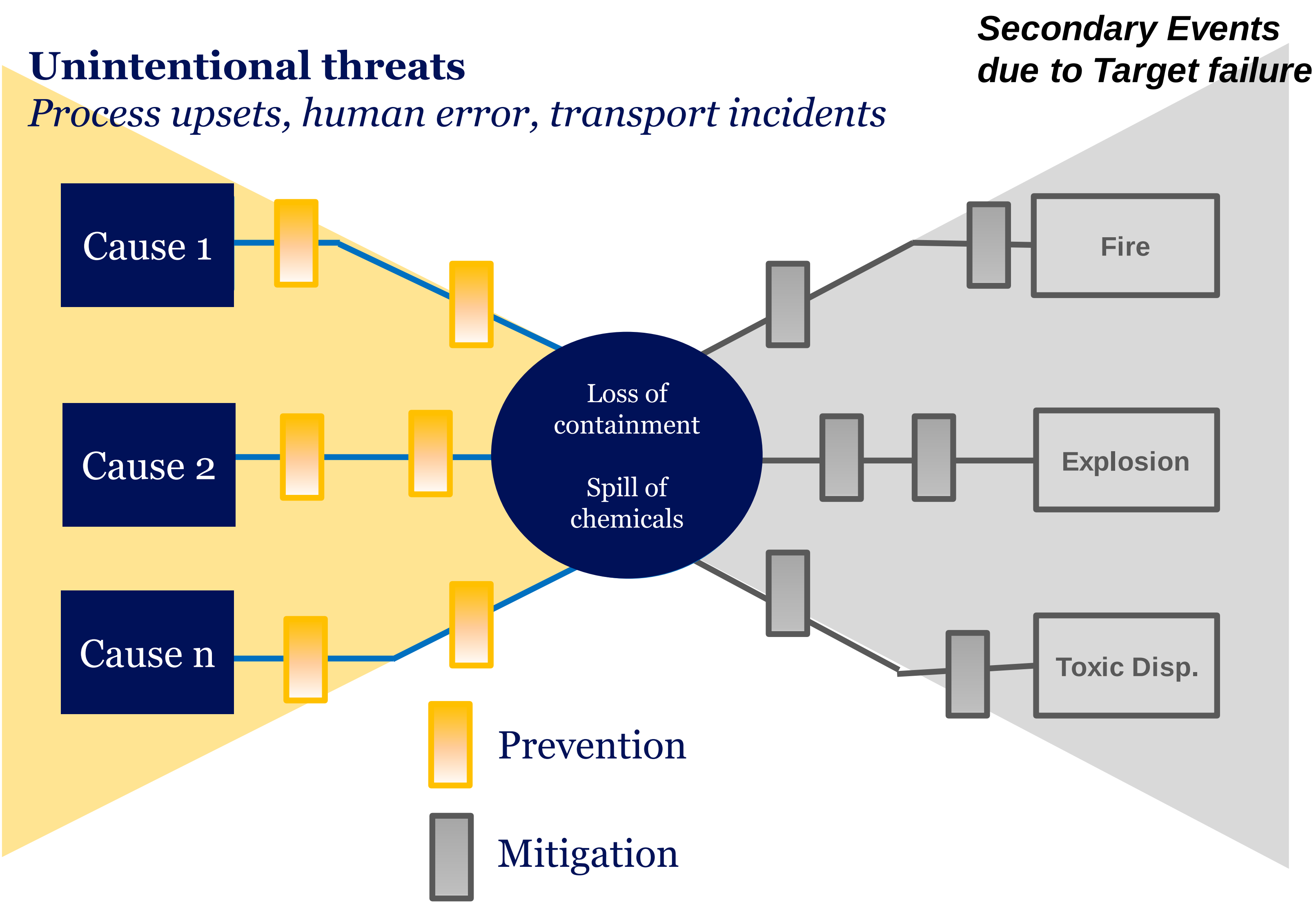

Viareggio, 2009


Chiba, Japan, 2011

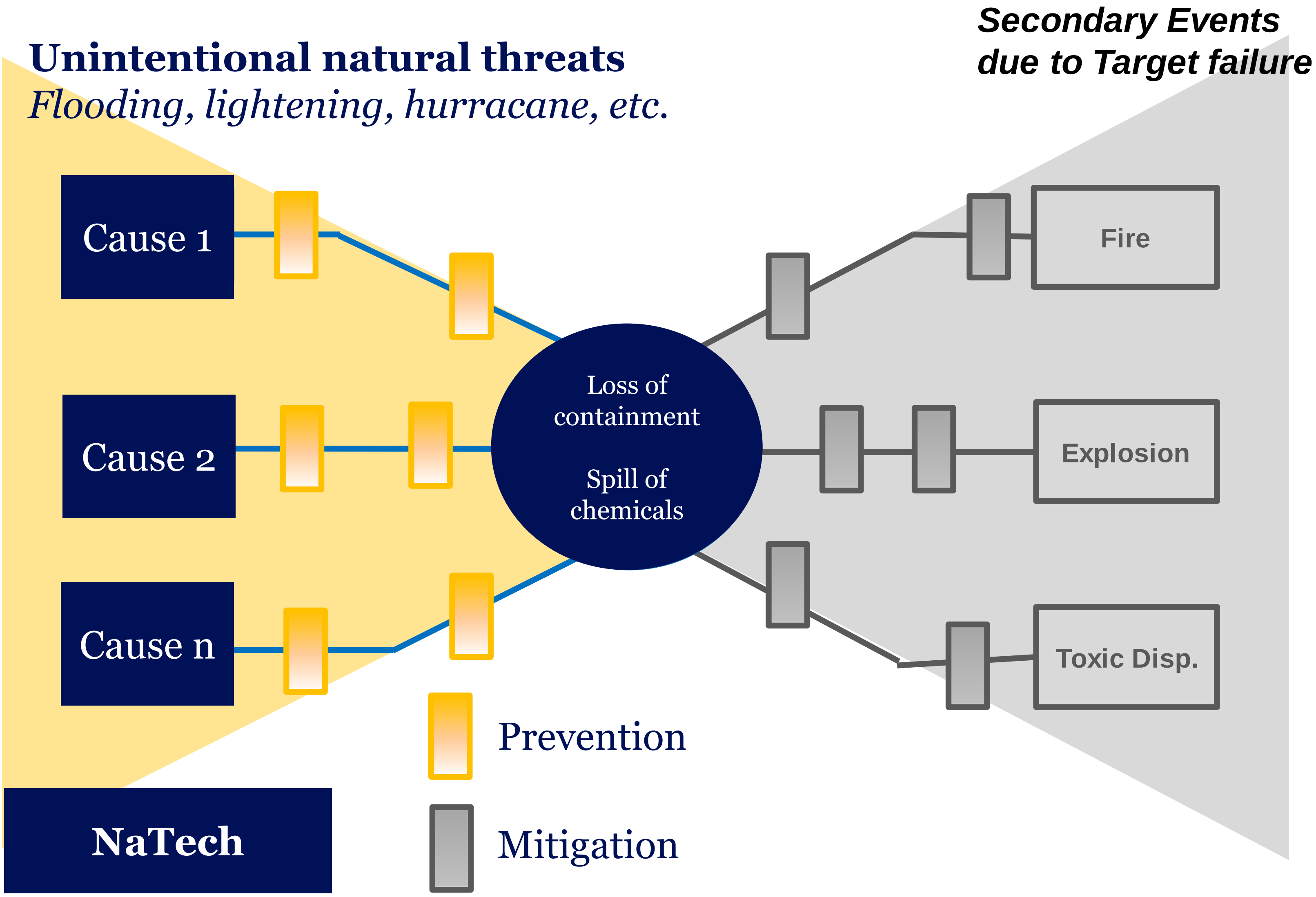
MAJOR ACCIDENTS: FIRES, EXPLOSION, TOXIC DISPERSIONS

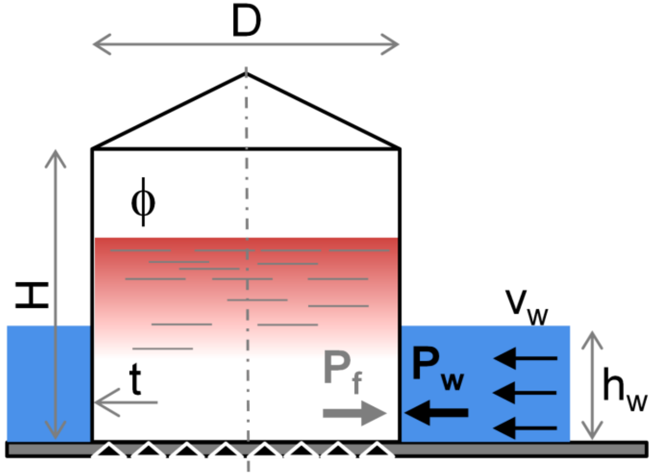
* https://www.journals.elsevier.com/journal-of-loss-prevention-in-the-process-industries

The bow-tie approach to cascading events



The bow-tie approach to cascading events

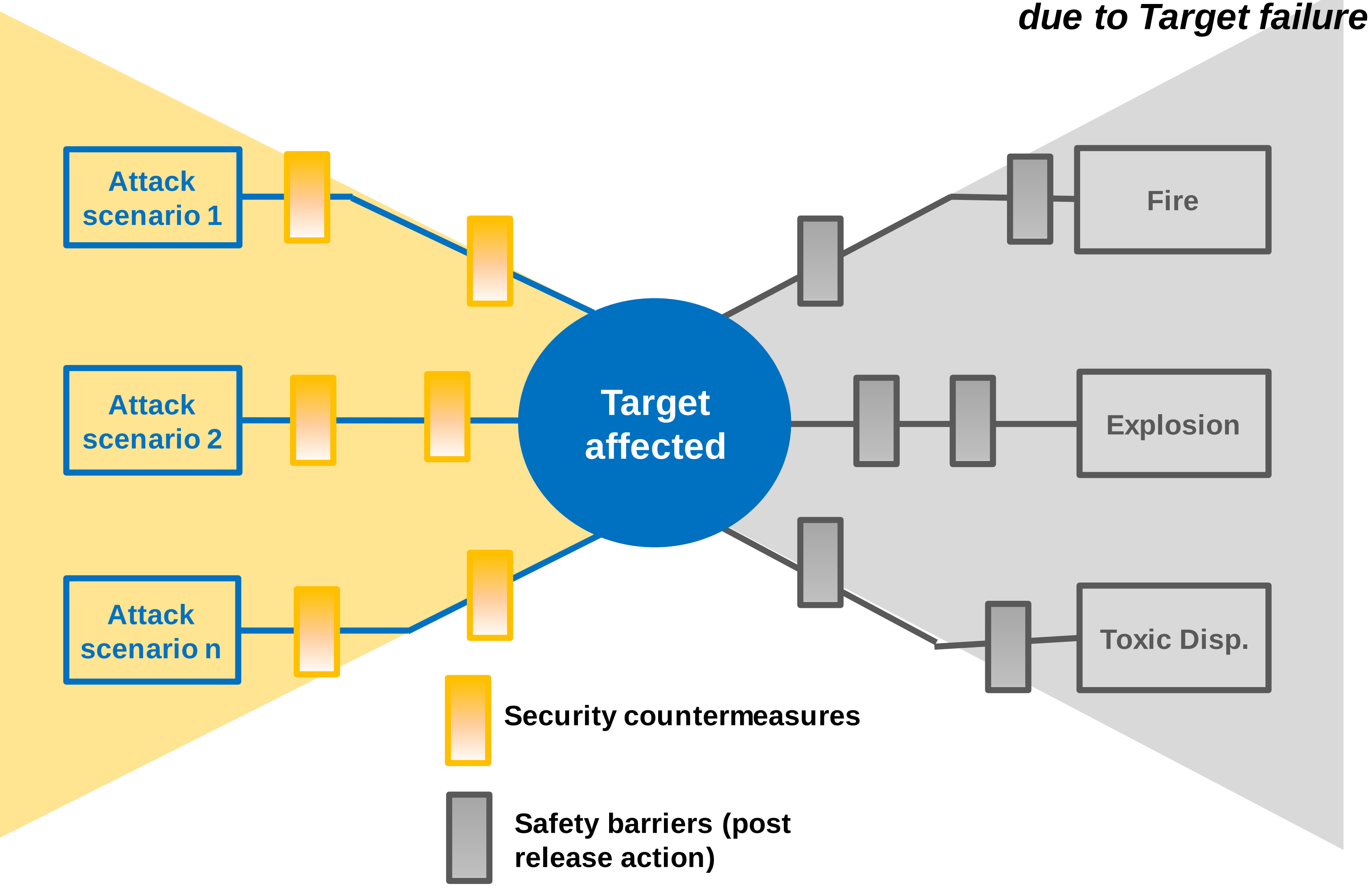




The bow-tie approach to cascading events

DELIBERATE ATTACK

Secondary Events due to Target failure



France attack: Man decapitated at factory near Lyon

26 June 2015 | Europe

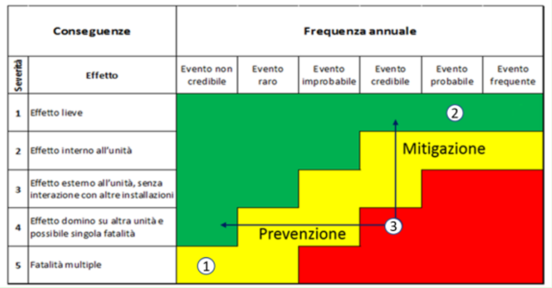
«The attackers intended to blow up the facility»

Tank fire at LyondellBasell refinery, near Marseille

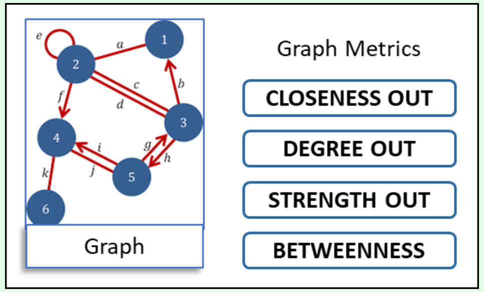
Theme 1: risk assessment of industrial scenarios

Advanced tools (probabilistic) for DOMINO EFFECT

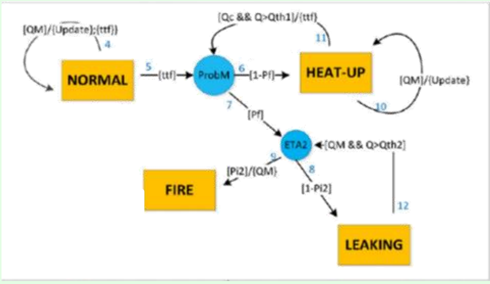
Risk matrix



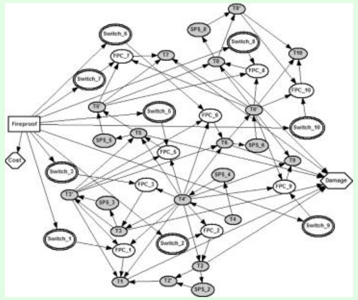
Graph Theory



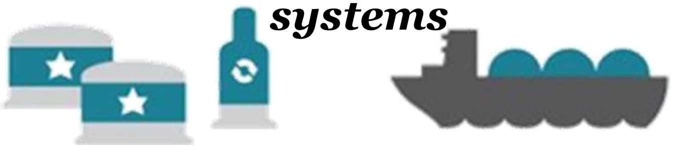
Agent based modelling



Bayesian networks

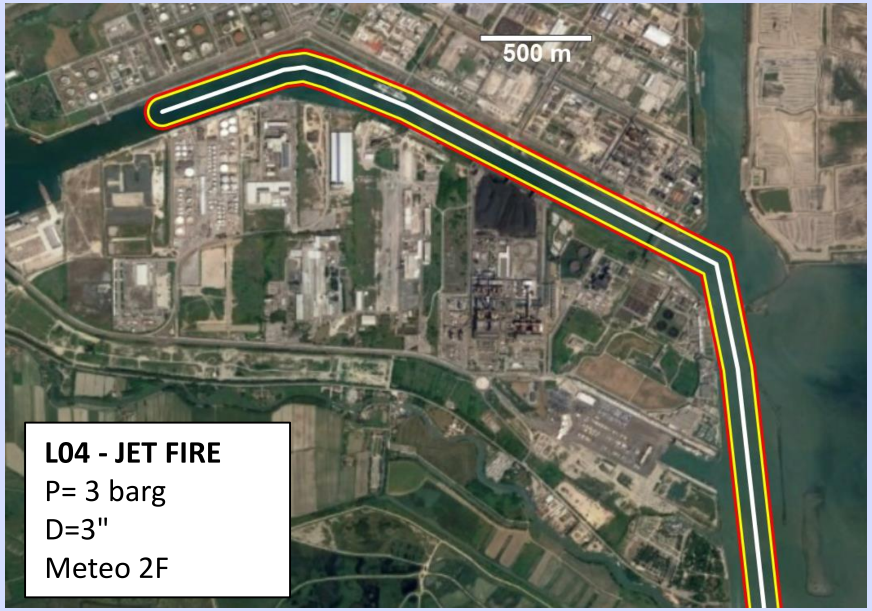


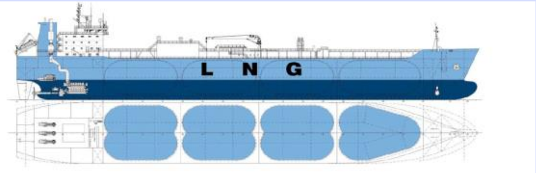
Application to
fixed installations *and* ***transport systems***



Food industry???

Contact person: Dr. Federica Ovidi





Example: risk assessment of LNG ships access to Venice harbour area

Theme 1.1: Risk Matrix

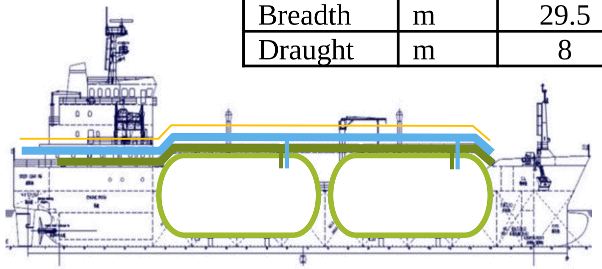
*Application to **transport systems***

Risk assessment

1. Characterisation of the system
2. Identification of hazards
3. Frequency evaluation
4. Consequence evaluation

1

Item	Units	**Ship A**	**Ship B**
Reference	-	Wartsila	ENI fleet
Capacity	**m^3**	**30,000**	**65,000**
Length	m	170	216
Breadth	m	29.5	34
Draught	m	8	9.5



2

<table>
<tr><th>Node 01</th><th>Diameter</th><th>Inventory</th></tr>
<tr><td rowspan="2">Liquid piping system</td><td>10 mm</td><td>Line Volume</td></tr>
<tr><td>3”</td><td>Line Volume</td></tr>
</table>

<table>
<tr><th rowspan="2">Node 02</th><th rowspan="2">Diameter</th><th colspan="2">Duration</th></tr>
<tr><th>Mitigated</th><th>Unmit.</th></tr>
<tr><td rowspan="2">Boil Off Gas piping</td><td>10 mm</td><td>1 min</td><td>30 min</td></tr>
<tr><td>3”</td><td>1 min</td><td>30 min</td></tr>
</table>

3

$$f_i = F \times P_r \times P_{e,i}$$

$F = F_0 \times n_{ship} \times L_{route}$

$F_0 = 1.4 \times 10^{-6}$ ev/(y vessel km)

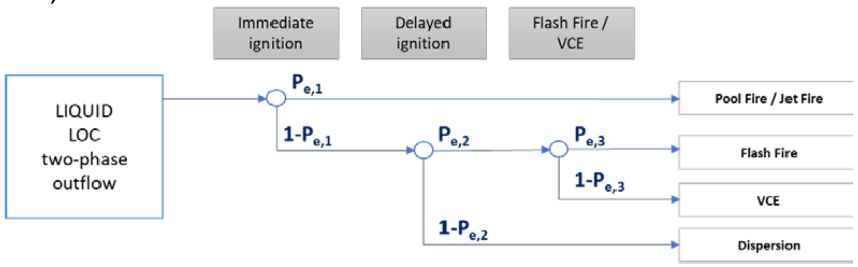
$P_{r,1} = 0.025$; 10 mm hole

$P_{r,2} = 0.0012$; 3’’ hole

Purple Book

$P_{e,1} = 0.5$; immediate ignition

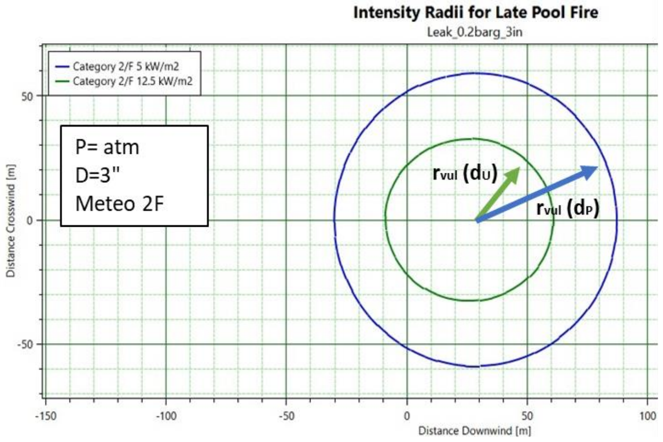
$P_{e,2} = 0.1$; delayed ignition



4

Phast 8.1

DNV·GL



Theme 1.1: Risk Matrix

*Application to **transport systems***

Risk assessment

1. Characterisation of the system
2. Identification of hazards
3. Frequency evaluation
4. Consequence evaluation

5. Risk recomposition

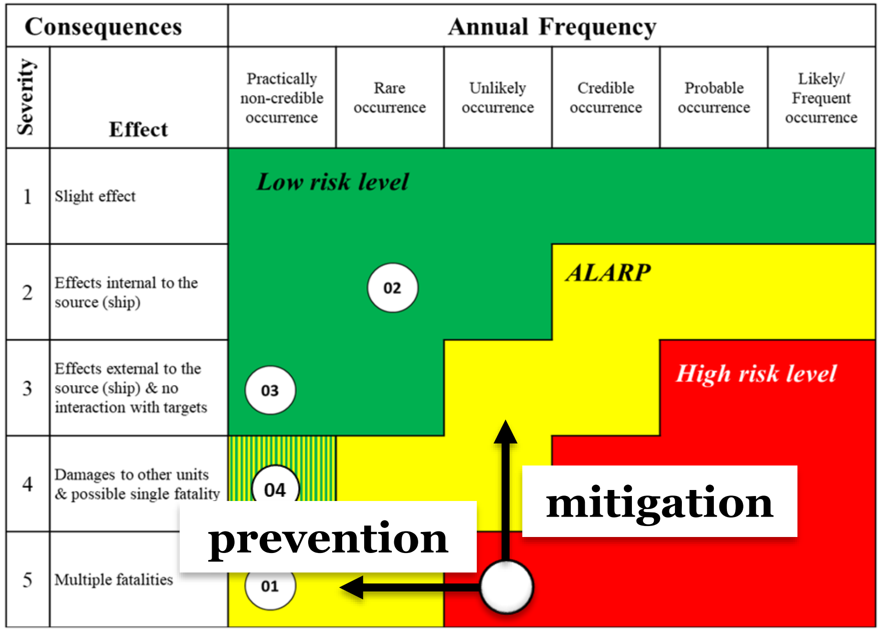
Likelihood (F)	Qualitative Rating
$f_i < 10^{-6}\ y^{-1}$	Practically non-credible
$10^{-6} \le f_i < 10^{-4}\ y^{-1}$	Rare
$10^{-4} \le f_i < 10^{-3}\ y^{-1}$	Unlikely
$10^{-3} \le f_i < 10^{-1}\ y^{-1}$	Credible
$10^{-1} \le f_i < 1\ y^{-1}$	Probable
$f_i \ge 1\ y^{-1}$	Likely/Frequent

Severity (M)	Qualitative Rating
$r_{vul} < 1$ m	Slight effect
$1\ m \le r_{vul} < d_N$	Effects internal
$d_N \le r_{vul} < d_U$	Effects external
$d_U \le r_{vul} < d_P$	Damages to units
$r_{vul} \ge d_P$	Multiple fatalities

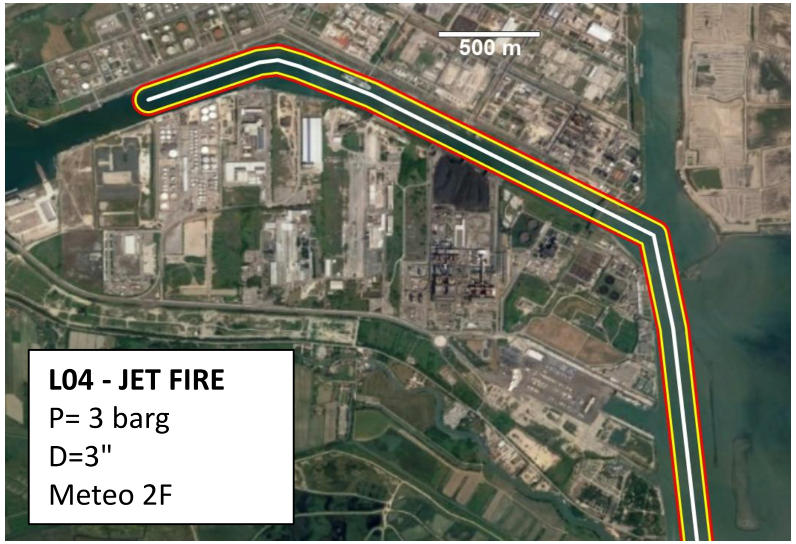
Risk register

Source	ID	Scenario	F	C	R
Liquid piping system	01	VCE	1	5	M
BOG piping	02	Jet Fire	2	2	L
Steam piping manifold	03	Flash Fire	1	3	L
Liquid piping system	04	Jet Fire	1	4	M

Risk matrix



Buffer zone



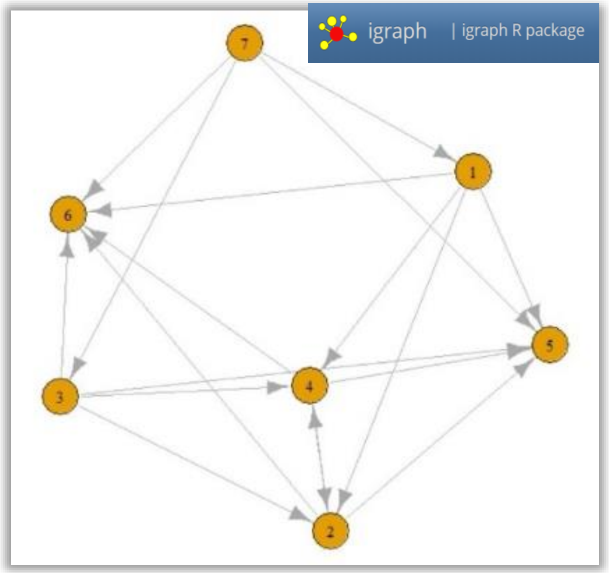
Theme 1.2: *Graph Theory*

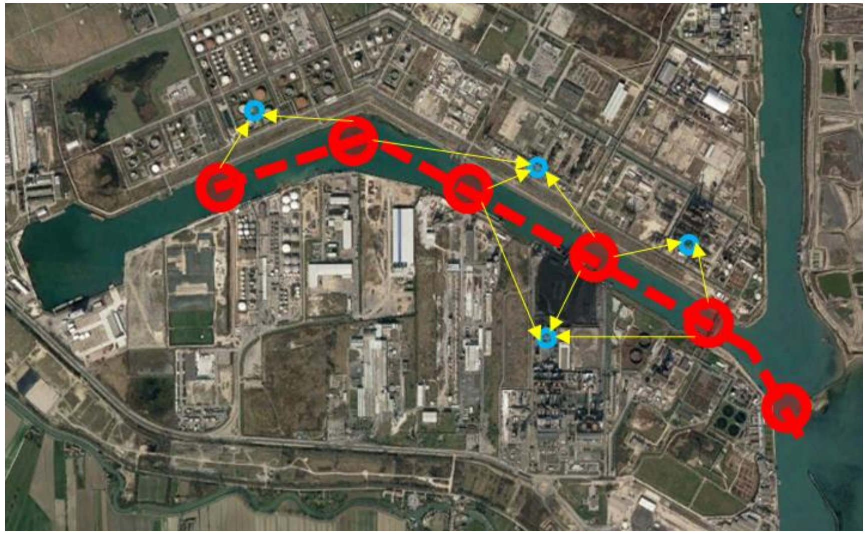
*Application to **transport systems***

Risk assessment

1. Characterisation of the system
2. Identification of hazards
3. Frequency evaluation
4. Consequence evaluation

5. **Risk recomposition**





Nodes

- Transportation system
- Other industrial plants
- Populated areas

Arcs

Physical consequences following an accidental scenario:

- Heat radiation
- Overpressure
- Toxic concentration

Theme 1.2: *Graph Theory*

*Application to **transport systems***

Risk assessment

1. Characterisation of the system
2. Identification of hazards
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4. Consequence evaluation

5. Risk recomposition

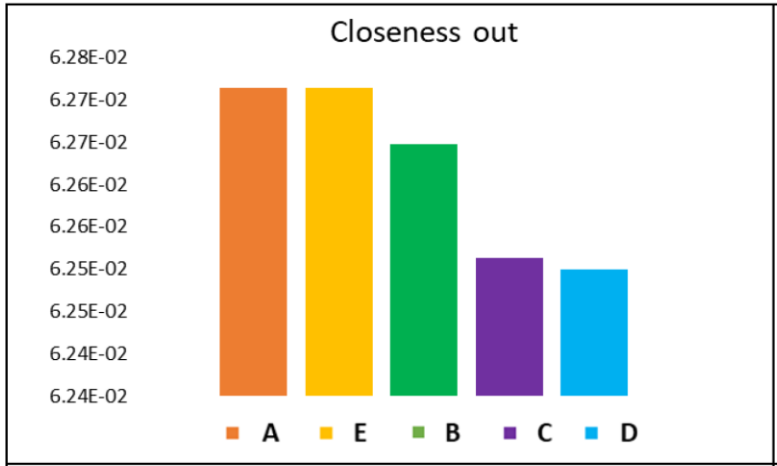
Graph Metrics

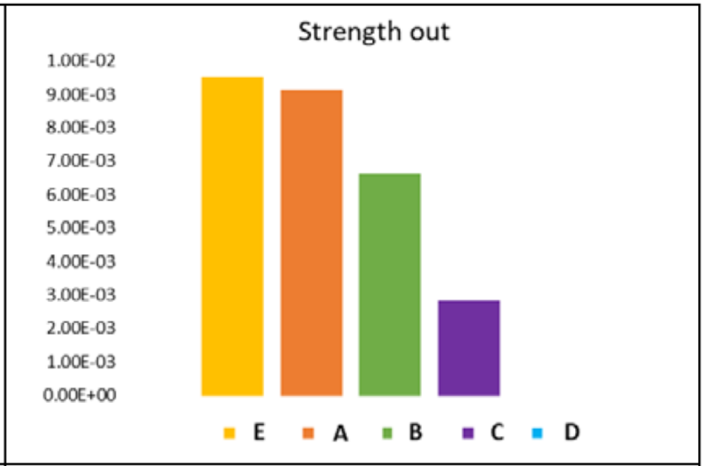
CLOSENESS $C_{C-out}(i) = \dfrac{1}{\sum_j d_{ij}}$

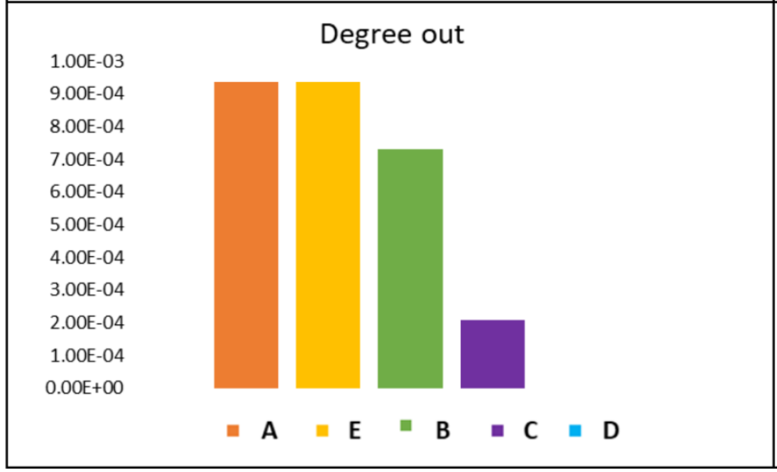
measures the node centrality and relies on the length of the paths from a node to all other nodes

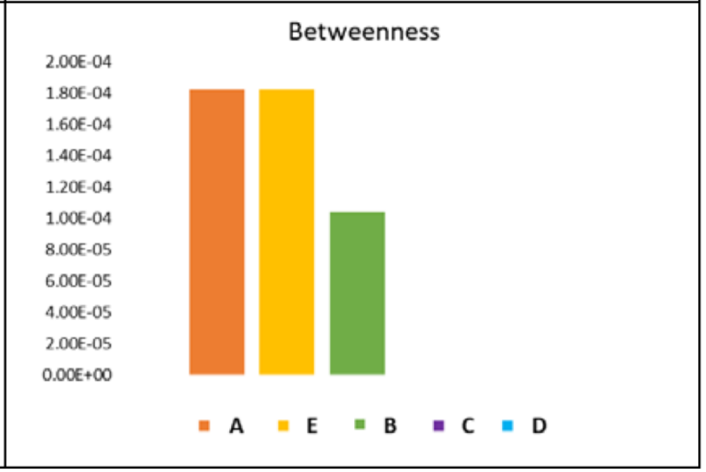
BETWEENNESS $C_B(i) = \sum_{j,k} \dfrac{d_{j,k}(i)}{d_{j,k}}$

Identifies the shortest path between two nodes and measures the number of paths that passes through a node





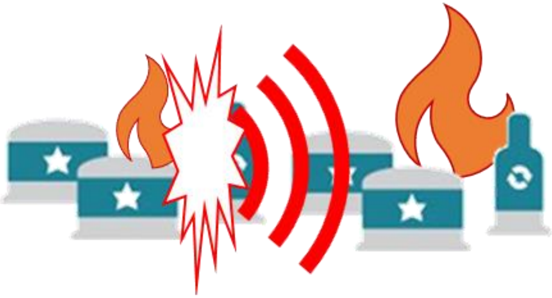




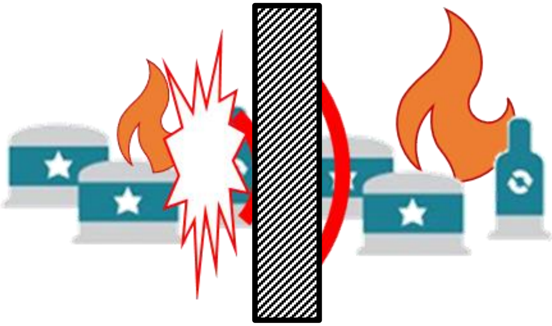
Theme 1.3: *Agent based modelling & Bayesian networks*

*Application to **fixed installations***

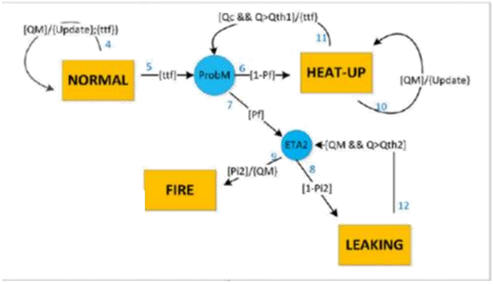
Elements in **Domino Event**:
1. a primary accidental scenario
2. an escalation vector,
3. at least, a secondary scenario



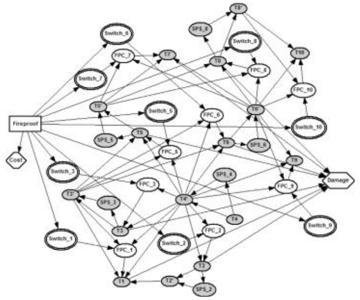
Safety barriers:
"physical and/or non-physical means planned to prevent, control, or mitigate undesired events or accidents"



Agent based modelling



Bayesian networks



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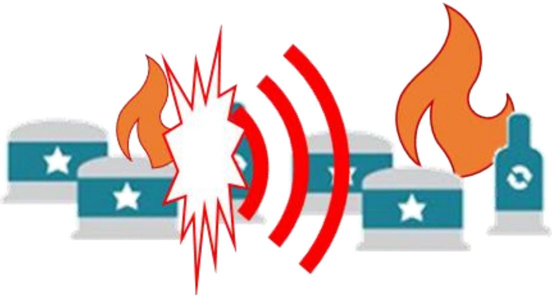

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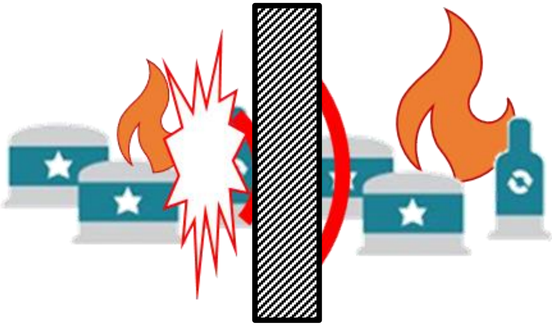
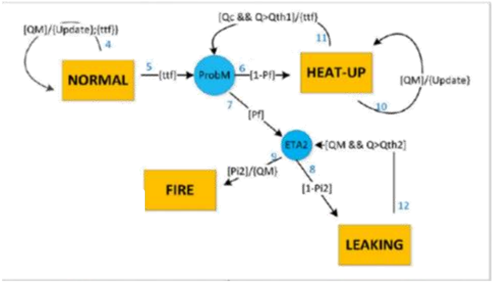
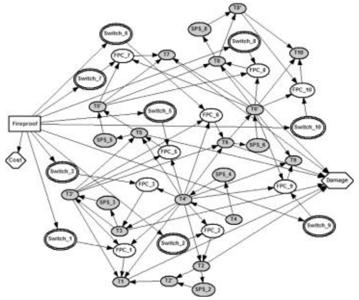


Agent based modelling



Bayesian networks



Theme 1.3: *Agent based modelling*

*Application to **fixed installations***

1. **Equipment modelling**
   - Pressurised
   - Atmospheric

2. **Safety barriers modelling**
   - Passive
   - Active
   - Procedural

3. **Validation of the model** through specific Event Tree Analysis

   analytical results VS simulated results

4. **DAMS-P**

   Domino effect assessment by agent-based modelling and simulation accounting for protection systems

1. Equipment

Type of Tank	ttf correlations
Atmospheric	$\ln(ttf) = -1.13\ln(Q) - 2.67\times10^{-5}V + 9.9$ (1)
Pressurized	$\ln(ttf) = -0.95\ln(Q) + 8.85V^{0.032}$ (2)

2. Safety barrier

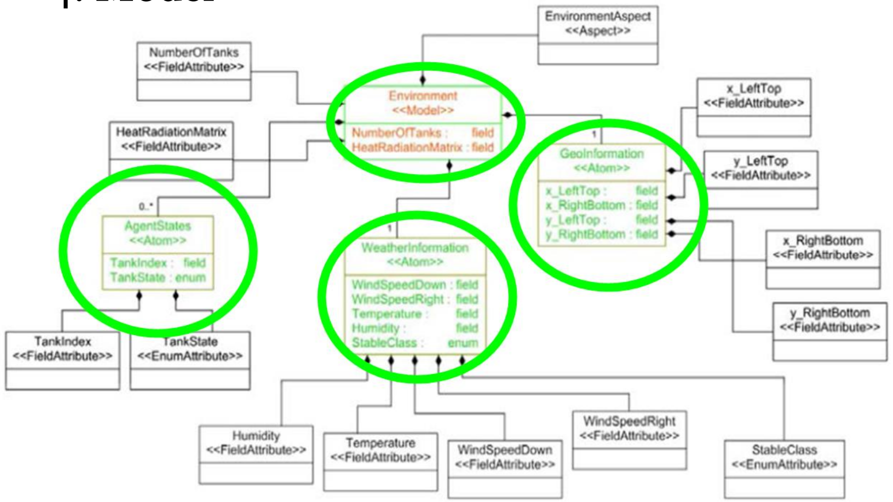
- Availability (PFD): representing the probability of failure on demand (PFD) of the safety barriers;
- Effectiveness (η): representing the probability that the SB, once successfully activated, will be able to effectively prevent/mitigate the escalation.

IN → a

$OUT_1 = IN\times[PFD+(1-\eta)\times(1-PFD)]$

$OUT_2 = IN\times(1-PFD)\times\eta$

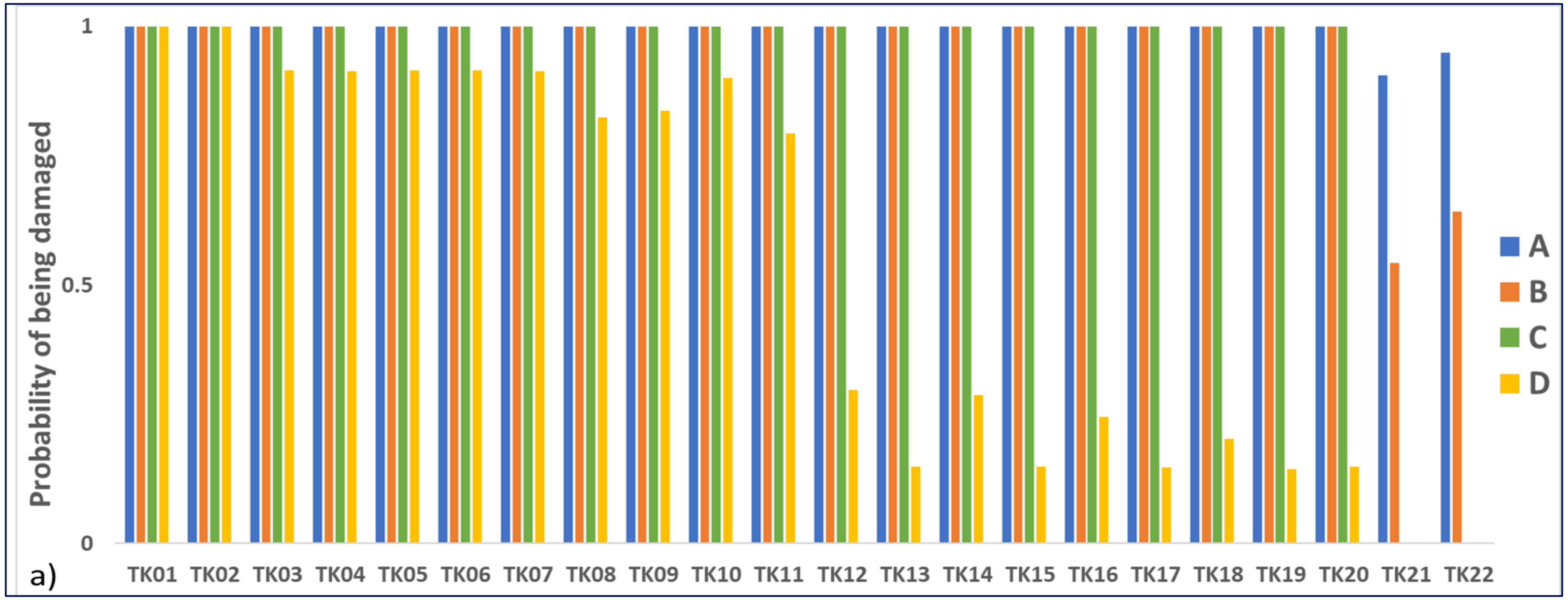
4. Model



Theme 1.3: *Agent based modelling*

*Application to **fixed installations***

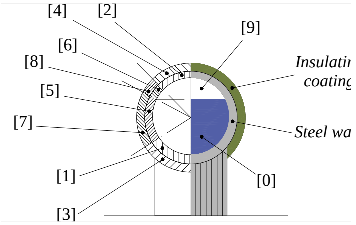
- A – base-line case. All tanks are unprotected
- B–atmospheric tanks equipped with FWS
- C –atmospheric tanks equipped with FWS; pressurized tanks equipped with WDS and PFP
- D –atmospheric tanks equipped with FWS; pressurized tanks equipped with WDS and PFP, and EEI is considered

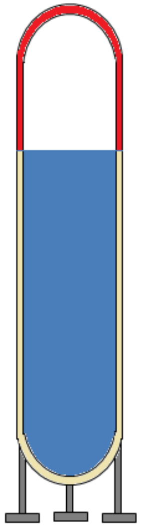


Theme 1: risk assessment of industrial scenarios -> DOMINO EFFECT events simulation

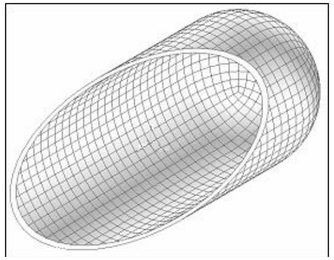
Domino triggered by fire

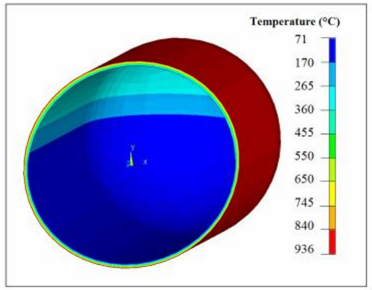
Domino triggered by explosion and fragments (link with security??)

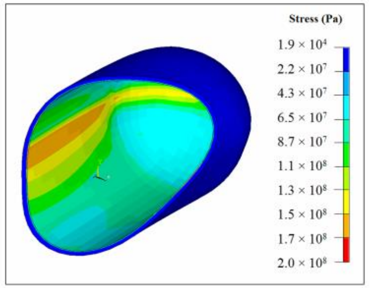




LUMPED APPROACH

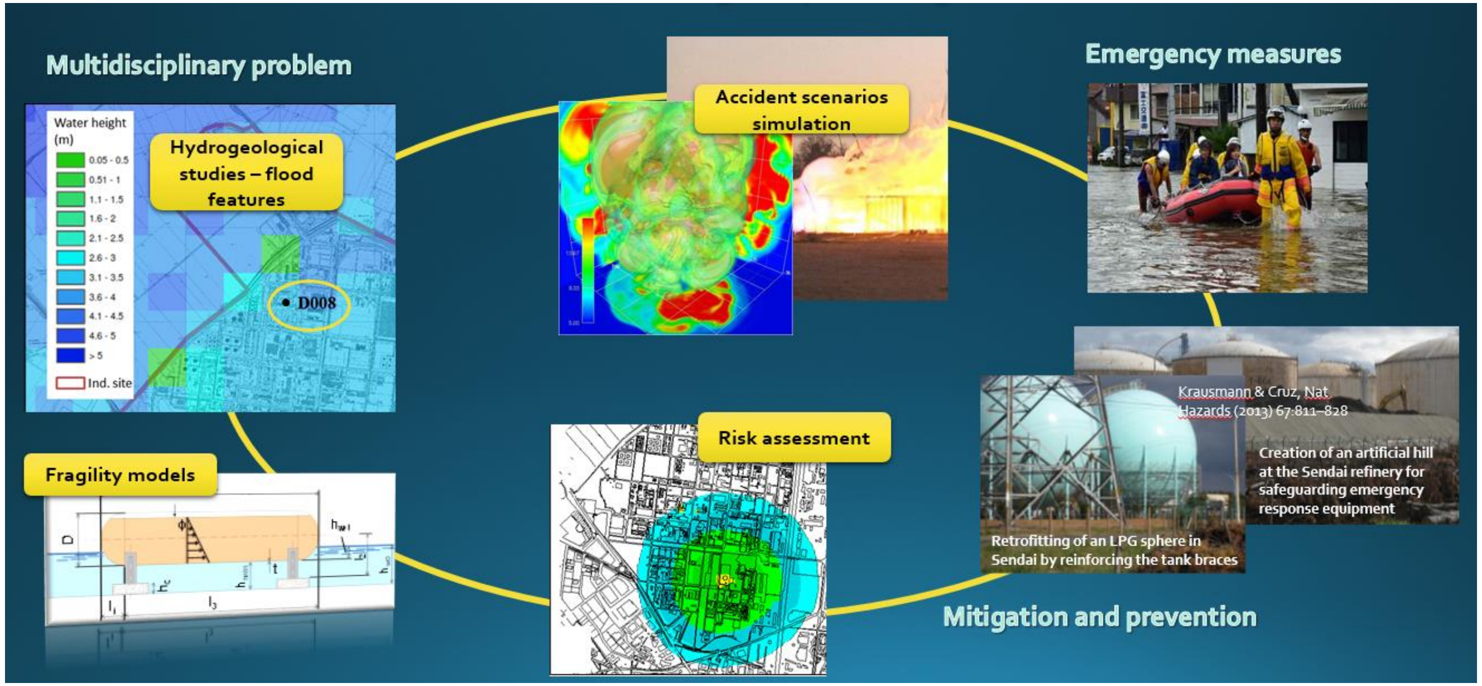






DISTRIBUTED PARAMETERS APPROACH

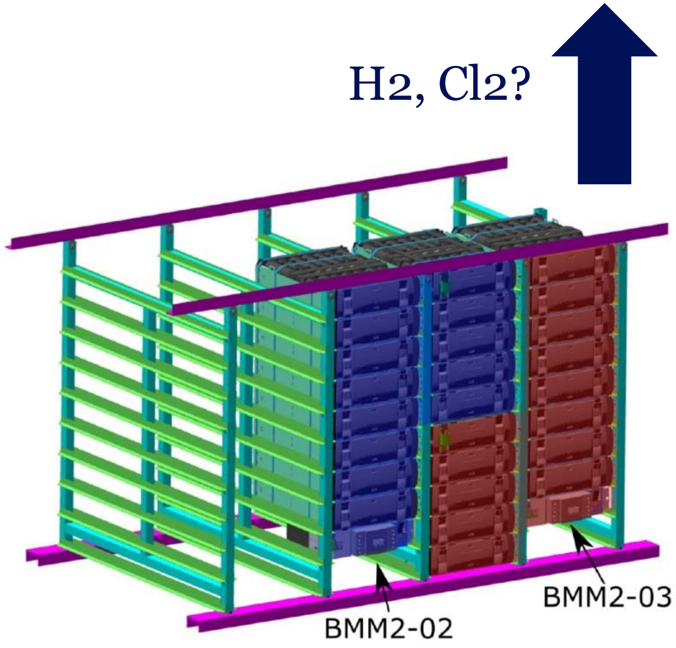
Theme 2: Analysis of accidents triggered by natural events (NaTech)



Contact person: Mr. Lorenzo Rossi

Theme 2A: accidents triggered by flooding in industrial plants

Theme 2B: accidents triggered by flooding in large battery units → electrolysis and gas development



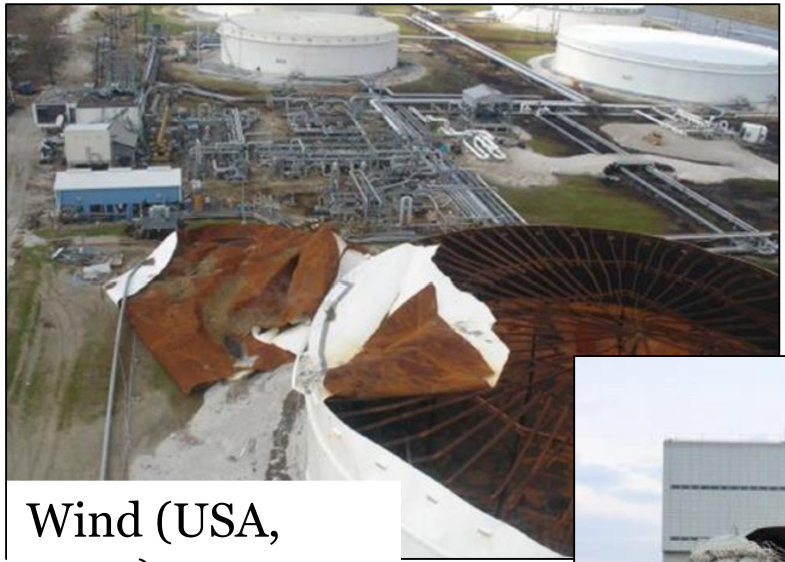
Co-supervisor: Dr. Antonio Bertei

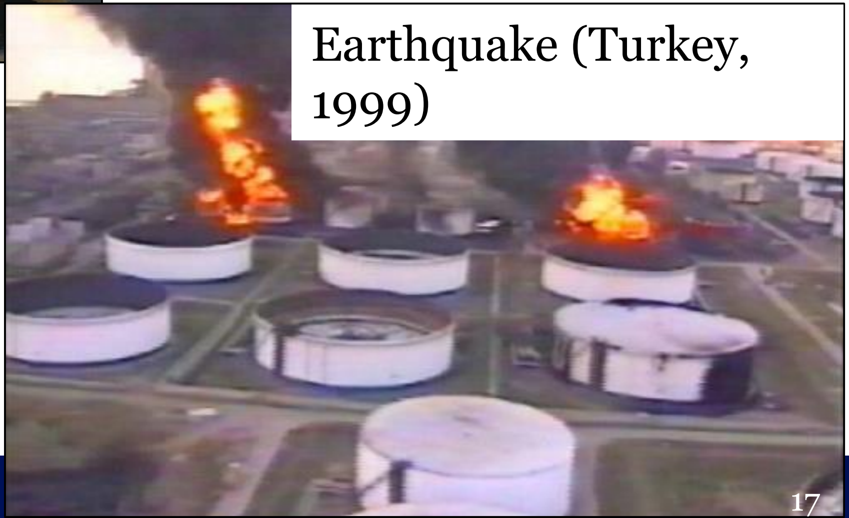
Theme 2: Analysis of accidents triggered by natural events (NaTech)

Technological accidents triggered by natural events ⟶ **NaTech**


Lightning (USA,2010)


Flood (USA, 2007)

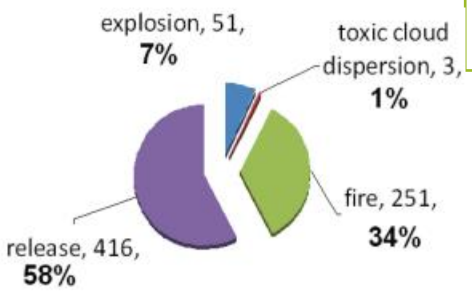

Wind (USA, 2005)

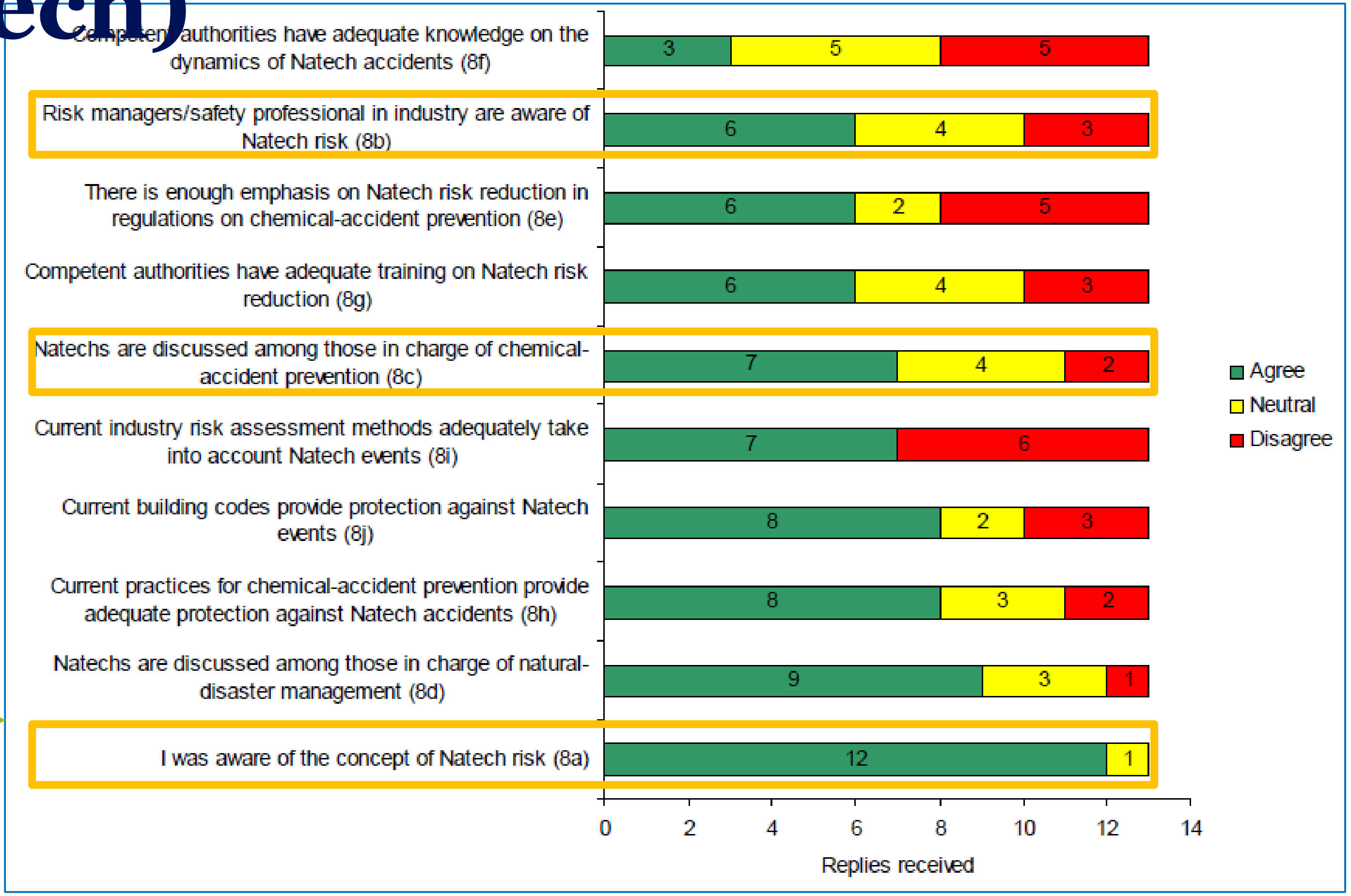

Earthquake (Turkey, 1999)


Tsunami (Japan, 2011)

Theme 2: Analysis of accidents triggered by natural events (NaTech)

Due to climate changes, in recent years an increment in natural disasters can be observed and there is an higher awareness in competent authorities for this emerging issue. (Krausmann E. Analysis of Natech risk reduction in EU Member States using a questionnaire survey. 2010)



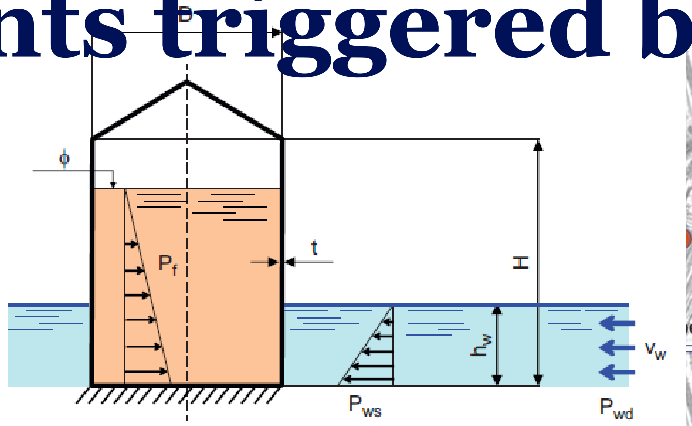


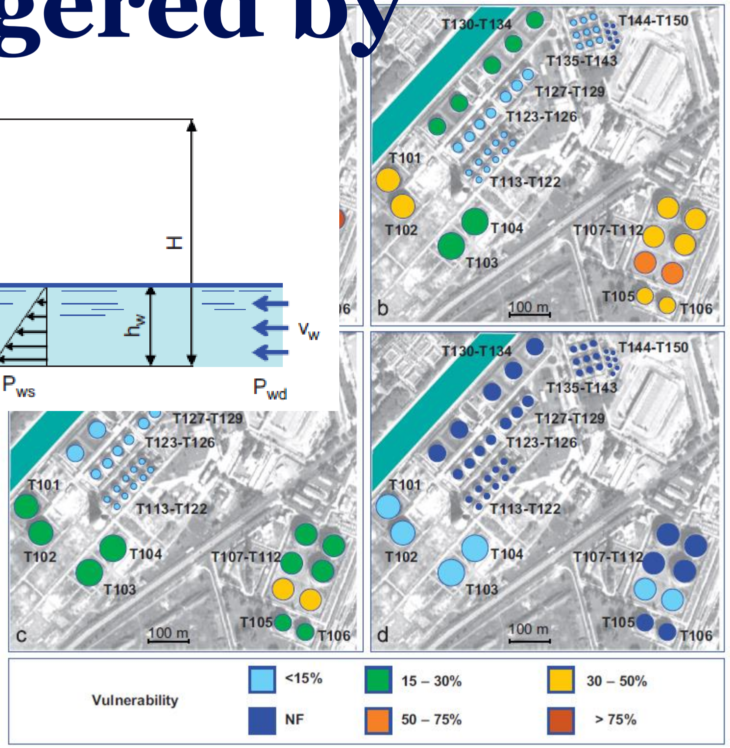
Natural events are very dangerous for chemical plants in particular because of the dangerous materials involved. A loss of containment can lead to very harsh consequences (fires, explosions, toxic dispersions, contamination), involving large areas and having huge effects on the surrounding population.

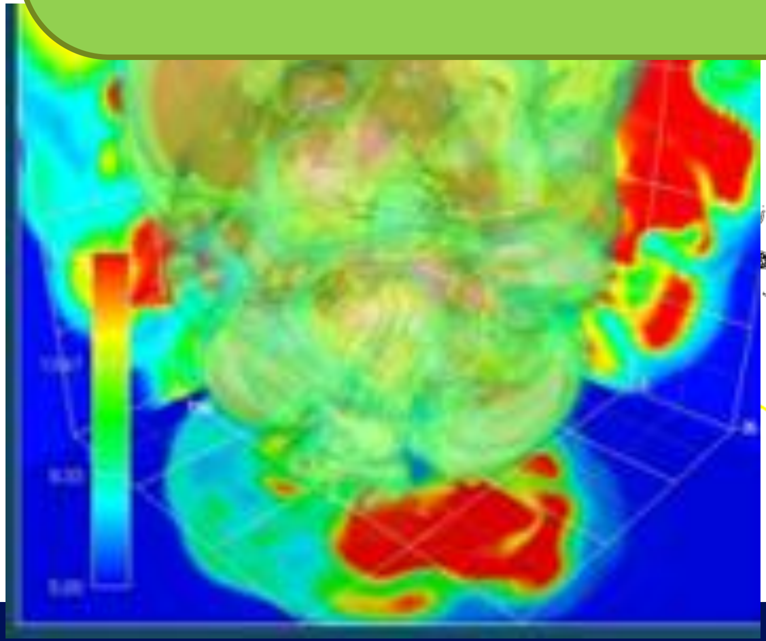
Theme 2: Analysis of accidents triggered by natural events (NaTech)

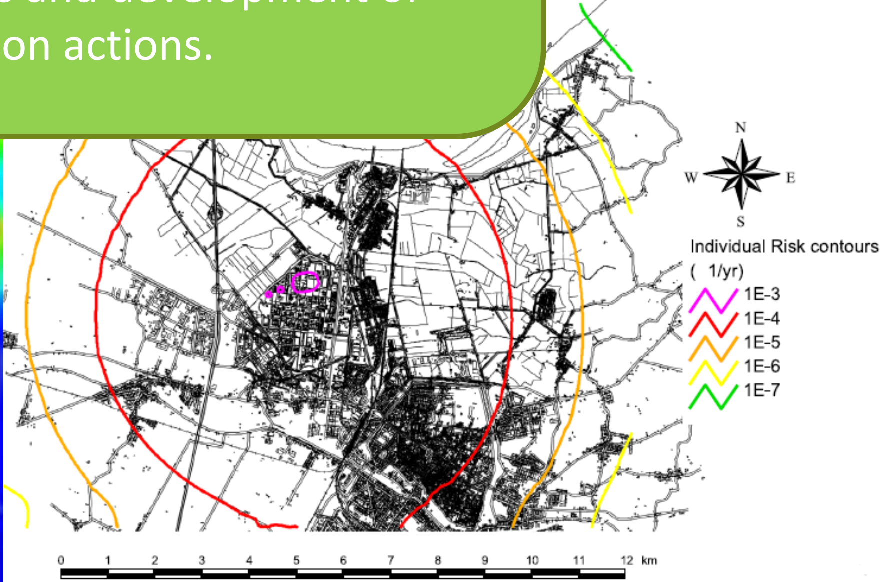
Main activities on this topic:

- Development of fragility models for critical industrial equipment;
- Accident scenarios simulations;
- Development of risk assessment methodologies;
- Analysis of emergency measures and development of suitable mitigation and prevention actions.









Theme 3: Security assessment

Preliminary Analysis

1A. **Identification of critical assets**

1B. **Identification of security threats**

Scenario-based Vulnerability Analysis

2. **Definition of security scenarios**
Asset/threat agent/ attack mode combinations

3. **Calculation of likelihood of attack** L_1

4. **Identification of security PLs**
relevant for the security scenario of concern

5. **Calculation of likelihood of success** L_2

Consequences, impact

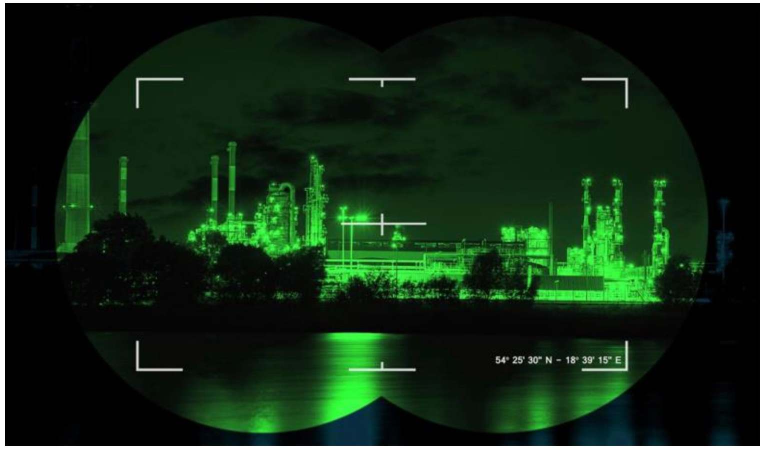
$$R = L_1 \times L_2 \times C$$

Probability that the attack is performed to a given asset, function of:

- **threat agents**' intent and capabilities
- **target attractiveness**

conditional probability of successful execution of the attack given the attack attempt
→ **protection systems**

Theme 3: Security assessment (terrorist attacks)

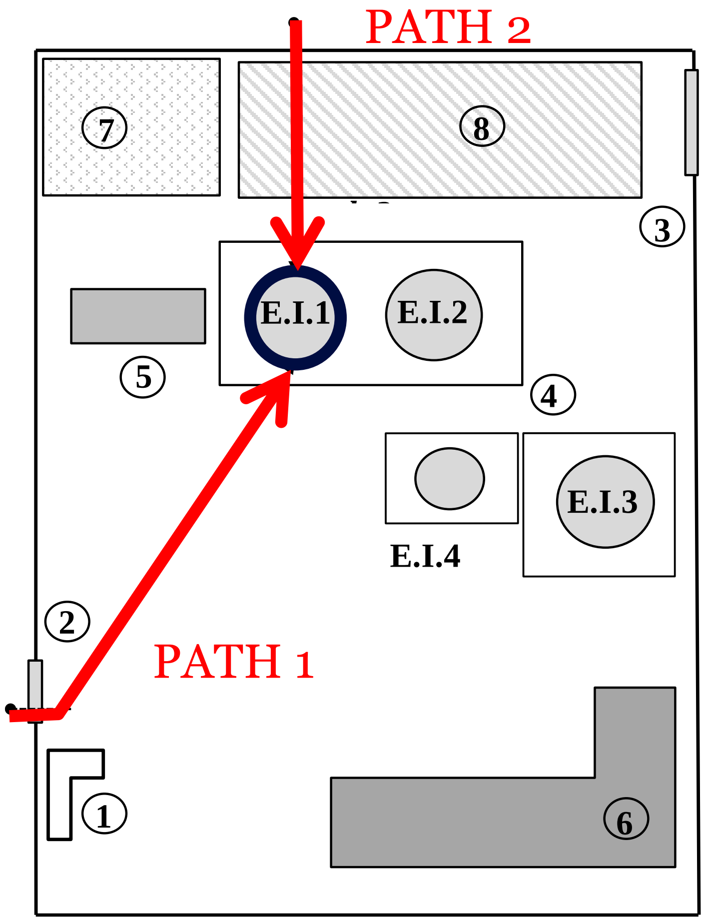


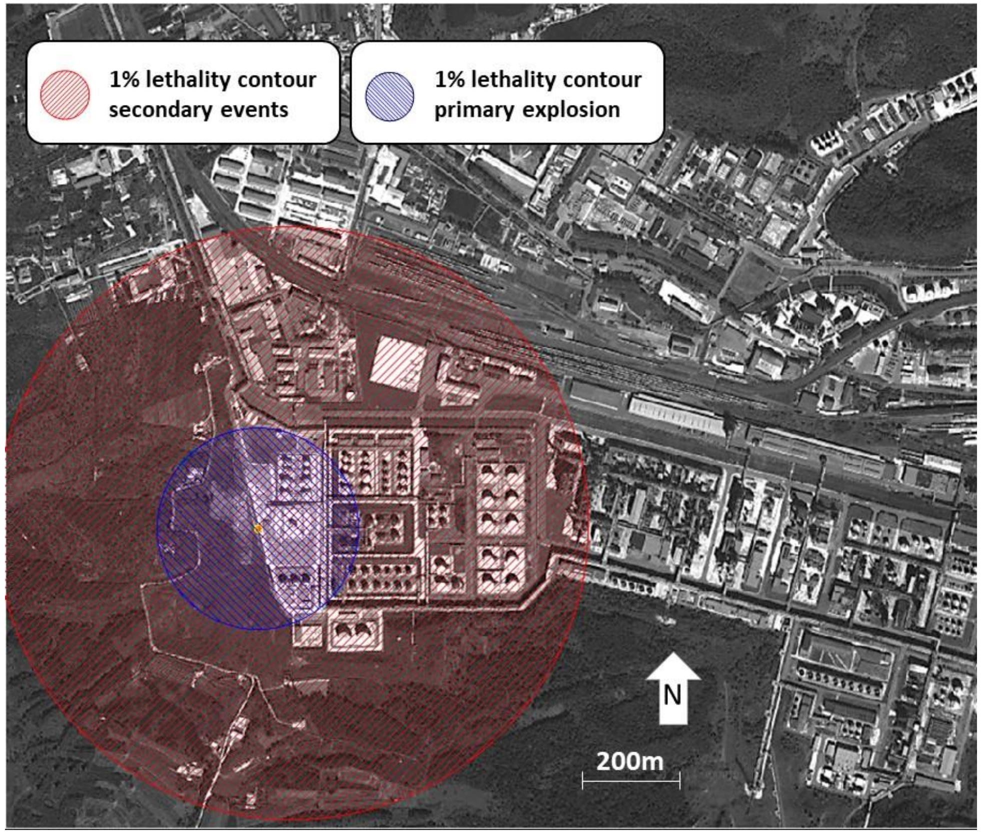
Evaluation of the vulnerability of a chemical facility

Target E.I.1.

Attack carried out by a terrorist acting alone.
Attack mode: use of IED

Two alternative terrorist's paths are analysed.





Theme 4: Low phi-factor adiabatic calorimeter (PHI-TECH2)

OPERATING RANGE

Temperature: 25 – 400 °C

Pressure: 0 – 137 bar

Exotherm detection sensitivity:

0.02 °C/min

Tracking capability:

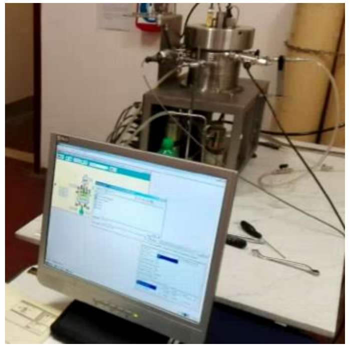
up to 200 °C/min

Pressure compensation system:

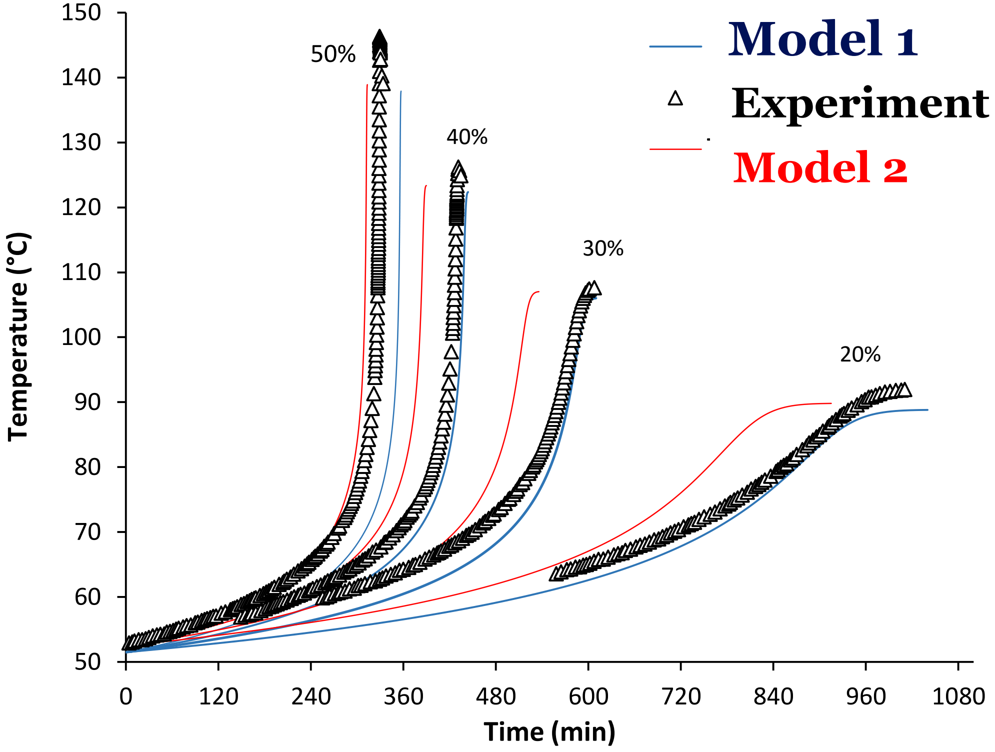
up to 100 bar/min

OPERATING MODES:

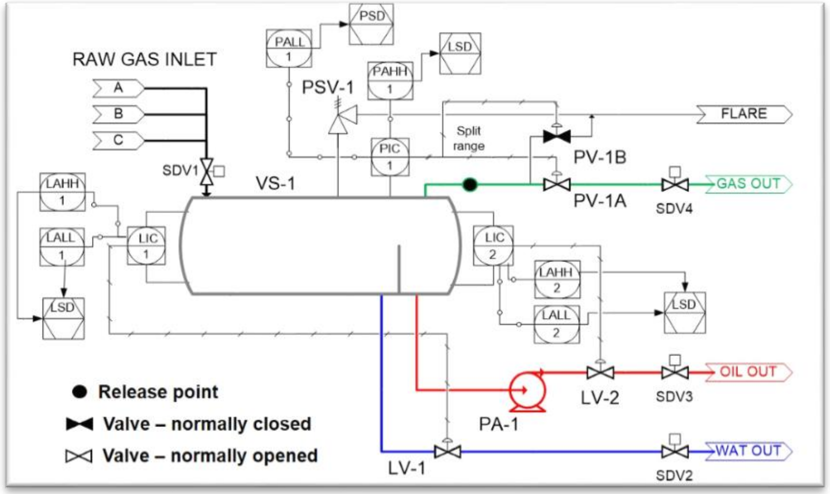
- Heat – Wait – Search
- Closed can test
- Open cell test

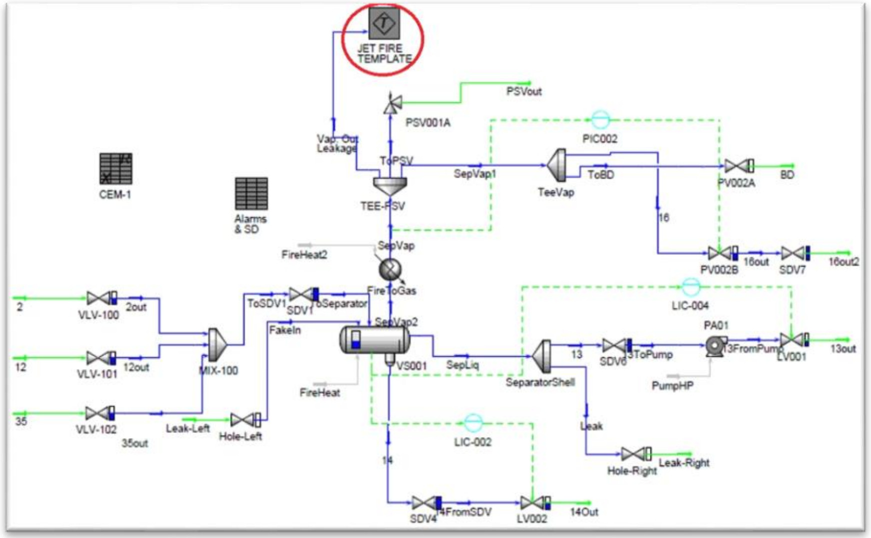


Lauroyl Peroxide (LPO) Decomposition

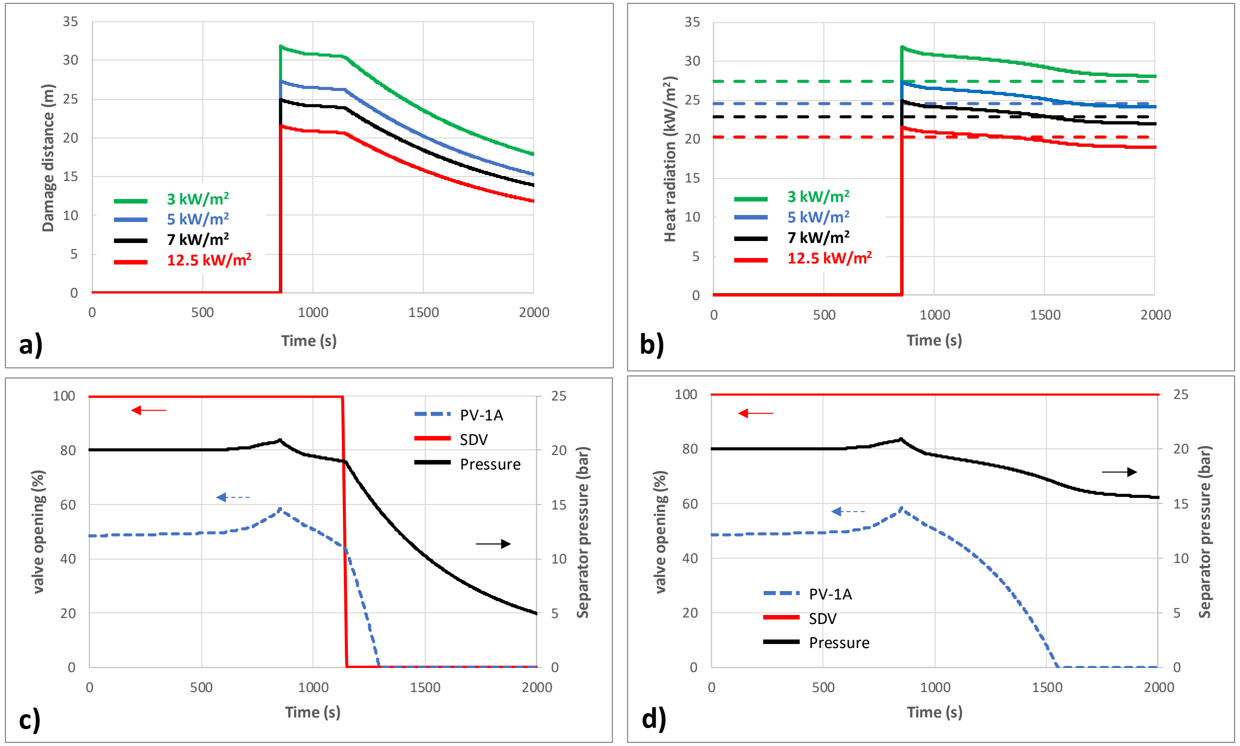


Theme 5: Consequence and risk assessment – dynamic process simulators





- Set up of dynamic process simulator to analyze the consequence of **JET-FIRE** following the leak of flammable materials (Ref. Prof. Pannocchia)
- Specific template developed in UniSim®: calculation spreadsheets embedded in the process simulator



Partners and internships:

University of Leiden (the Nethelands)

University of Bologna, (Italy)

TU Delft (the Netherlands)

京都大学防災研究所
Disaster Prevention Research Institute, Kyoto University
- Joint Usage/Collaborative Research Center for Multidisciplinary Disaster Prevention Study -

Crisisplan (the Netherlands)

Cascading events triggered by external acts of interference or natural events (NaTech)

University of Bologna, (Italy)

TU Delft (the Netherlands)

Queen's University (Canada)

Universitat Politècnica de Catalunya (Spain)

Ecole de Mines Alès (France)

Safety and risk assessment of chemical plants

Industrial partners