European Commission

Technological Disruptions Triggered by Natural Events: Identification, Characterization, and Management

Proceedings of the 61st ESReDA Seminar
Politecnico di Torino, Italy
22-23 September 2022

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2024

Joint Research Centre

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JRC138988

PDF ISBN 978-92-68-20411-5 doi:10.2760/4847612 KJ-01-24-000-EN-N

Luxembourg: Publications Office of the European Union, 2024

How to cite this report: European Commission, Joint Research Centre, *Technological Disruptions Triggered by Natural Events: Identification, Characterization, and Management*, Demichela, M., Kopustinskas, V. and Simola, K. editor(s), Publications Office of the European Union, Luxembourg, 2024, https://data.europa.eu/doi/10.2760/4847612, JRC138988.

Contents

Abstract

These proceedings are the outcome of the 61st ESReDA seminar "Technological Distruptions Triggered by Natural Events: Identification, Characterization, and Management" that took place at Politecnico di Torino, Italy, 22-23 September 2022. The seminar attracted a good mix of academic and industrial participants from many countries, and provided a platform for stimulating discussion on the state of the art and on-going developments in the NaTech risk assessment techniques and methodologies.

The editorial work for this volume was supported by the Joint Research Centre of the European Commission in the frame of JRC support to ESReDA activities.

Foreword

European Safety, Reliability & Data Association (ESReDA) is a European Association established in 1992 to promote research, application and training in Reliability, Availability, Maintainability and Safety (RAMS). The Association provides a forum for the exchange of information, data and current research in Safety and Reliability.

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http://www.esreda.org/

1 Introduction

These proceedings are the outcome of the 61st ESReDa Seminar Hosted by Politecnico di Torino, in its Lingotto site on 22-23 September 2022.

We would like to thank the participants for attending and contributing to the seminar dedicated to “Technological disruptions triggered by natural events" and its multidisciplinary dimension.

As expected, the seminar provided a stage for stimulating discussion and debate and that participants were able to take the opportunity to form new, collaborative links and share their knowledge, also in relation to the impact of climate change.

We would like to thank the local organising committee in Turin, with the collaboration of PhD students from the SAfeR research group of the Department of Applied Science and Technology of Politecnico di Torino.

The seminar saw the presentation of 13 contributions, 3 of which were Key Notes: from Marcelo Masera, former Head of Unit "Energy Security, Distribution and Markets", Joint Research Center, The Netherlands, Valerio Cozzani, Full Professor at Bologna University and George Boustras, CERIDES Director, Professor at the European University, Cyprus.

These proceedings contain 8 full papers and 1 extended abstract and several presentations, with authors representing several domains. The seminar attracted a good mix of academic and industrial participants from many European countries.

We wish to thank the Technical Programme Committee for their efforts during the review process of the contributions, and all the authors during the presentations and the final stages of paper preparation. We look forward to future opportunities for collaboration and hope to see you at future events.

The editorial work for this report was supported by the Joint Research Centre of the European Commission in the frame of JRC support to ESReDA activities.

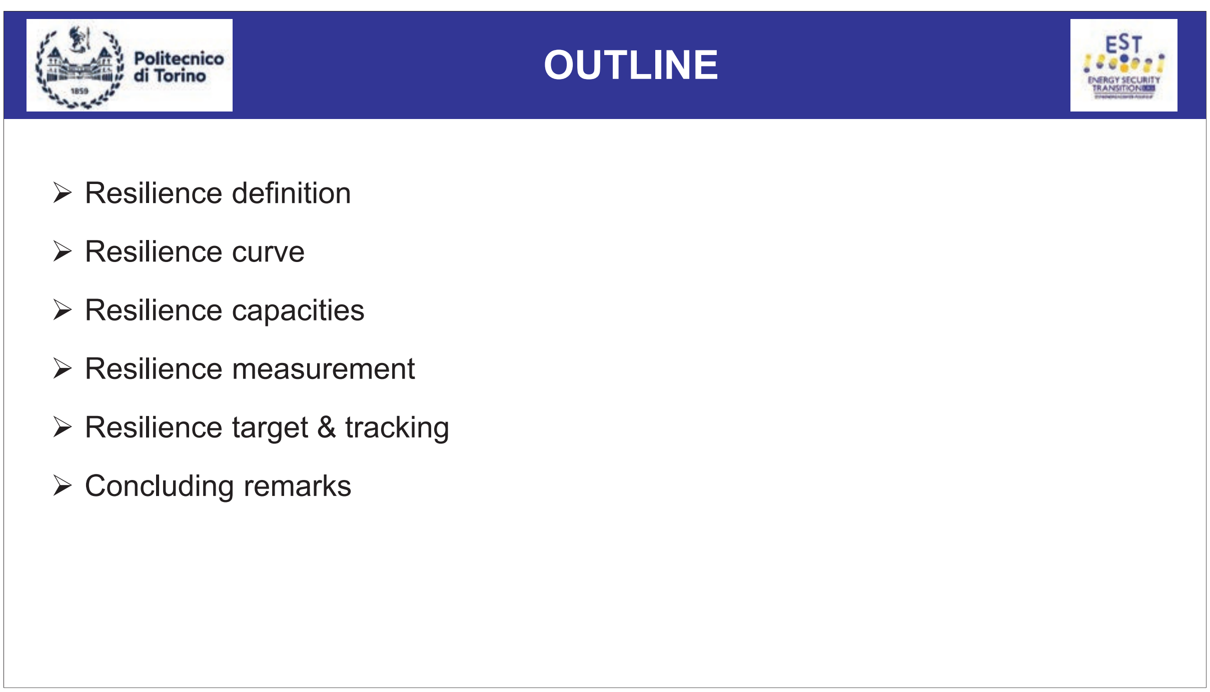
Assoc. Prof. Micaela Demichela,

Politecnico di Torino

Dr. Vytis Kopustinskas & Dr. Kaisa Simola

European Commission, Joint Research Centre (JRC)

Conference presentations



Resilience definition

- *The capacity of the energy system and its components to cope with a hazardous event or trend, to respond in ways that maintain its essential functions, identity and structure as well as its capacity for adaptation, learning and transformation.*
- *It encompasses the following concepts: robustness, resourcefulness, recovery* *

➢ Hence: resilience is neither a state of the system, nor a generic condition or attribute, nor a plan.

* OECD/IEA, Making the energy sector more resilient to climate change (2015)

Resilience definition /2

- What resilience is
  - Set of systemic capacities
  - Against (uncertain) threats/hazards
  - Along a process
  - At a given time

Resilience	
What?	*System-wise*
For what?	*Essential functions*
Against what?	*Threat/hazard*
How?	*Capacity*
Phases?	*R, R, R**
Key features?	*Adaptation, learning, transformation*
When?	*Short, mid, long term*

* Robustness, Resourcefulness, Recovery

Resilience curve

Figure 1. The bathtub shape of resilience

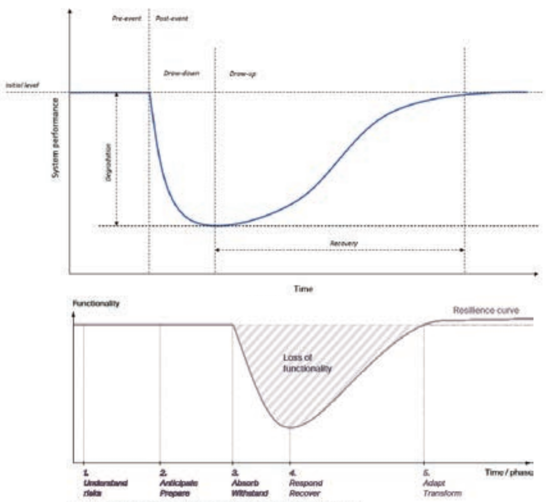
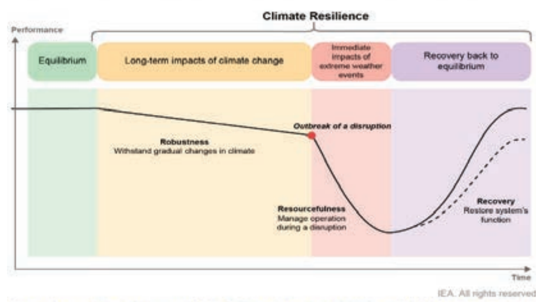


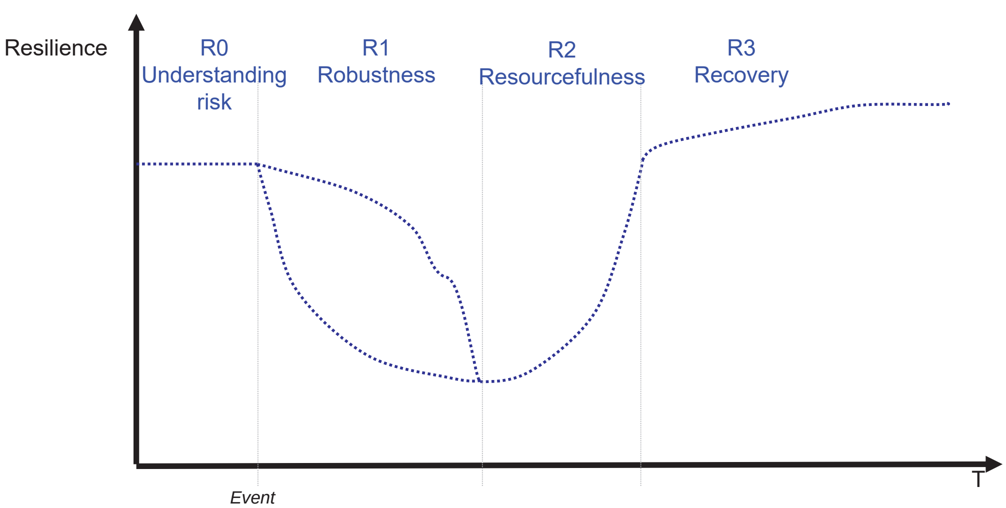
Figure 1: The five phases of functionality in a resilient system (Ren et al., 2018)

Figure 18 Conceptual framework for climate resilience of the electricity system



Source: Argonne National Laboratory (2012), Resilience: Theory and Applications (ANL/DIS-12-1), as modified by International Energy Agency.

Resilience curve /2



RESILIENCE SUMMARY

- Integrative concept
  - 4 phases: Understanding + 3 R
  - Arrangement of many capacities
    - of different nature, needed for secure the delivery of essential services, responding, adapting and transforming the system against a certain risk event/process
  - Several risk scenarios
    - Various attributes as the essential services might be disrupted in diverse ways
  - Anticipating resilience
    - Uncertainty
    - Targets + tracking

- Q: *At which level of the energy system?*
- *A: At all levels (from T to D to communities, from overall systems to specific assets)*

- *Q: Which risk attributes?*
- *A: Those needed for defining the "essential functions"*

- *Q: What is measured by resilience?*
- *A: The readiness/aptness of capacities to deliver their intended actions*

RESILIENCE CAPACITIES

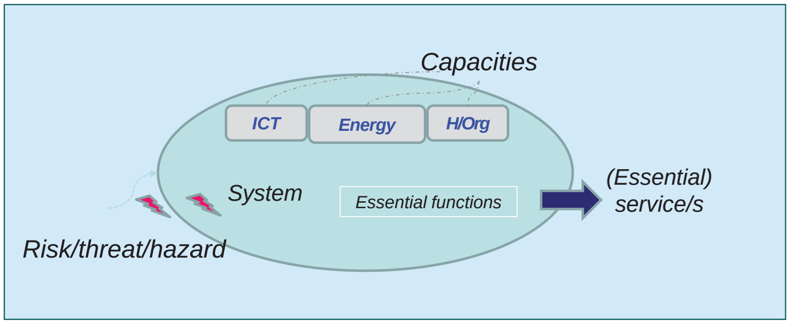
- **ICT**
  - Observability
  - Controllability
  - Communicabili
  - Cyber-security
- **Energy**
  - Genera
  - ardening
- **Human/o ganisational**
  - l adaptation, ransformation)
  - (logistics, etc)
  - Economics/finance
  - Governance/coordination

Resilience is about what a system can do*

Intrinsic + Extrinsic

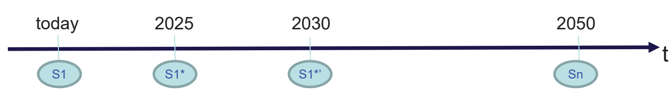
* Hollnagel & Woods, Epilogue: Resilience engineering precepts (2006)

RESILIENCE CAPACITIES /2

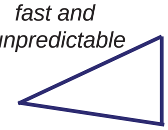


Risk anticipation → Resilience curve - phases → Resilience capacities – per phase → Integration/planning of capacities

RESILIENCE CAPACITIES /3



Arms race, fast and unpredictable



– Threat/hazard changes

– System evolution
- topology, rules, structure
- technological/market innovation
- integration

– Components obsolescence (sw) & degradation/ageing (hw, skills)

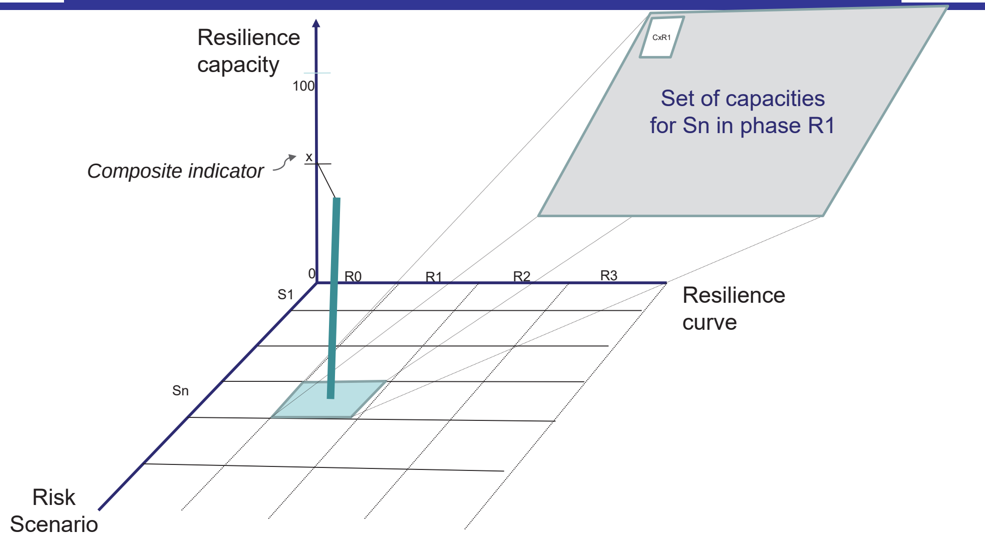
Need to be **anticipatory**
Resilience measures, but for when: today, **2030, 2050**?

Resilience measurement

- Per phase
  - R0 (risk U&P)
  - R1 (robustness)
  - R2 (resourcefulness)
  - R3 (recovery)
- Specific indicators
  - one per capacity x phase
- Composite indicators
  - for each risk scenario/phase

- Q: How to typify/detail capacities?
- A: Identify key attributes: how they contribute to the action foreseen for them
- Q: How to measure?
- A: Define a normalized range (eg 0-no…. 100-full)

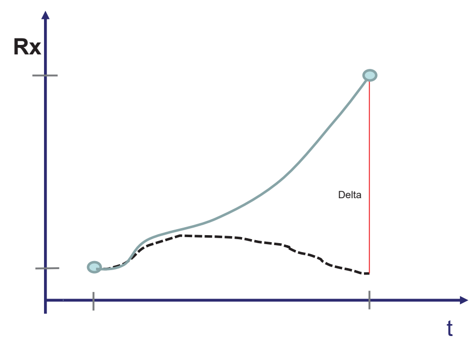
Resilience measurement /2



Resilience target & tracking

Anticipation of future Resilience

- Target in a future T
- Need to track evolution towards Target:
  - *Are R capacities up to expectations?*
  - *Does it look realistic/feasible to reach target?*
  - *Which are the weak points/gaps*



Concluding remarks

Resilience

- Common approach can facilitate **dialogue** across energy sectors
- Better definition of who is **responsible** for what, need for **investment** in terms of capacities
- Better **anticipation** of future needs

Policy measures

- Foster **common framework** for the entire energy system – and beyond
- Benefit of **common ontology** and **common resilience scenarios**
- Common **indicators** for better communication and clear objectives
- **Table-top exercises** as a means for testing resilience preparedness

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Resilience indicators for a power grid with focus on natural hazards

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Abstract

The paper presents a study to develop a framework of resilience indicators for a power grid focusing on natural hazards. Here, resilience is understood as the ability to prepare and plan for, absorb, recover from, or more successfully adapt to actual or potential adverse events. The natural hazards dimension is based on a multi-spectral concept of resilience, incorporating its fundamental properties and dimensions through multiple perspectives. A structure of the indicator framework is developed for the electricity sector.

Extended abstract

Natural hazards can affect the electricity supply and result in power outages that can trigger accidents, bring economic activity to a halt and hinder emergency response until electricity supply is restored to critical services.

For the purpose of creating a power-grid/natural-hazard dimension of a Critical Energy Infrastructure resilience index, resilience is construed as the combination of four fundamental properties, robustness, redundancy, resourcefulness and rapidity, which are commonly referred to as the 4 Rs of resilience [1]. The natural hazard dimension comprises four components, one for each property. Robustness corresponds to the system's inherent strength and includes several aspects of hazard mitigation. Redundancy addresses the diversity of resources and the system's excess capacity. Resourcefulness is a measure of response and recovery capabilities. Rapidity reflects actions taken to expedite the power grid's recovery. Robustness, redundancy, resourcefulness and rapidity should not be seen as distinct activities, but as components of a comprehensive disaster prevention process.

In the most frequent representation, engineering resilience is a function of time of the system performance during a disruption. The resilience curve is commonly rendered as a bathtub shaped curve (see Figure 1). The system performance, in turn, depends on the type of the system, the service provided and the scope and type of analysis. It may be a unit-based value, as well as a qualitative measure of performance.

There is a vivid discussion, though, related to the resilience phases. In other words, what can be done, and when, in order to enhance the resilience of a system and, consequently, which phases should be addressed when seeking the measuring and enhancing resilience of a system. All resilience concepts applicable to energy systems describe the 'draw-down' and 'draw-up' phases of the resilience curve, but they differ with respect to the extent of consideration of the pre-event and post-event phases [3, 4]. There are even very generic approaches, e.g. Manca et.al. proposes a conceptual societal resilience framework [5] oriented towards the resilience of society.

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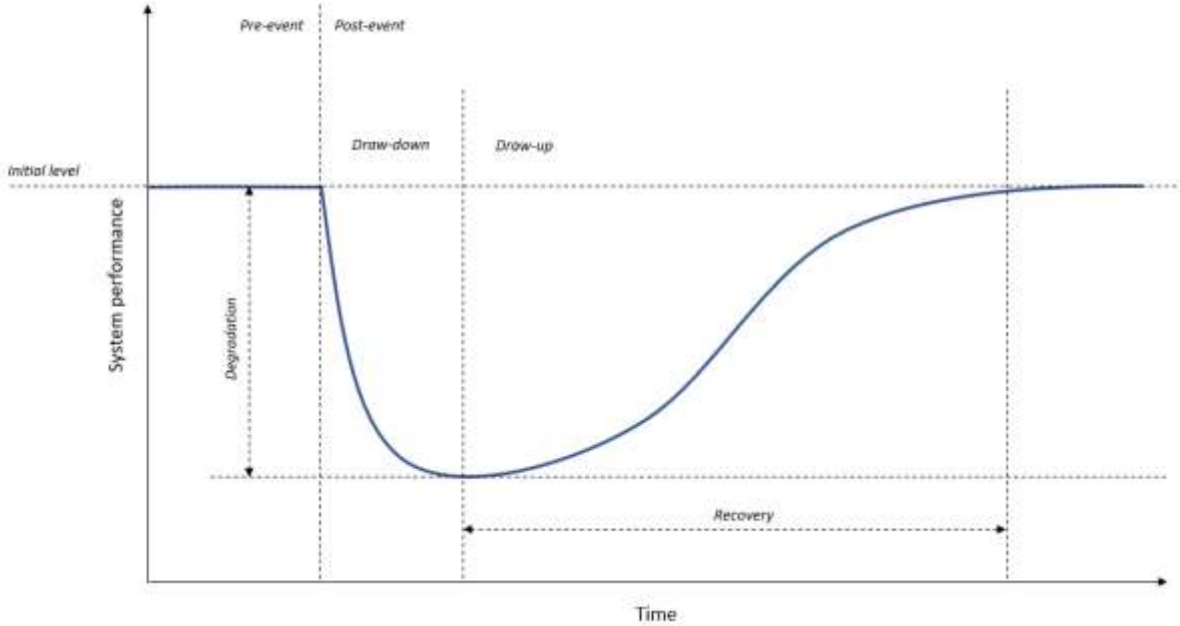
Figure 1. The bathtub shape of resilience



Source: JRC, 2021 [2]

Different natural hazards affect the power grid in a different way. In addition to the level and type of damage, resilience also depends on the design of the grid and emergency response capabilities of electric utilities. Resilient networks can maintain an acceptable level of service despite failures. Resilience also depends on utilities' emergency response capabilities, that is, the mix of training, organizations, plans, people, leadership, management, equipment and facilities to perform required emergency response functions. Emergency planning can speed the response by developing the system to deliver capabilities before disaster strikes.

The proposed structure of the power-grid/natural-hazard dimension of the Critical Energy Infrastructure resilience indicator framework in presented in Table 1.

Table 1: Structure of the resilience indicator framework

	Microscopic level **(single TSO/DSO or country)**	**Mesoscopic level** **(European electricity sector)**	**Macroscopic level** **(interdependencies)**
Robustness	Effectiveness of hazard mitigation measures	Hazard mitigation at the EU level	Mitigation of the interdependencies among electricity and other infrastructures
Redundancy	Resource diversity of individual companies	Excess capacity in the European of national electricity market	Mitigation of the interdependencies among electricity and other infrastructures
Resourcefulness	Corporate and community response and recovery capabilities	European-wide response and recovery capabilities	Cross-sector response and recovery capabilities

Rapidity	Measures to expedite repair and recovery of infrastructure assets and facilities	Measures to expedite recovery at the EU level	Measures to expedite the recovery of other infrastructure sectors

Source: JRC, 2021 [2]

In Table 2 we present a tentative list of indicators for the first 2 Rs of the resilience concept: robustness and redundancy.

Table 2: A list of indicators for robustness and redundancy.

	Microscopic level	**Mesoscopic level**	**Macroscopic level**
Robustness	— Fraction of assets located in a defined hazard zone, aggregated by type — Percentage of assets in the hazard zone designed to withstand the projected hazard intensity level — Percentage of assets protected by external structural mitigation measures	— Fraction of assets located in a defined hazard zone, aggregated by type — Percentage of assets in the hazard zone designed to withstand the projected hazard intensity level — Percentage of assets protected by external structural mitigation measures	— Fraction of CEI support assets located in a defined hazard zone, aggregated by type — Percentage of CEI support assets in the hazard zone designed to withstand the projected hazard intensity level — Percentage of CEI support assets protected by structural mitigation measures
Redundancy	— Network betweenness centrality — Percentage of node connections operated manually, automatically and remotely — Percentage difference between current average demand and generation capacity. — Black start capabilities as percentage of total demand	— Network betweenness centrality — Percentage of node connections operated manually, automatically and remotely — Percentage difference between current average demand and generation capacity. — Black start capabilities as percentage of total demand	— Percentage of telecommunications infrastructure assets equipped with alternative power supply (weighted by duration of supply) — Percentage of healthcare facilities equipped with alternative power supply (eventually weighted by duration of supply) — Centrality of the road networks or communications infrastructure around electricity transmission and distribution nodes

Source: JRC, 2021 [2]

Future efforts could focus on the development of the natural hazards dimension of the composite indicator. Once a definitive set of indicators is selected, we can identify appropriate data as variables. Data can be collected, treated and normalized in accordance with the theoretical framework. Then, we can assign a suitable weighting and aggregation method that respects the conceptual framework and the properties of the data. The composite indicator can be checked for statistical coherence, robustness and quality, as required. Based on the availability of data, the indicator could be tested with one or more case studies.

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Resilience of Power Grids

Natural Hazards perspective

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Resilience indicators for a power grid with focus on natural hazards

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In the most frequent representation, engineering resilience is a function of time of the system performance during a disruption. The resilience curve is commonly rendered as a bathtub shaped curve (see Figure 1). The system performance, in turn, depends on the type of the system, the service provided and the scope and type of analysis. It may be a unit-based value, as well as a qualitative measure of performance.

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JRC TECHNICAL REPORT

Development of indicator framework for resilience of critical energy infrastructure

Project CEI-Resilience Deliverable 2020

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2021

Topics

- Resilience - the new kid on the block
- Why this 'system'?
- How to tackle this issue?
- The objective
- Observing the 'system'
- Observing the threats
- Where and how to intervene?
- The Power Grid resilience framework
- Potential resilience indicators
- Future work?..
- Potential approach for the Resilience Index
- Concluding remarks

Image by Freepik

The quest for Resilience

C. S. Holling, 1973: "Resilience and stability of ecological systems"

- No universal agreement.
- Multitude of definitions.
- Multitude of conceptual and (scarcity of) operational frameworks.
- A plethora of classifications based on the resilience characteristics (*engineering* vs. *ecological* vs. *adaptive* resilience) or domains (e.g. organizational, social, economic or engineering resilience)

Image by bublikhaus on Freepik

No common approach? There shouldn't be any!

RESILIENCE IS…

- Multi-dimensional concept
- Multi-disciplinary effort
- Depending on the perspective and final objective of the analysis:
  - Psychology: the capacity of individuals to withstand major traumatic events and to continue to function effectively.
  - IT: a measure of how well a communication network is able to cope with the disruption of service, epitomized by a power failure.
- Fundamentally dependent on:
  - the positioning and mind-set of the analyst,
  - the system under scrutiny
  - the objective of the assessment

THEREFORE

- No 'good' or 'bad' approach towards resilience
- Important to:
  - Be 'fit-for-purpose'
  - Answer to:

resilience **of what, against what, for whom**

Why this 'system'?

FACTS

- Ubiquity of electricity
- Increased dependability.
- Significant increase of the extreme disruptive events affecting the energy sector.
- Increase in frequency expected.
- Emergence of new type of threats.
- Expansion of the potential enemy pool.

FIGURES

- 24-hour blackout could cost more than the corresponded GDP-per-day of a nation;
- two-weeks gas dispute may leave millions of households without heating during the coldest period of the year;
- almost 80% of the severe power blackouts between 2003 and 2012 caused by severe weather

OBSERVATION

- Traditional risk management strategies are insufficient to prevent against these extreme events, originating from multiple sources and, sometimes, completely out of our control.

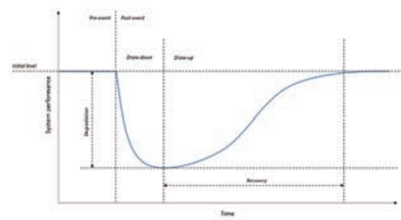
WHAT'S NEEDED

- A 'new way of thinking'. Think the unthinkable.
- From 'what can we do to prevent/resist to/deflect an attack' to 'what can we do to continue to function as good as possible when (and not if) we are under attack from anyone/anything and anywhere'.

Bogdan Vamanu (IFIN-HH)

61st ESReDA Seminar, 22-23 September, Torino

How to tackle the issue?



Engineering

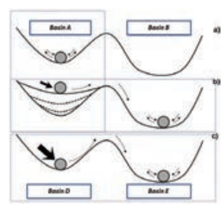
- Rooted in materials sciences
- Highly related to the principles of risk management.
- Emphasizes importance of *resistance* / *robustness*
- Focus on *efficiency* and *consistency*.

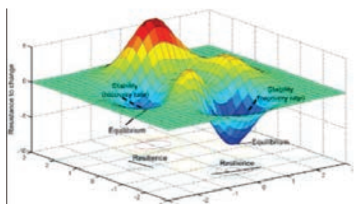
Ecological

- Rooted in the behavior of the ecological systems.
- Theory of complex, adaptive systems (CAS).
- Emphasizes importance of the *tolerance* of the system to disturbances and changes.
- Focuses on the *absorbance* and *reorganization* characteristics of the system.

Socio-ecological

- The need to incorporate the *transformative* capacity of systems





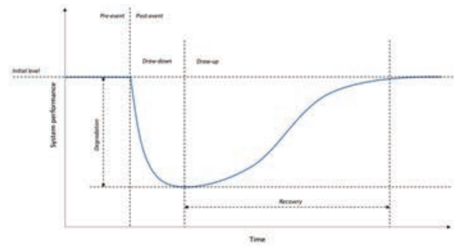
Source: Systemic Steering and Governance

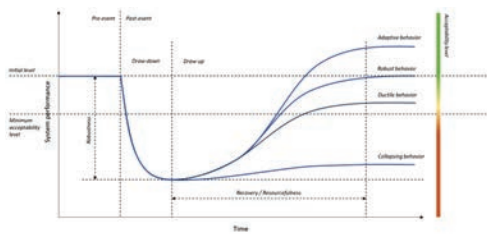
The importance of the 'what's' and 'whom'

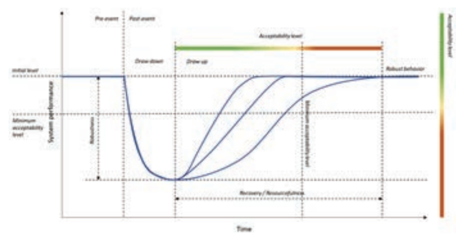
Engineering	Socio-economical
PROVIDE	**FOSTER**
Full control over the system	Partial control over the system, constrained by moral and democratic rules
Understanding of the functioning and governing rules and phenomena	Hoping to understand how it works
The system 'has nothing to say'	Reluctant to change, adaptable
Behavioral consistency	Sometimes unpredictable
Structural consistency	Dynamic systems
Top-down solution	Top-and-bottom up solution

What is the objective?

- Different behaviors of the system.
- New dimensions to acceptability







The resilience of the power grid against Natural Hazards

- Large geographical extent
- Intrinsic frailty
- Backbone of the electricity sector

- the most vulnerable component of the electricity infrastructure, against Natural Hazards
- each natural hazard generates a different type of stress
- results in different types of damage and affects another set of power grid components

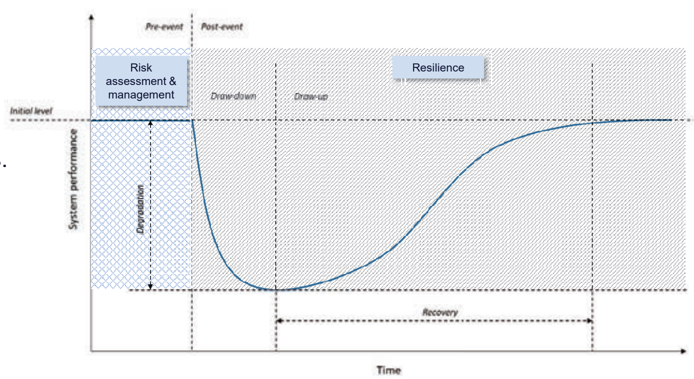
Damage types and natural hazard impacts the power grid

	Earthquake	Space weather	Flood	Storm
Damage types	Structural damage due to inertial loading. Foundation/ground failure.	Damage to transmission and generation equipment from GICs. Potential for system-wide impact.	Damage to transmission tower foundations due to erosion and/or landslides. Moisture and dirt.	Bending failure due to wind pressure. Impact of flying debris. Inundation (substations mostly).
Contributing factors	Soil liquefaction. No warning time.	Early warning possible.	Early warning possible.	Early warning possible. Disaster preparedness.
Most vulnerable equipment	Heavy equipment (e.g. generators, LPTs). Ceramic parts (e.g. bushings, bus bars) or equipment (e.g. transformers).	Equipment vulnerable to direct current (e.g. transformers). Equipment protected from DC excitation	Transmission towers. Substation equipment.	Utility poles and overhead lines. Substations (including transformers).
Recovery time driven by	Number of items in need of repair or replacement. Access to conduct repairs	System-wide impact. Delayed effects	Floodwaters recession (access). Number of items in need of repair or replacement.	Number of items in need of repair or replacement. Access to conduct repairs.
Recovery time range	A few hours to months; most commonly, 1 to 4 days.	When impact is limited to equipment tripping, power is restored within less than 24 hours after the end of the storm. Repairs of damaged equipment may take several months.	Less than 24 hours to 3 weeks. Longer recovery times (up to 5 weeks) with hurricane and/or storm damage.	A few hours to six months; most commonly, up to one month. Recovery time was longer for hurricanes than for other storms.

Which Resilience phases?

- What should be address?
- Where and when to intervene?

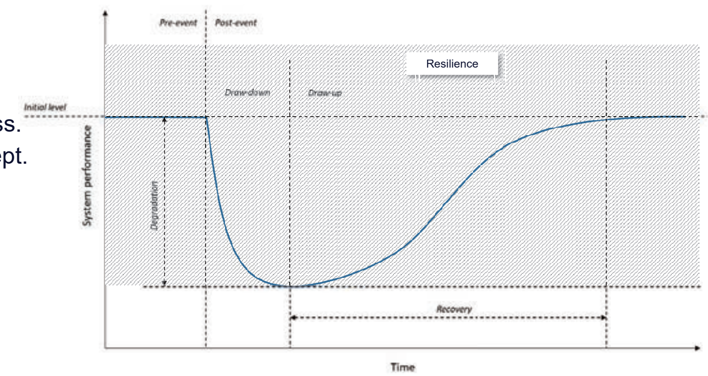
Yet another argument…
- Resilience as separate business.



All Resilience phases

- What should be address?
- Where and when to intervene?

- Resilience as separate business.
- Resilience as enhancing concept.



For a resilient power grid, interventions should go towards the capability and the means of deflecting or mitigating the disruptions <u>before</u>, <u>during</u>, and <u>after</u> the event occurrence

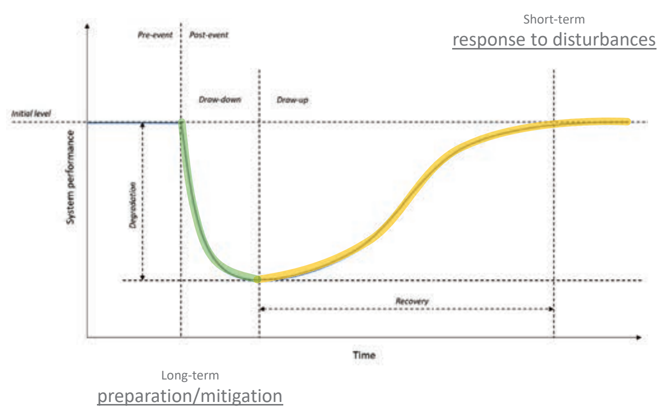
Intervention targets

Short-term measures

- Preventive & correcting.
- Days/weeks before, during or after an event.
- Increase the ability of fast restoration of the system.

Long-term

- Strategic & operational planning, policies.
- Structural & topological hardening.
- Reduction of the consequences of an event and /or its frequency of occurrence



Framing up the problem

Resilience is the ability to prepare and plan for, absorb, recover from, or more successfully adapt to actual or potential adverse events.

Resilience is given by:

- constituent components
- system architecture
- operational procedures
- emergency procedures

To enhance resilience one should address:

- the different *levels* of the system
- all the factors contributing to strengthening the system, namely: preparedness, mitigation, response and recovery

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Contributors to the power grid resilience

- Design of the grid
- Network configuration
- Emergency response capabilities
  - mix of training, organizations, plans, people, leadership, management, equipment and facilities to perform required emergency response functions
- re-routing through interconnections
- interconnections may also contribute to damage from GICs

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Conceptual framework

- four levels of increasing specificity
  - dimensions,
  - components,
  - indicators
  - variables
- resilience is construed as the combination of four fundamental properties, robustness, redundancy, resourcefulness and rapidity
- each property addressed from three perspectives, namely on a micro-, meso- and macroscopic scale
- natural hazard dimension shall comprise four components, one for each property

Levels

Microscopic

- individual companies, including generation companies, TSOs and DSOs.

Mesoscopic

- the European electricity market and sector
- includes the ENTSO-E network

Macroscopic

- interdependencies between the electricity sector and other critical infrastructures

Properties

Robustness

- system's inherent strength
- includes several aspects of hazard mitigation

Redundancy:

- the diversity of resources
- the system's excess capacity

Resourcefulness

- a measure of response and recovery capabilities

Rapidity

- actions taken to expedite the power grid's recovery

On Rapidity

- Quantification of the speed of recovery.
- Most difficult to operationalize.
- Depends on:
  - type, magnitude and location of the disruptive event,
  - scale of disruption,
  - availability of spare parts and repair crews,
  - the accessibility to the disrupted areas

- Also depends on the assessment level: facility, system, regional or national.

Two major directions in assessing the speed of recovery

1. **Direct** – quantify the speed of recovery in respect to time.
2. **Indirect** – *semi-quantitative assessment of the recovery capabilities* of the system, based on a series of measurable structural, organizational and operational characteristics of the system

On Rapidity

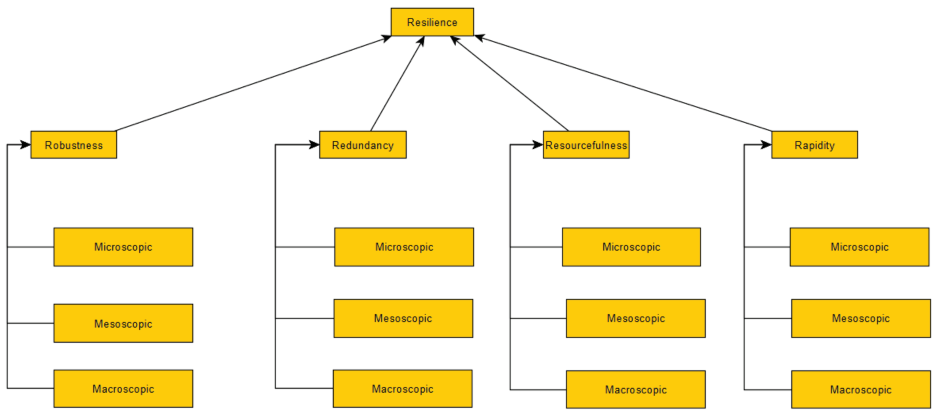
- Speed of recovery of the energy system is given by a series of measurable characteristics indirectly describing its performance:
  - good coordination between the actors involved in the operation and management of the system,
  - ability to quickly identify and communicate failures and their location,
  - the availability of equipment and highly trained personnel,
  - technical and managerial flexibility to change the infrastructure and/or operational procedures based on the lessons learned from the event.

- Performance is estimated in respect to an **incident management procedural anatomy** that follows the succession (Panteli & Mancarella, 2015):
  1. Event occurs
  2. Component outages
  3. Coordination between system operators and repair crews
  4. Data gathering; damage assessment; priority setting
  5. Repair crews dispatch
  6. Restoration of damaged components
  7. Notification of system operators
  8. Decision-making and corrective actions

Proposed structure of the CEI resilience framework

	Microscopic level	**Mesoscopic level**	**Macroscopic level**
Robustness	Effectiveness of hazard mitigation measures	Hazard mitigation at the EU level	Mitigation of the interdependencies among electricity and other infrastructures
Redundancy	Resource diversity of individual companies	Excess capacity in the European of national electricity market	Mitigation of the interdependencies among electricity and other infrastructures
Resourcefulness	Corporate and community response and recovery capabilities	European-wide response and recovery capabilities	Cross-sector response and recovery capabilities
Rapidity	Measures to expedite repair and recovery of infrastructure assets and facilities	Measures to expedite recovery at the EU level	Measures to expedite the recovery of other infrastructure sectors

Proposed structure of the CEI resilience framework



The Indicators

Address technical, organizational, social and economic aspects

- Technical aspect shall incorporate physical systems.
- The organizational aspect will strive to grasp the dynamics of organizations involved in the electricity sector.
- The social aspect should focus on the dynamics of communities and populations.
- The economic aspect should integrate the micro-, meso- and macroeconomic attributes and dynamics of the electricity market, as they pertain to resilience

Quantitative or Qualitative?

Both!

Robustness indicators

Microscopic

- Fraction of assets located in a defined hazard zone, aggregated by type.
- Percentage of assets in the hazard zone designed to withstand the projected hazard intensity level.
- Percentage of assets protected by external structural mitigation measure

Mesoscopic

- Fraction of assets located in a defined hazard zone, aggregated by type.
- Percentage of assets in the hazard zone designed to withstand the projected hazard intensity level.
- Percentage of assets protected by external structural mitigation measure

Macroscopic

- Fraction of CEI support assets located in a defined hazard zone, aggregated by type
- Percentage of CEI support assets in the hazard zone designed to withstand the projected hazard intensity level
- Percentage of CEI support assets protected by structural mitigation measure

Redundancy indicators

Microscopic

- Network betweenness centrality
- Percentage of node connections operated manually, automatically and remotely
- Percentage difference between current average demand and generation capacity.
- Black start capabilities as percentage of total demand

Mesoscopic

- Network betweenness centrality
- Percentage of node connections operated manually, automatically and remotely
- Percentage difference between current average demand and generation capacity.
- Black start capabilities as percentage of total demand

Macroscopic

- Percentage of telecommunications infrastructure assets equipped with alternative power supply (weighted by duration of supply)
- Percentage of healthcare facilities equipped with alternative power supply (eventually weighted by duration of supply)
- Centrality of the road networks or communications infrastructure around electricity transmission and distribution nodes

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Resourcefulness indicators

Microscopic

- Fraction of facilities compliant with regulatory requirements and/or international standards in terms of emergency plans.
- Fraction of emergency plans developed using a defined planning process
- Percentage of emergency and crisis response positions for which staff are cross-trained.
- Percentage of emergency and crisis response staff trained in accordance with regulations and position requirements

Mesoscopic

- Fraction of facilities compliant with regulatory requirements and/or international standards in terms of emergency plans.
- Fraction of emergency plans developed using a defined planning process
- Percentage of emergency and crisis response positions for which staff are cross-trained.
- Percentage of emergency and crisis response staff trained in accordance with regulations and position requirements

Macroscopic

- Percentage of emergency and crisis response positions for which staff are cross-trained.
- Percentage of emergency and crisis response staff trained in accordance with regulations and position requirements
- Number of disaster and crisis response exercises conducted per year
- Emergency repair capabilities as a percentage of planned demands
- Emergency response team average response time as a percentage of projected incident speed of onset

Resourcefulness indicators

Microscopic

- Number of disaster and crisis response exercises conducted per year
- First-response capabilities as a percentage of planned demands.
- Emergency response team average response time as a percentage of projected incident speed of onset

Mesoscopic

- Number of disaster and crisis response exercises conducted per year
- First-response capabilities as a percentage of planned demands.
- Emergency response team average response time as a percentage of projected incident speed of onset

Macroscopic

Rapidity indicators

Microscopic

- Percentage of critical equipment for which replacement parts are readily available
- Percentage of critical equipment for which replacement parts are available through mutual-aid agreements or standby contracts
- Estimated time of availability of replacement parts available through mutual-aid agreements or standby contracts
- Projected capability of readily available repair crews.

Mesoscopic

- Percentage of critical equipment for which replacement parts are readily available
- Percentage of critical equipment for which replacement parts are available through mutual-aid agreements or standby contracts
- Estimated time of availability of replacement parts available through mutual-aid agreements or standby contracts
- Projected capability of readily available repair crews.

Macroscopic

- Percentage of critical CEI support infrastructure for which replacement parts are readily available
- Percentage of critical CEI support infrastructure for which replacement parts are available through mutual-aid agreements or standby contracts
- Estimated time of availability of replacement parts for CEI support infrastructure available through mutual-aid agreements or standby contracts
- Projected capability of readily available repair crews

Rapidity indicators

Microscopic

- Projected capability of repair crews available through mutual-aid agreements or standby contracts
- Estimated time of mobilization of repair crews available through mutual-aid agreements or standby contracts

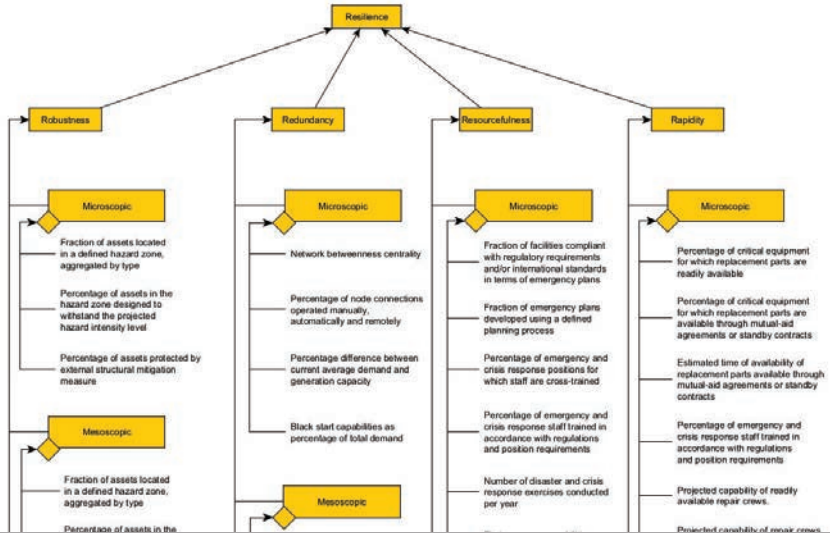
Mesoscopic

- Projected capability of repair crews available through mutual-aid agreements or standby contracts
- Estimated time of mobilization of repair crews available through mutual-aid agreements or standby contracts

Macroscopic

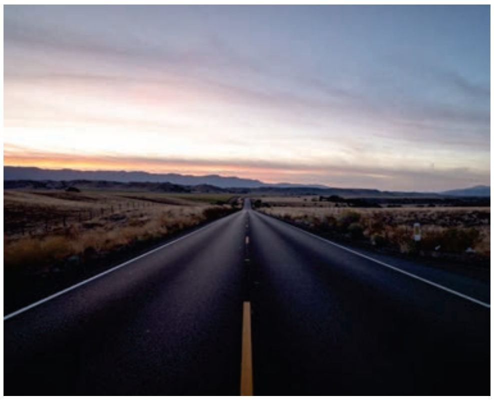
- Projected capability of repair crews available through mutual-aid agreements or standby contracts.
- Estimated time of mobilization of repair crews available through mutual-aid agreements or standby contracts.

The global picture



Future work…

- development of a composite indicator for the natural hazards dimension;
- identification of appropriate and available data as variables;
- data collected, treated and normalized in accordance with the theoretical framework;
- assigning a suitable weighting and aggregation method that respects the conceptual framework and the properties of the data;
- testing the indicator with one or more case studies.



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At a closer look…

Logic model

- Effective tool for describing and organizing a complex system in terms of structure, assets, actors, flows and interactions between them;
- Allows describing the system from both the strategic and operational perspective.
- Employ clusters and hierarchies, as the means to group conceptual, functional, or operational characteristics of the system depicted.

Hierarchical model

- Depiction of the dependability between the constituent variables of the model
- Capturing the contextual effect (variation of influence) between the model variables
- Allows applying a logic that flows from specific to general in the form that subordinate attributes describe the broader ideas above
- Ends up at a level containing the 'metrics' (i.e. raw data or indicators) that can be more easily found available, computed, or evaluated.

A possible Resilience Index

- Composite index to characterize the system's overall resilience.
- Expression of the comprehensive, multidimensional measure of the level of resilience from the performance in achieving the objectives defined by the four properties for each individual levels.

- Monitoring the evolution in time.
- Identifying the 'weak spots'.
- Testing alternative scenarios and their impact on the overall resilience.

- Derived in a deterministic manner.
- Approach rooting in the multi-attribute utility theory (MAUT)
- Scores computed using the additive form of MAUT

$$U = \sum_{i=1}^{n} w_i u_i$$

w_i – the importance weight for attribute i in the realization of the current attribute;
u_i – the utility (score) of attribute i.

$$\sum_{i=1}^{n} w_i = 1$$

A possible Resilience Index (Scoring system and scale)

- Accommodate the different type of indicators (quantitative and qualitative) within the same computational scheme.
- Preserve balanced influence of all indicators, which means avoiding a higher influence of one quantitative indicator given by its sheer value.
- Provide meaningful and comparable results

⇒ 5-point modified Likert scale (0 added)

	0	1	2	3	4	5
Attribute ratings	Not applicable	Low	Moderately Low	Moderate	Moderately High	High
Weight ratings	No influence	Low influence	Moderately Low influence	Moderate influence	Moderately High influence	High influence

Normalization

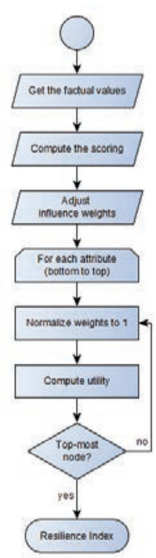
$$I = 5 * \max\left(1, \frac{V_a - V_{min}}{V_{max} - V_{min}}\right), 0 \le I \le 5$$

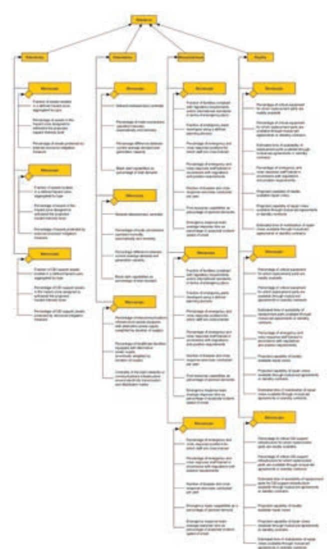
$$I = 5 * \left[1 - \max\left(1, \frac{V_a - V_{min}}{V_{max} - V_{min}}\right)\right], 0 \le I \le 5$$

V_a – the actual value of the attribute
V_{min}, V_{max} - the minimum and maximum value of the attribute

Computing the Resilience Index

1. Get the factual values of the instrumental (quantitative) indicators.
2. Assign the scoring of the instrumental parameters:
   a) Either by normalizing the factual values using the provided equations (for quantitative indicators); or
   b) Directly in the 0 to 5 scale for qualitative indicators, based on your expert opinion.
3. Adjust the influence weights of the system model (0 to 5 scale) according to your preferences.
4. For each attribute on a higher hierarchy:
   a) Normalize to 1 the influence weights.
   b) Compute its value (utility).
5. Repeat Step 4 until reaching the top-most attribute (i.e. System's Resilience)





Wrapping up…

+ Flexibility
Scale
Scope
Subject Objective

+ Conceptual soundness
Operationalization of the narrative

+ Simplicity
Clear concepts,
Simple and natural techniques for modelling
Basic algebra in the analytical expression

+ Valuable results and insights
Snapshots
Trends
Past performances
Monitoring / Scenarios evaluation

- Availability & Quality of data
Garbage-in garbage-out principle

- Intrinsic level of subjectivity
For our case, is a must for capturing the effects of the 'un-tangibles'.
Certain level of objectivity can be achieved through 'equal-weights' approach.

Wrapping up…

! we do not pretend to have perfectly captured resilience within the concepts and metrics presented;

further insights of experts and interests of all stakeholders must be thus considered and incorporated to an appropriate extent;

additional viewpoints would undoubtedly broaden our understanding and assessment of resilience in the energy sector.

Thank you

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A monitoring-based management approach for Natech-related risks: reflection from a case study

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Abstract

Natech risk management is an example of the difficulty of understanding and dynamically monitoring several physical phenomena in order to prepare a decision to adapt an industrial tool. On the one hand, the models on which to base the decision are very contextual and complex, integrating several hypotheses to be controlled. On the other hand, there are choices to be made concerning the parameters to be followed. Finally, there is a management of modifications, the analysis and monitoring processes being iterative. The monitoring must allow to trigger the eventual decision, and/or to lead to the evolution of the models and/or the choice of new monitoring parameters. We will present this difficulty from the case of an installation located at the seaside, confronted with a risk of submersion/flooding due to the recession of the coastline, to the erosion of the dunes, to the possible bypassing of the dunes during storms, to the rise of the water table during storms. This problem is obviously linked to global warming, but not only. It is also a contextual situation, aggravated by developments carried out over the last forty years by a municipality close to the site to avoid a coastal risk, and by the operating choices of several other industrialists nearby. How can we monitor the evolution of these phenomena and their potential impact on the integrity of installations? How to define selection criteria? How can global models and contextual factors be articulated? How to put this work in perspective with regulatory requirements? How can we bring together in a simple process the many actors who will participate in these analyses, follow-up actions and decisions? Our purpose is to discuss the mode of organization of expertise and knowledge that we envisage, which consists in using digital technology to co-construct: 1/ the models adapted to the case study and to the characteristics of the decision to be served, 2/ the analyses and choice of parameters to be monitored, 3/ the monitoring systems, 4/ the principles of the decision, 5/ the management of changes at all levels (model, parameter, monitoring, decision). All this with the concern of giving the actors to follow a scientific method where uncertainty management plays a central role.

1 Introduction

As stated in the JRC Risk Management Technical Report for Natech (2022), Natech risk assessment requires a significant amount of input data, such as information on the natural hazard, the vulnerable equipment, damage models and data linking damage to releases, consequence analysis models for human health and the environment / ecosystem, likelihood estimates and information on the risk receptors. And the authors add that there are a number of uncertainties in Natech' s data and risk models. (especially for very rare events). The key finding is the following. Natech risk analysis usually contains a larger number of uncertainties compared to the analysis of other types of technological risks:

- missing and fragile data for specific natural hazards and for certain types of vulnerable equipment.

- the absence of consolidated models for Natech risk analysis (including damage or consequence analysis models for human health and the environment / ecosystem[1]). The analyst may resort to using expert judgement that is - by nature - subjective to complete the missing information, adding further uncertainty to the analysis.
- the increase and transformation of Natech phenomena in the future; disaster scenarios that seemed too improbable to be really taken into consideration seem to be more and more possible and appear to us as new; in a context favourable to territorial mutation (galloping urbanization, rapid industrialization, deforestation, soil artificialisation).
- the randomness of certain phenomena which constitute natural sources of uncertainty (some appear to us -and are perhaps- intrinsically indeterminate).
- the major nature of the risks (which is a decisive subjective dimension): the more we want to control risks, because their consequences are considered more and more unacceptable, the more precise we have to be in managing the realities of dangerous phenomena, installations, and practices, the more precise the data and the risk control models have to be... the more we encounter shortcomings and uncertainties.

When these uncertainties concerns major accident scenarios[2] there is a major problem:

- it is therefore not possible to regulate prevention on the basis of feedback from accidents, because these accidents, being by definition major, it is unacceptable to accept its occurrence.
- there are too many uncertainties to know exactly what risk control measures to implement.

How to manage major Natech risks in an acceptable way? It seems necessary to turn to a management approach centered on the acquisition of new data as sources of a dynamic design and re-interrogation of the assumptions that form the basis of the acceptability of risk control models on which risks taken are based. In simpler terms, we can say that it would be a management approach based on periodic “active” monitoring (vs a passive follow-up that does not try to question the realism of the model, and vs a more traditional and bureaucratic management focused on the implementation of procedures -paperwork approach).

This article attempts to reflect on this management logic, that would take note of these uncertainties (Leva, M.C., 2015). The challenge would be to lay the foundation for a duplicable and scalable approach to better manage Natech risks, including site and territory levels. However, because it is easier to ask questions based on an example, this article will begin by presenting a case study.

2 Case study: the need for a specific monitoring system

The case study X presented here describes a perfectly realistic and typical problem. The case study focuses on a Natech risk associated with the operation of a dangerous substance depot. This depot is located near the Sea, about 1km from the coastline. In the 50's, the site of this depot is built in a completely natural environment. Fifty years later, a seaside town has been built nearby. The area where the site is built is extremely low. Almost the entire area is less than 2 meters above sea level. Only a few dune strips exceed this altitude.

There is an increasing risk of marine flooding due to storms surges and wave setup that can easily raise the water level by 3 meters, or even 4 meters in the most extreme cases. Developments related to climate change tend to amplify this risk by playing on the rise in sea level and the increased probability of stronger storms. But this is just one of the factors. The main problem comes from the retreat of the coastline for several years, due to the developments made near the depot which have on the one hand cut the supply of sand (industrial

(1) Let us insist on the fact that consequence analysis models must take into account human health and the environment (ecosystems), in accordance with the orientation of the EU Seveso-III Directive - 2012/18/UE, even if in the national translations of this regulation the part concerning the environment is poorly - or not at all - treated. It should also be noted that natech scenarios affect both the probability of pollution events *and* their intensity or geography. For example, a flood may increase the likelihood of a pipeline rupture but also transport large quantities of pollutants away from the site.

(2) In The EU Seveso-III Directive - 2012/18/UE ‘major accident’ means an occurrence such as a major emission, fire, or explosion resulting from uncontrolled developments in the course of the operation of any establishment covered by this Directive, and leading to serious danger to human health or the environment, immediate or delayed, inside or outside the establishment, and involving one or more dangerous substances.

developments on a nearby location), and on the other hand created currents that remove the sand at the location of the depot. The coastline has retreated about 500 meters since the creation of the depot (and the phenomenon will continue), the slope of the beach steepens, risking the discovery of a pipe, and storm waves lead to the erosion of the dune line. In addition, it is possible that during storms the water table in the land near the repository may rise due to the temporary increase of the sea level. This point is still to be studied.

The consequences of saltwater flooding on the integrity of the site must also be studied. Among them, there will certainly be an increase in the risk of corrosion on the steel plates that make up the tank walls. This risk in particular is currently the subject of numerous and complicated discussions with the inspectorate, because several regulatory texts apply concerning major risks, the ageing of installations, and the implementation of good practices included in the legislation. This risk is also the subject of an in-depth study, with the participation of several type of experts, on the whole network of depots managed by the operator across several countries with different legislations. These tanks have been designed in such a way that the external walls of the steel are not accessible. The analysis of a possible corrosion must be done when the tanks are empty and cleaned, from the inside.

To ensure the control of the risks of "small leaks" (accidental but chronic leaks that are difficult to detect with traditional operating means) that a possible corrosion could cause, the operator has implemented:

- a periodic osculation program, which proceeds by sampling on the basis of a study which concerns the 150 tanks, revisable according to the results (modification of the sampling and/or of the periodicity...)
- a monitoring system, implemented on all its plants, based on the transfer time of hydrocarbons which conditions the detection of possible small leaks, on a very sophisticated and precise level control device, on detectors in the drains, and on a network of piezometers whose positioning has been defined on the basis of hydrogeological studies (not all sites are equipped).

The whole system is monitored by an international level steering committee every 6 months. This entire organization can be re-examined for our case study site, as the criticality of the risk of a small leak could be modified by the flooding problem.

The following points should be noted from this case study:

- The contextual nature of the problem, and the interweaving of global phenomena such as sea level rise and the increased probability of strong storms with local land use issues around industrial sites. If the site had been built 500 meters further along the coast, where currents (largely related to land use) deposit sand, there would be no risk of flooding but a reinforcement of the dunes against storms.
- The abundance of regulations to take into account and the complexity of discussions with the administration in charge of operating permits, and with local stakeholders.
- The diversity of monitoring actions to be nested:
    - i. On the side of natural risks: Monitoring of coastline retreat by satellite image; Monitoring of dune erosion during each storm; Monitoring of flooding near the site to see if there is possible bypassing of dune ridges during storms; Analysis of water table variation during sea level rise during storms; and if there is a correlation; analysis of flooding risk; Geolocation of marine pipeline and analysis of sand height above it; Consider modeling/projection incorporating flooding and rising water table.
    - ii. On the side of technological risks: Study of cascading effects integrating flooding risks, review of criticalities, quantification of the severity of environmental consequences of a possible pollution (not required by law but particularly critical in this case study); Monitoring of the possibilities of access to the site, according to the needs related to the various scenarios of crisis management; In-depth study of the integrity of the safety devices (barriers), in particular of the possible common failure modes by operating phase, analysis of the criticality of the possible impacts, and possible revision of the exclusions; In-depth study of the impact of Natech scenarios on the risk of corrosion; Study of the impact of Natech scenarios on the safety of the

workstation; Assessment and identification of modifications to be considered in the safety management system.

- The necessarily dialectical character of the assessment and monitoring approach, characterized by a possible questioning of the risk control model according to the analysis of the monitoring results. For example, in order to know whether the water table evolves with the rise in water levels during storms, specific monitoring work needs to be put in place? Similarly, the periodicity and sampling of the evolution of possible corrosion points on the external walls of the tanks concerned will have to take into account the occurrence of such and such a type of flood, to be determined and monitored in the field. Perhaps this will change the criticality, and therefore the need to revise the leakage risk prevention strategy; but it will be necessary to optimize the ad hoc prevention strategy to be implemented at the problematic site with the national and international strategy to harmonize them, and to guarantee both a reduction in their costs and in the effectiveness of their management (scale effect), Etc.

We assume that these are in fact typical aspects of Natech problems (Rey-Valette H, Balouin Y, 2016). This would mean that Natech risk monitoring must be based on a specific logic that is flexible enough to cope with the complexity of contextual problems, regulatory issues, a wide variety of monitoring actions, and a continuous dialectic with risk assessments that incorporates multi-scale requirements, both at the level of disciplines to be mobilized to deal with natural and technological hazards, at the level of territories, sites and networks of sites, and at the temporal level (Pilone, E., Demichela, M, 2019).

3 Typical issues

How can Natech' s risk monitoring be flexible enough to deal with the complexity illustrated by this case study? Monitoring is clearly a part of the ISO-31000 risk management process proposed as the basis for risk management by the JRC Risk Management Technical Report for Natech (2022). However, good monitoring practices able to cope with the complexity never seem to be explained in detail. In the 55-page JRC report (2022), there are no more than 10 lines on risk monitoring.

Since 2014, facing monitoring problems of the type that need to be tackled for our case study, INERIS and SNOI with Interactive have been thinking about and developing a flexible risk monitoring approach and tool[3]. The difficulties encountered could be classified into 5 categories. These difficulties are all related to the problem of the dialectic between monitoring and risk assessment. The fifth is by far the most important, because it characterizes the difficulty to have an approach which allows to deal frontally the problem of the complexity of the specific, diverse, and multi-scale problems, therefore of the uncertainties which justify the dialectical approach. It should be noted that this fifth category of difficulties requires the resolution of the first four.

The first category of problems concerns the fact that the monitoring of a major accidental risk is based on a risk control model (singular) that crosses several studies (plural). In our case study, we see, for example: the study of major risks, the study of aging, the derogatory study (demonstration booklet of a double envelope alternative), and the studies of natural risks. This means that the scope of risk monitoring is not the same as that of risk studies. It is not a question of having a monitoring logic specific to each study, but an overall logic that is fed by the diversity of the studies. This means that the management of monitoring is independent of, or even transversal to, that of the risk studies, in order to allow cross-referencing. In concrete terms, this means that the risk studies must be carried out in relation to each other in order to feed the same risk control model from which the monitoring work will be carried out. This point obviously poses significant difficulties, as experts generally work independently of each other, and risk studies are generally closed in on themselves (in the sense that they are not co-constructed around a reference framework shared with others). It is up to the operator to reconstitute his risk model in a unified way... a difficult task when it has not been anticipated from the beginning of the risk studies. Let's add that it is a very difficult task without a computer tool, and that a database will be much more convenient than an excel file, when the systems considered are complicated (and they all are when the studies must be precise because the stakes are of major importance), as it is the case in our example.

(3) This research started within the framework of the European project TOSCA and gave birth to the CBMS approach (Computerized Barrier Management System) renamed, by 2020, in MIRA (Monitoring Integré des Risques Actualisés).

The second category of problems concerns the fact that risk assessment often takes a generic approach, whereas risk monitoring is necessarily specific. Risk assessors will always seek to treat facilities or practices as coherent whole. To speed up and facilitate the analysis, their approach will seek to be as abstract as possible. So, for example, in our case, the risk studies consider a "tank system" that is valid for several tanks that are deemed identical for the purposes of the study, grouping together some of the piping and all the safety devices. However, the monitoring will have to be done by tank... which are never totally identical, if only because they are not always equipped with the same safety systems of the same technology, or simply because they are not located in the same place. A tremendous amount of work will need to be done to ensure that risk assessments and facilities match actual operational practices. This work is partly carried out by maintenance in particular, which must take charge of the specifications considered in the risk studies, for example with regard to safety barriers (response time of safety chains, independence from the installation's operating system, etc.). But, on the one hand, this work is not systematically carried out. On many sites, it is common to observe a disconnect between risk assessments and the reality of the installations: assessments can be significantly modified without any change in practices or installations in the field, or vice versa. On the other hand, maintenance does not consider exactly the same elements as monitoring. For example, monitoring must reconstruct the systems considered abstractly by the evaluators, by tank, to have the means to update the calculations; this is not a requirement of maintenance, as this type of system is an abstraction only useful for risk assessment or monitoring.

The third category of problems concerns the fact that risk assessment are not always consistent. The complex and voluminous studies are carried out with Excel and Word, without the support of a database, and it is difficult for the writers to verify their integrity, especially when, at the time of writing, the assumptions are changed, the names evolve, the calculations are redone, the descriptions are modified, etc. This poses problems of consistency within a study, but also between studies, and even more so at the level of a multi-site network that would like to have harmonized management of its facilities and operating practices. All of this usually goes unnoticed because the reader has no way to verify their integrity. Not to mention that the readers are rarely the same, that each study has its specialists, and that they are rarely responsible for correcting all the studies of an entire network (at least if they are, they rarely have the means). Moreover, these studies are composed of numerous annexes, not always up to date, provided by different services, which the authors of the studies do not have the time, the means or the mission to control. The most astonishing example is that of the analysis tables (preliminary analysis, Hazop, etc.), made in Excel, where the means of risk control are not managed in a single list and therefore change name from one line to another, or from one tab to another... and this does not bother the analyst when he does not have to anticipate the management of these means. This poses a problem for monitoring, which must have clear and consolidated lists of what to monitor.

The fourth category of problems concerns the difficulty of identifying, in risk assessments, the parameters and computational elements that will constitute the conceptual infrastructure for monitoring. All the elements needed for monitoring are (or could be, or should be) in the risk studies, but these studies are not done to help with the monitoring work. The risk studies seem most of the time (we know of no counterexample) to be focused on the steps of the methodological reasoning, so that the critical components and tasks are presented in different parts of the reports, in an unsystematic and non-explicit way, from several angles, with several levels of abstraction, and sometimes (often) with different names (the same equipment can be named differently in the same study). Moreover, the analyses are not systematically conducted with the same level of depth. For example, the means of controlling risks identified as "MMR" (i.e., as barriers that must meet the requirements of the French regulations) will be analyzed in greater detail than the safety measures that do not fall into this category. It is up to the operator to voluntarily make the effort to systematically analyze with the same level of depth all his means of risk control as if they were "MMR". But, for control purposes, an equal and systematic level of analysis is needed, clearly describing all parameters (technical components and tasks) and all calculation elements.

Let's take stock. The monitoring of a major accidental risk is based on a risk control model, whose constitution and updating must be an objective in itself of the management, and which implies working on the basis of risk studies on the problems of correspondence with the realities of the installations and practices, of coherence, and of systematic identification of all the parameters and all the elements of calculations which constitute this model. But that's not all.

There is a fifth category of problems: monitoring data should not only be used to say whether, given the model, risk control is satisfactory or not, they should also lead to questioning the model itself, helping to improve it. Monitoring is understood here as a key element of scientific reasoning on risk control modeling. It is about being able to dynamically manage a model, a monitoring system and modifications of the whole. This is what we see in our case study, and it is all the interest of the Natech problematic whose uncertainties will perhaps obliterate in a certain way to enter in this follow-up logic. Since the problems are contextual, as our case study perfectly shows, with an imbrication of natural risks, technological risks, land use choices and uncertainties at all levels that cannot be solved by existing regulations or good practices, it seems necessary to adopt an interactive management approach based on a dialectic between the elaboration of an action model and the modification of this model in order to reorient the action on the basis of the results produced by the monitoring. Indeed, it is a matter of putting at the heart of risk management a scientific reasoning approach that is precisely designed to tackle uncertainties head on, by accepting to proceed by hypotheses. Here, the boundary between scientific research and the industrialization of management practices (Taylorian tendency) is blurred in favour of an integration of science into the very dynamics of the management life cycle which cannot be done without a comprehensive review of risk management (see the discussion section of this article).

4 Proposal for a digital approach

How to deal with the five categories of difficulties we have just listed, in order to deal with the complexity of Natech risk as seen in our case study? There appears to be a need to organize the management of a “major risk control model”, which would be what is questioned by the monitoring in the risk studies to demonstrate that the risks remain acceptable over time. This model would be unique and continuously evolving/ constant change, while risk studies and monitoring are plural and discontinuous/ periodically redone.

A/ The major risk control model of a plant would be exclusively made of calculation elements and risk calculation parameters.

1. Parameters. These would be:
    - (a) Critical components. We propose to name in this way all the physical components that enter as parameters in the risk calculations. These components are:
        - i. the facilities, buildings, equipment, safety devices, etc.
        - ii. the substances
        - iii. the elements of land use planning: housing, critical infrastructure,
        - iv. the natural environment: ecosystems, water, etc.
    - (b) Critical tasks. We propose to name in this way all the tasks that are performed on or with these critical components in normal or degraded situation, and that enter as parameter in the risk calculations. For example, the task of an operator who has to press an emergency stop button within x minutes if an alarm appears. Or the task of maintaining this alarm. In our opinion, these tasks are systematically (or should be systematically) described in the safety measures/barriers, and explained in the associated procedures.
2. Calculation elements. These would be the elements of the risk calculations, which aim, at the end, at estimating the acceptability of the risks. They take as parameters the critical components and tasks (some calculations are also based on other elements like weather data). These elements of the risk calculations are:
    - (a) The events (initiating events, central feared events, consequences), for the calculation of the probability, the intensity, the distance of effect and the gravity of the dangerous phenomena.
    - (b) Measures/ barriers, for calculating the performance of risk control measures.

    Note that events are possibilities, that means abstractions, associated with components, and that measures/ barriers are also abstractions generally grouping several components and tasks. We consider them as elements of computations because they carry the computations, while the parameters (components and tasks) are exclusively variables representing current realities whose changes of state can impact the result of the computations.

    Example. The corrosion of a steel plate is a change of state of a parameter. The corrosion of this type of plate at a frequency x is an event whose possibility enters a probability calculation.

B/ The risk studies would design the model:

- Establish the lists of critical components and tasks with detailed specifications, and establish how these parameters are used for calculations.
- Establish the calculation algorithms.

C/ The monitoring work would use and question the model:

- Monitoring would be done by checking the status of the parameters (critical components and tasks) that are used in the risk calculations. The monitoring would consist in having the means to periodically update calculations on the basis of the update of their parameters, and in verifying that observed deviations do not affect the acceptability of the risks.
- Monitoring would ensure that the correspondence of actual installations to the specifications of these components and that the correspondence of actual operating practices to the specifications of these tasks is effective and correctly check; because the monitoring is based on the establishment of correct lists of:
    - o all critical components, with: labelling in the field; codes in operating tools (CMMS, ERP, control panels, etc.); location on a ground plan; location on PIDs; location on a GIS; their specifications, which validate the demonstrations of an acceptable risk level
    - o all critical tasks: whose specifications are described in the human barrier analysis or in the associated procedures; which form the basis of the organization of the control of major risks (support and management processes)

The studies and monitoring of risks would be part of a virtuous improvement dialectic. Monitoring would be based on risk studies, and it would lead to rereading, to checking the consistency of the studies, to verifying the correspondence of the studies with the realities of the installations and practices.

A database should be used to support at the same time the management of the model, of the risk assessment processes, and of the monitoring works, in order to:

- Improve the back and forth between all the stages of the studies until the monitoring stages, and in particular, to carry out directly, the constitution and the verifications of the lists of specifications of the parameters and the calculation algorithms, as the risk studies are carried out through monitoring actions.
- Strengthen collaborative work and review cycles for studies and monitoring by stakeholders
- Promote consistency and data sharing between sites, territories, and inspectors
- Manage the multiple and extensive data processed by monitoring.

The central idea is that, basically, risk studies and monitoring work would constitute one and the same action: the design, control and updating of the risk control model. Conducting a risk study would automatically and implicitly prepare the monitoring work from the start. And conversely, doing the monitoring work would automatically and implicitly be doing a review and possible update of the studies. All this would be controlled by the major risk control model, which would guarantee a continuous internal consistency check between the studies and the operational tools (EPR, CMMS, etc.) that feed the monitoring.

From a knowledge management point of view, the only requirement, and it is a big one, is to try to stop using Word or Excel, because they are not databases and they do not allow to manage the integrity of the model. To ensure this integrity, you need an application that allows you to manage each critical component and each critical task in a single copy, and that allows their integration into the calculations (which are also managed in a single copy), via screens and operations adapted to each stage of the studies and monitoring. It is important to note that these parameters should not be ordered in relation to each other, classified beyond what is necessary for the calculations. They are only parameters, that is, they only have meaning from the perspective of these calculations. It is the way in which they are used by the calculations, in the different steps of the risk analyses, that allows them to be classified.

Managing each element (component, task, calculation) in a single copy is crucial. This allows to:

- Ensure that it is the same element, this element with its properties, that plays this or that role in the risk control model
- List all the elements that must be managed, monitored and maintained over time
- Measure the consequences of a failure of a particular element
- Better control its errors (having mischaracterized the properties of the concepts/knowledge and their dynamics) by giving the stakeholders the means of criticism
- Better identify the principles and limitations of a model, ... in order to better question and improve it if necessary

5 Project and tools

This approach need to be specified, improved, and tested. IT difficulties are obviously numerous[4]. It would be necessary to have the means to manage:

- all the stages of risk studies and monitoring work
- the parameters resulting from studies on natural and technological risks, with the actors who are able to identify, design, build, modify and control them
- the complex and diverse computational methods, especially when it is necessary to integrate the spatial and temporal problems characteristic of Natech problems
- a platform approach rather than a closed software, in order to keep the necessary flexibility to respond to the diversity of needs of operators, territories and inspectors, and to accompany the evolution of these needs over time. You have to be able to design and maintain not one application but as many applications as there are particular cases.

This will be the next challenge of BRGM and INERIS, with SNOI and other operators interested in this approach, through the coupling of two already existing and operational IT tools[5]:

- VIGIRISK for Natural risk analysis and for analysis of cascading effect analysis and system resilience (from BRGM).
- MIRA-InOV for Physical & technological risk analysis, for resilience option selection, and for decision support & monitoring (from INERIS, SNOI and Interactive).

VIGIRISK is a tool for incorporating expert-users, methods, data and tools to deal with natural risks in a territory. It is a web platform allowing the execution of risk assessment workflows and the production of valued data sets useful to the natural hazard communities. This platform ensures reproducibility, allowing transparency but also improving efficiency by easing collaborative work and sharing results and practices to different end users or to scientists working on related topics. The scientific scope is risk assessment in the domain of natural hazard (e.g. seismic, landslide, submersion) from the phenomenon modelling to the impact evaluation on exposed elements such as buildings and networks. It is intended to have a wide range of methods for calculating hazard and susceptibility and relations between risk and vulnerability for calculating damages on identified assets. The platform supports workflow for data analysis, preparation and transformation. This platform will allow the use of scientifically validated methods, but it will also serve as an innovation tool allowing scientists to propose new methods of risk assessment and to proceed their validation more easily on several datasets covering different study areas. Currently several workflows are implemented for damage and risk calculation for different combinations between several hazards and different levels of description of the exposed elements (landslides, earthquakes, tsunami).

([4]) In the literature several authors have highlighted the steps required in the development of an expert system or a decision-making support system as part of a complex of intelligent technological management of the reliability and efficiency of oil and gas systems (Zemenkova et al. 2020), and many of those steps are in common with the one followed when developing IT solution for Natech risk assessment and monitoring.

([5]) This is one of the objectives of the IRIMA project (a French research project planned over eight years, starting in 2023). We come back to this project in conclusion.

MIRA-InOV (Integrated Monitoring of Updated major Risks – Monitoring Intégré des Risques majeurs Actualisés)[6] was initially developed within the EU funded project TOSCA with the contribution of: INERIS, Interactive, TU Dublin, and POLITO. Then, it has been continuously improved through research partnerships with industrialists, and particularly with the SNOI. MIRA is an integrated web-based risk management tool, for major hazards (which, by definition, cannot be regulated by trial and error, but by driving a model). It is an IT solution based on a continuous updating of risk control models and, consequently, of all the knowledge supporting the modeling of risks and their uncertainties. MIRA monitors the criticality of the technological risks (and of all the items allowing its calculation), the internal consistency of the models and their correspondences with actual facilities and practices. It numerically integrates thousands of pages of risk studies, operational procedures and recording. MIRA allows direct entry and dynamic management of all descriptive data, on processes, products, equipment, potential hazards, dangerous phenomena, exclusions and their justifications, internal/ external sources of aggression, safety measures/ barriers and their linked operational procedures for managing major risks. MIRA makes risk studies operational by integrating procedures, operating modes and field operator records into a single model of real activities. It also provides the means for data manipulation, risk assessment (Preliminary Risk Analysis, Hazop, Bow-tie, Barrier analysis, etc.), and periodic recalculation of the probability propagation based on daily reporting of operating data. MIRA has been developed and is used with the InOV technology (from Interactive company), which is a flexible platform based on a user-oriented programming logic, and a set of IT packages (such as task management, notification and e-mailing system, GIS, DMS, document editor, interoperability management through the provision of web services and an API, integrated screen and workflow management systems for the design and display of operations and rights) for designing ontologies, running web applications but also for designing and prototyping without coding by the systematic reuse of proven components, in order to ensure bug-free developments within the reach of super users.

Vigirisk and MIRA will be hosted and secured by BRGM, which will promote the use of territorial data (urbanization, critical infrastructures, ecosystems, etc.) to which BRGM, as an operator of the French State, has access via a reliable datacenter.

6 Discussion

It would be a profound change to organize the licensing process on the basis of the monitoring process described below (Fraccascia, L., 2018). Currently, this authorization is based on the instruction of risk studies and then on field inspections. But the five categories of difficulties we have listed above are not addressed together. In other words, inspections are carried out on a spot-check basis, not in a systematic way. In short, the administration seems to rely mainly on paperwork. And yet, in several in-depth audit or field survey we have conducted, we have found significant discrepancies between the studies and reality. Why is it that, if the studies always match reality, the law requires that they be reviewed every five years? Why do many risk experts consider that the new French regulations concerning this revision (we are thinking here of the procedures for re-examining hazard studies) are too light and should systematically involve new in-depth risk analyses? Why do operators still experience (let's say the vast majority of them) the performance of these studies as an administrative cost and not as the basis of their risk management? One could imagine better safety monitoring by asking operators to produce periodic reports (once or twice a year, with validation by a steering committee) on their risk management model (combining study and monitoring). Is this not the spirit of the Seveso III directive? But wouldn't putting it into practice be a revolution, as it would clash with well-established organizational practices?

When the question of the correspondence between studies and the reality of installations and practices does not arise, operators do not have to invest in monitoring. And their documentation system can be satisfied with being formally correct, administratively compliant. And many organizational biases can be put in place without being discovered. What about risk assessment workgroups where one participant systematically takes the floor without leaving room for the expertise of others? What about groups that focus on details when time is limited because the number of working days has been contracted in advance? What about groups where process engineers are absent? Or when field operators are absent or muzzled because they are afraid to reveal their true practices? In most cases, it is consulting firms that are in charge of carrying out the studies... but they do not know the realities of the field. Reorganizing the work of risk assessment around the verification of the

([6]) The development of MIRA is based on a preliminary analysis of the problem of managing major accidental industrial risks which was the subject of a publication: Plot, E., 2007.

correspondence between studies and the reality of facilities and practices would be a profound change that would help to counter many of the organizational shortcomings of operators that affect the quality of risk studies.

From the point of view of the consulting firms, working on paper is perhaps preferable in that it is much easier to organize. An expert can take charge of a whole study, alone, with the support of other skills, in an essentially analytical approach that he will carry out in his office, from the documents that he will have requested and that will have been provided to him (even if these documents are not up to date). His first concern may be to respect the costs and deadlines of his company, because he will undoubtedly be judged first on this criterion... insofar as no one will be able to question the correspondence between the study carried out and the reality of the practices and the installations.

At the end of the day, shouldn't we simply organize the stakeholders around the spirit of the Seveso III Directive where the safety management system is central and which we interpret as being centered on the monitoring work (annex III element vi) "for the ongoing assessment of compliance with the objectives set by the operator's MAPP and safety management system"? … provided that the five categories of difficulty discussed in this article are met.

Many seem to read this directive by overvaluing the requirement of procedures, as opposed to the requirement of demonstration, tending to consider, as is undoubtedly too often the case in France, that the existence of procedures is a sufficient demonstration. Procedures seem to play a central role in a bureaucratic approach, insofar as they can be distanced from reality and self-validated by records that are managed only by formalism. It is obviously easier to comply with the Seveso 3 directive by interpreting it as requiring procedures than as requiring primarily demonstrations based on a monitoring process fed by risk assessments.

This situation is not too problematic when it comes to managing facilities and practices that are well known to operators in the field who have long experience, and informal practices that are well established within the collectives to correct the shortcomings of the formalism of procedures. But when dealing with evolving Natech risks, which are new to everyone and truly complex, isn't it important to give ourselves the means to rethink risk management approaches around a demonstration and monitoring logic? The issue seems too serious to be treated lightly. It would therefore be important to rethink risk management practices in light of the challenges posed by the Natech problem, for example around the organizational mode envisaged in this article.

7 Conclusion

The main idea is that:

- from a risk management perspective, the focus should not be on risk assessment but on monitoring (a simple idea with consequences we believe to be decisive);
- this could lead to an organizational "revolution" in risk governance (at the level of inspectors, operators, consulting firms, and territories);
- it is probably difficult to do otherwise when the phenomena to be managed are complex and relatively unknown, as are the Natech scenarios.

It is therefore necessary to specify the modalities of this "new" management principle and to build the ad hoc supporting IT platform, by connecting the Vigirisk and the MIRA-InOV IT tool. This work is already planned as a part of the IRiMa project (an exploratory French PEPR project) which we present below in order to explain the framework in which this research will be conducted.

IRIMA project (eight-year project starting in 2023) aims to produce a new "risk science" to contribute to the development of a new strategy for managing risks and disasters and their impacts in the context of global, anthropogenic and climatic changes. To do this, it implements a series of research and expertise (observation, analysis or decision support) to accelerate the transition to a society capable of facing a set of hazards (hydroclimatic, telluric, technological, health-related, mixed), to adapt and to be more resilient and more sustainable.

Over the period 1998-2017, France was the 10th most affected country in the world by disasters with an overall cost of more than 40 billion dollars. To face this challenge, increasing with ongoing warming, it seems necessary to stimulate and coordinate the national effort. The chosen approach in IRIMA, holistic and integrative of knowledge, aims to largely federate geosciences, climate sciences, engineering, data and digital sciences, as well as human and social sciences (in particular geography, history, economic and financial sciences, behavioral sciences). These different disciplines are now heavily involved in these issues, but still work too much in silos and / or, sometimes, without direct interaction with society.

By capitalizing on available knowledge and developing inter and transdisciplinary methodological approaches, it will be a matter of jointly developing and constructing new knowledge so as to better detect, quantify and anticipate risks, understanding their complexity (extreme events, multiple risks), and unsteady, coupling and cascading effects, multi-scale dynamics, taking better account of human and socio-economic issues, etc.) It will also be a question of making better use of data and citizen knowledge, and of better valuing new technologies, particularly those of information, by consolidating data acquisition and assimilation / modeling / decision support / policy implementation for crisis management and anticipation of future risks related to climate change and anthropization.

The IRIMA project is built around a national consortium largely federating major research universities, key universities in the field of risks (natural, technological and environmental), and organizations or establishments of national reference. To promote transdisciplinary dynamics, research stimulation and coordination mechanisms will be put in place, in particular calls for innovative projects, instruments for structuring regional centers, attracting talents and encouraging young scientists, partnerships international (European in particular), a renewed policy of training through research and life-long training, as well as an infrastructure of research platforms. The latter will strongly contribute to bringing together teams around the study of risk dynamics, crisis scenarios, as well as the evaluation of decision support tools, in vivo and in vitro experimentation with the different social actors. It will rely on collaborations between observatories, data and high-performance computing national infrastructures, creating synergies and novel convergences.

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Including natural events in dynamic risk assessments. A case study on landslides

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Extended Abstract

The present paper deals with the development of a dynamic bow-tie for an LPG storage facilities located in landslide-sensitive zones, which aim is to identify and mitigate potential hazards related to natural disasters, such as landslides. The bow-tie approach evaluates the likelihood and consequences of such events, and outlines control measures and response actions to minimize their impact. The dynamic aspect of the bow-tie involves continuous monitoring and updating of the identified hazards and risk controls, to ensure the facility remains safe and resilient to changes in the environment. The landslides precursors are identified through a data driven model trained with hydrogeological and related landslides events data.
The use of this approach can help ensure the safety of the LPG storage facility, obtained through the identification of the landslides precursors, as well as its surrounding communities, in the face of natural disasters.

Introduction

Predicting landslides is a complex and challenging task due to the various factors that contribute to their occurrence, such as geology, weather, and human activities. There are two main approaches to predicting landslides: physically based models and empirical models.
Physically based models attempt to simulate the physical processes that lead to landslides, such as soil mechanics, hydrology, and geology (Berardi, 2005). These models require detailed information on the site, including soil properties, topography, and meteorological data. Despite their theoretical accuracy, physically based models can be computationally intensive and require a significant amount of data, which can be difficult to obtain in many areas. In addition, these models are often based on simplified representations of the real world, making it difficult to accurately represent the complex interactions between the various factors that contribute to landslides (Baum, 2010).
Empirical models, on the other hand, rely on statistical relationships between landslide occurrence and environmental factors, such as rainfall and slope angle. These models are generally simpler and easier to implement, and can be used to make predictions with limited data. However, they are based on historical patterns and may not reflect changes in the environment or new landslide triggering mechanisms. In addition, empirical models often have limited spatial and temporal resolution, making it difficult to accurately predict landslides in real-time.
Predicting landslides using either physically based models or empirical models is a complex task and requires a comprehensive understanding of the site, as well as the ability to accurately model the various factors that contribute to landslide occurrence. Both approaches have their strengths and weaknesses, and the choice of model depends on the specific requirements of the site and the data available.
Data-driven models, such as machine learning algorithms, have gained popularity in recent years for landslide prediction. These models use historical landslide data and environmental factors as inputs to train algorithms to identify patterns and relationships between landslides and their contributing factors. The resulting models can then be used to make predictions based on new data.
Data-driven models have several advantages over physically based and empirical models. They can handle large amounts of data and can identify complex relationships between variables, making them well-suited for prediction tasks. In addition, they do not require detailed understanding of the physical processes involved in landslides, and can still produce accurate results with limited data.

Assessing a landslide natech event for an LPG storage facility

The present work focuses on assessing the Natech risk of an LPG storage facility located in the western part of Liguria region, in a landslide sensitive zone. Natech risk assessment is the process of evaluating the likelihood and potential impacts of natural hazards and technological disasters, such as earthquakes, landslides, and industrial accidents. The goal of Natech risk assessment is to identify areas that are at high risk for these types of events and to develop strategies for mitigating those risks.

For assessing the NaTech risk for an LPG storage facility in a landslide sensitive zone, according to the framework outlined in Vairo (2022), the following interdependencies are thoroughly evaluated.

1. How the Adversity affects the System.
2. How the System, when subjected to the Adversity, delivers the Capability of interest.
3. What is the quality of the Delivered Capability gaged against the Required Capability.

In the analyzed case study, the Adversity is a landslide, the System is an LPG storage facility, and the Capability of interest is the system safety. The Natech hazard identification, showing the interaction between the landslide and the given technological installation (Huang, 2022), is schematized the form of unconditional event tree in Table 1.

Table 1: Landslide triggered events on an LPG storage facility.

Off-site event	*Operator error*	*Abnormal load*	*Failures*	*Management*	*Loss of service*	*Triggered initiating event*	*Consequences*
Landslide	Containment degraded Failure to respond correctly to an alarm	Internal temperature or pressure outside design limit Pressurization / under pressure	Safety system degraded. Control system degraded. Containment system degraded	Inadequate materials or specification Hidden defect in containment system Failure to detect dangerous situation. Failure of process controls.	Loss of cooling water / nitrogen Loss of compressed air	Rupture of pipe on a pressurized storage system Sudden catastrophic failure of vessels Failure of an excess flow control valve on demand Failure of an automatic shutoff valve closure Failure of a level / flow sensor	Catastrophic failure - fireball and flash fire or pool fire Localised failure of a pressure vessel – jet flame and flash fire and possible explosion Pipe failures BLEVE of vessels Vaporiser leak jet fire, flash fire, and explosion. Leak inside cylinder filling plant - confined explosion

Bow-Tie development

The landslide initiating events presented in Table 1 are used to determine the landslide triggered events, by the means of a Bow-Tie centered on the critical event, as depicted in Figure 1.

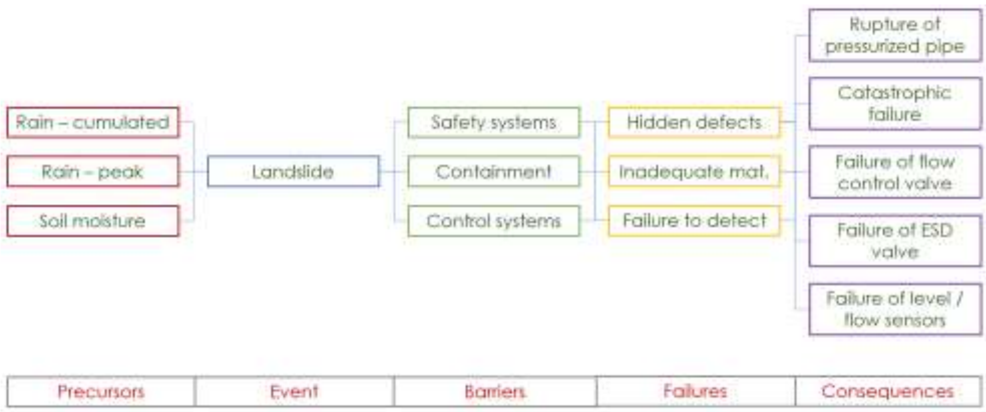

Figure 1: Bow-Tie centred on landslide event.

The left side of the Bow-tie, are the most probable precursors (Berti, 2012; Park, 2013), as obtained by an exploratory data analysis on a dataset containing:

- The cumulated rain over 12h;
- The rain peak over 12h;
- An empirical measure of the soil moisture, based on the hydrogeological characteristics of the zone;
- The day of the year.

The data were analyzed with a Gradient Boosted Tree (GBT) for determining the relative importance of the features (Ke, 2017) for predicting a landslide event.
The result of the feature importance is shown in Figure 2.

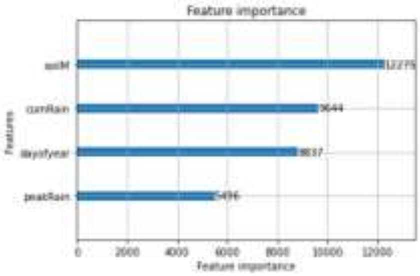

Figure 2: Feature importance.

Feature importance refers to the relative contribution of each feature to the prediction accuracy of the model. GBT algorithms build a series of decision trees, where each tree is designed to correct the errors made by the previous trees. The feature importance in GBT is calculated based on the number of times a feature is used in the trees and the improvement in the prediction accuracy that results from using that feature.
The method for calculating feature importance in GBT is the *gain Importance*. This method calculates the average gain in prediction accuracy that results from using a particular feature in the trees. The gain is proportional to the reduction in the loss function used to train the model. Features with higher gain importance contribute more to the prediction accuracy of the model.
Those features are thus chosen as the most suitable precursors of a landslide event.
Based on the bow-tie approach, it is possible to determine the initiating causes of an accidental event and final outcomes. As summarized in Table 2, the probabilities are evaluated by a MCMC sampling from the probability distribution determined from the predictive model. Each element is updated at new observation of the precursors (Rain-cumulated, Soil moisture, Rain-peak).

Table 2: Bow-Tie elements – landslide consequences / initiating events.

Cause	Expected pdf value
Rupture of pressurized pipe	1E-6
Catastrophic failure	1E-9
Failure of flow control valve	1E-5
Failure of ESD valve	1E-6
Failure of level / flow sensors	1E-3

Conclusions

The study found that accurately predicting landslide events greatly affects the likelihood of top events and the dynamic update of risk precursors is a crucial safety factor that enables early detection of potential threats. To further improve the method, ongoing research involves optimizing the predictive model's tuning parameters through a comprehensive sensitivity analysis, while taking into account a broader range of situations and configurations to enhance the overall early warning capabilities.

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INCLUDING NATURAL EVENTS IN DYNAMIC RISK ASSESSMENTS. A CASE STUDY ON LANDSLIDES

Tomaso Vairo – Stefania Magrì – Bruno Fabiano

Università di Genova | DICCA Dipartimento di Ingegneria Civile, Chimica e Ambientale

"*Distinguishing hazards from failures is implicit in understanding the difference between safety and reliability*"

Charles O. Miller

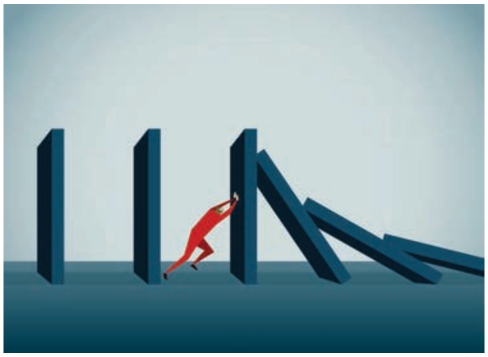
Agenda

The systemic approach
- dealing with complexity and uncertainty
- system requirement

Predicting landslides
- different approaches
- identifying and monitoring precursors
- a data driven approach

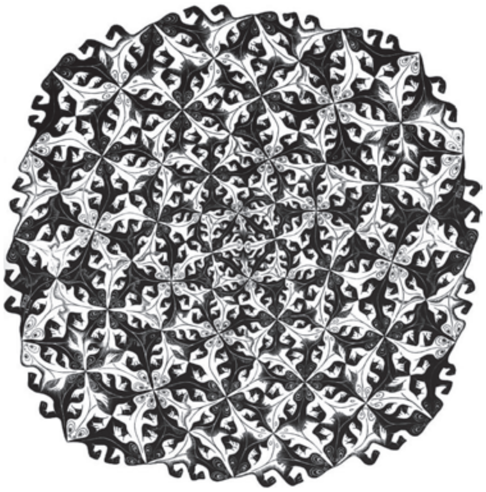
An applicative case
- Integrated Bow-Tie
- Results and discussion

Conclusion



The systemic approach

Complexity...



System: from greek syn + histánai, put together. Establish a context. Exploring the nature of interdependence.

The past is characterized by a reductionist approach:

INDEPENDENT PHENOMENA – SEPARATE STUDIES

Systemic Approach

CATCH INTERCONNECTIONS AND RESONANCE

The systemic approach

Complexity...

Safety in complex systems is an emergent system property and cannot be determined through component reliability

the ability to simulate the behavior of complex systems is imperative to ensure safety.

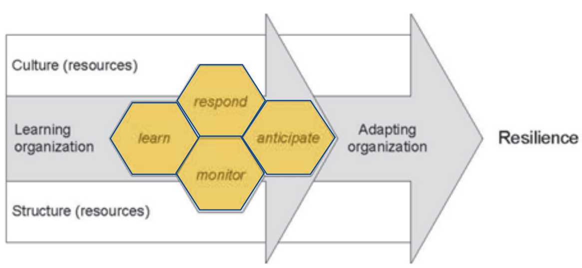
SAFETY IS AN EMERGENT PROPERTY OF THE SYSTEM

AND **RESILIENCE** IS THE ENABLING PROPERTY

The systemic approach

Complexity...

Resilience has been defined in the literature as the ability of systems to adapt to changing conditions in order to **maintain a system property**.



Keywords

MONITOR
LEARN
ANTICIPATE
RESPOND

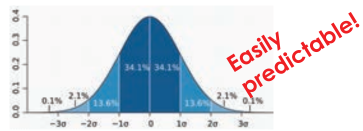
- ✓ Improving system **knowledge**
- ✓ Understanding **interactions**
- ✓ Building reliable and robust **predictive models**.

The systemic approach

Uncertainty…

Three types of unexpected events

White Swans result from the 'Normal' randomness of a Gaussian Distribution



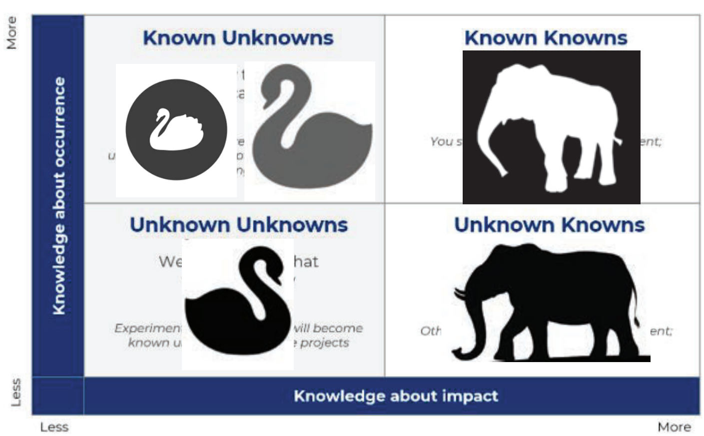
Grey Swans result from circumstances where Power Law (Fractal or Fat Tailed) randomness occurs

Black Swans result from all those forms of nonlinear randomness that we do not know about

?

The systemic approach

Uncertainty…



Don't confuse swans with elephants!

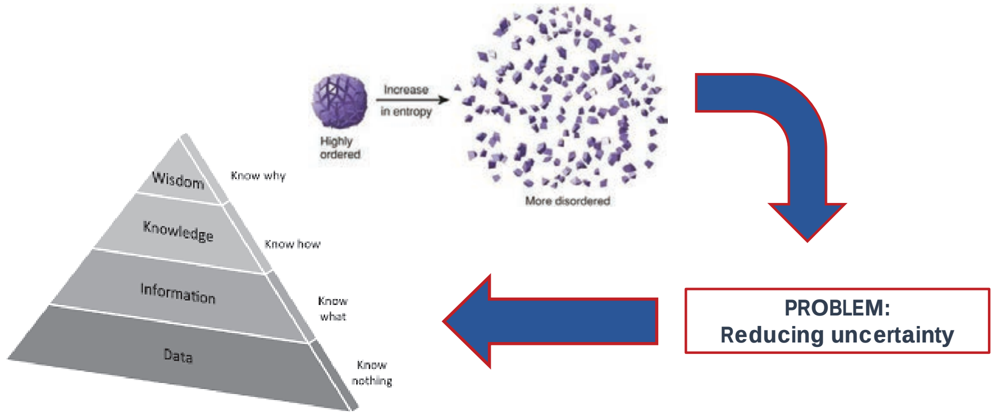
White elephants: Well-known obvious risk

Black elephant: A probable, high impact yet neglected threat

The systemic approach

Reducing uncertainty

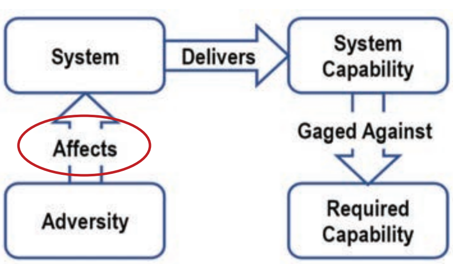
Monitoring and analyzing data to increase information and transform it into knowledge to reduce uncertainty

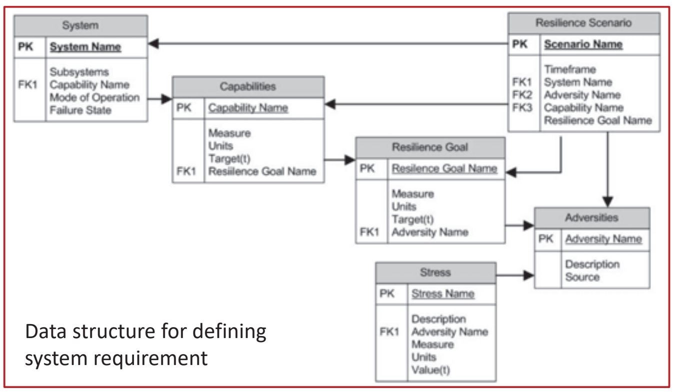


The systemic approach

Define system requirement

Systems, by definition, provide the desired capabilities. **It is the quality of the delivery of that capability - in the face of adversity - that resilience addresses**.



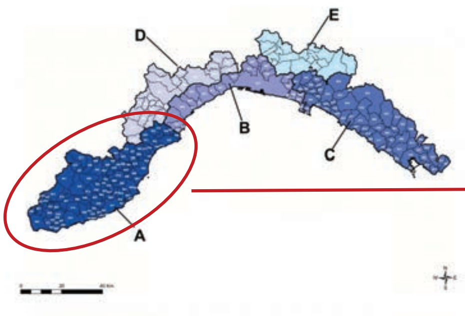


Data structure for defining system requirement

Predicting landslides

Landslides in Liguria region

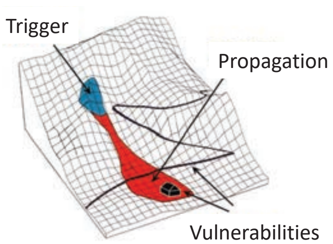
The Ligurian regional territory is divided into 5 warning zones, shared with the National Civil Protection Department.

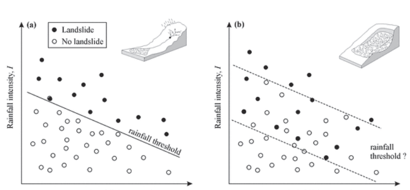


LPG storage facilities in landslides sensitive zone

Predicting landslides

In Italy, **rainfall** represents the most common **triggering factor for landslides**.





(M. Berti et al. 2012)

physically based approaches
Determination of **trigger** and **propagation**
Based on the **Richards equation** (1931)

$$\frac{\partial \psi}{\partial t}\frac{\partial \vartheta}{\partial \psi} = \nabla \cdot \left[K(\vartheta)\nabla \psi\right] + \frac{\partial K(\vartheta)}{\partial z}$$

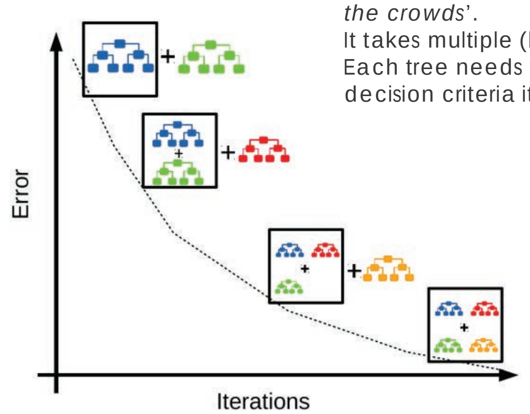
- K is the hydraulic conductivity
- Ψ is the piezometric height
- z is the elevation
- θ is the volumetric water content

The use of physically based approaches requires the calibration of many parameters, such as hydraulic and mechanical properties of soil, the effect of vegetation, and local rainfall variation in space and time, which makes their use over large territories **difficult to apply.**

The most diffused methodology relies on the definition of empirical correlation between rainfall and landslide, obtained from historical data of landslides occurrence.

Predicting landslides

A data driven approach – the algorithm



The Gradient Boosting algorithm takes advantage of the '*wisdom of the crowds*'.
It takes multiple (but different) decision trees and makes them 'vote'.
Each tree needs to predict the expected outcome based on the decision criteria it picked

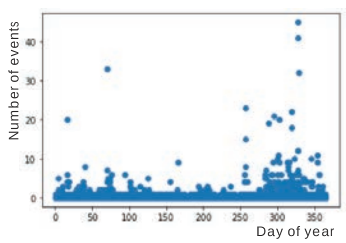
The principle is improving error of the previous learner through the next learner.
Weak learners are used which perform only slightly better than a random chance.
Boosting focuses on sequentially adding up these weak learners and filtering out the observations that a learner gets correct at every step.
The next learners handle the remaining difficult observations at each step.

Predicting landslides

A data driven approach – the dataset

head of the dataset

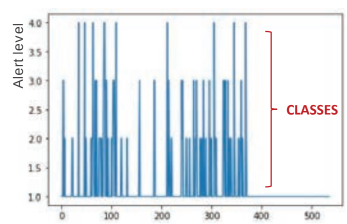
	sm_value_first	rain_cum_12H	rain_peak_3H	event_n	dayofyear	Zona_n
0	0.816	6.060	7.0	2	336	1
1	0.653	0.014	0.2	1	334	1
2	0.916	1.535	6.6	1	329	1
3	0.994	50.172	47.4	7	328	1
4	0.747	88.336	73.0	12	327	1



Alert	Events	description
White	0	No events
Green	1 ÷ 2	few shallow landslides
Yellow	3 ÷ 5	shallow landslides and rapid mud flows of limited size
Orange	6 ÷ 13	limited slope instability
Red	≥ 14	extensive slope instability

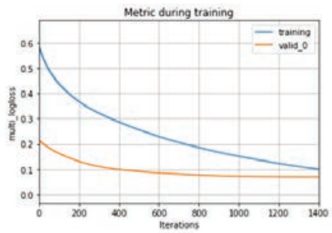
(S. Magri et al. 2022)

«White» entries removed
Classification by alert level



Predicting landslides

A data driven approach - results

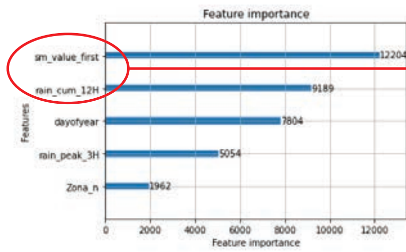


Training accuracy: 0.9925
Testing accuracy: 0.9792

True label \ Predicted label	1	2	3	4
1	1781	14	1	0
2	5	12	0	0
3	6	1	3	0
4	0	0	0	2

!

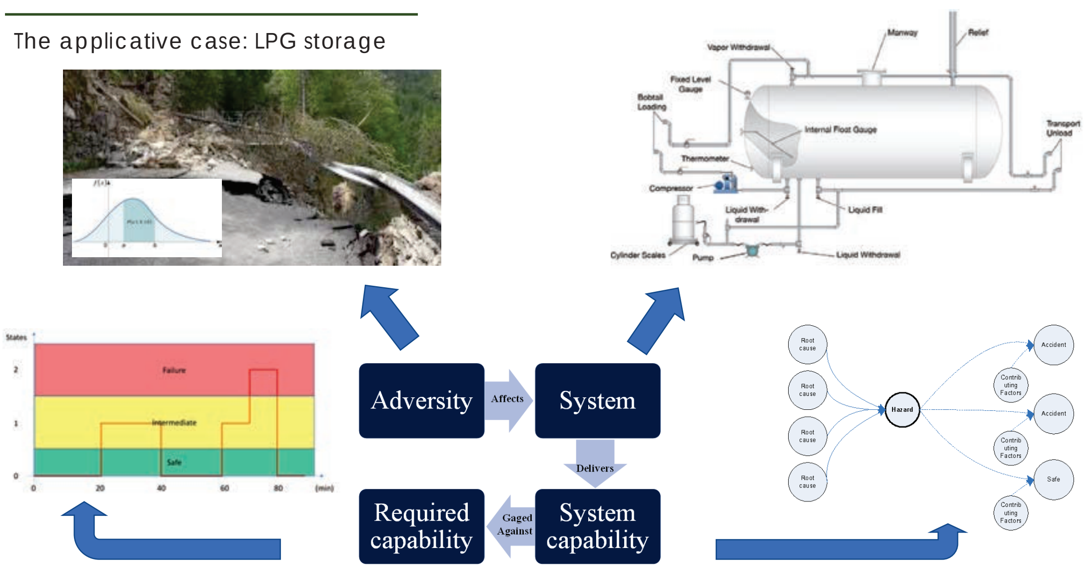
Alert	Label	Events
Green	1	1 ÷ 2
Yellow	2	3 ÷ 5
Orange	3	6 ÷ 13
Red	4	> 13



Most relevant features

Predicting landslides

The applicative case: LPG storage



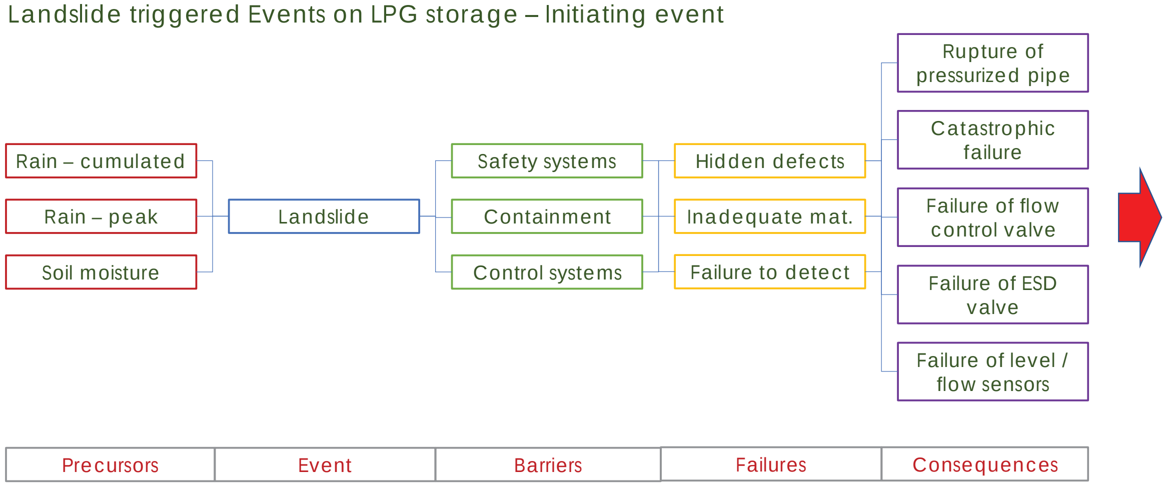
Predicting landslides

The applicative case: LPG storage

Off-site event	Operator error	Abnormal load	Failures	Management	Loss of service	Triggered initiating event	Consequences
Landslide	containment degraded. failure to respond correctly to an alarm.	internal temperature or pressure outside design limit. Pressurization / under pressure	safety system degraded. control system degraded. containment system degraded.	Inadequate materials or specification. hidden defect in containment system. failure to detect dangerous situation. failure of process controls.	Loss of cooling water / nitrogen. Loss of compressed air	Rupture of pipe on a pressurized storage system Sudden catastrophic failure of vessels Failure of an excess flow control valve on demand Failure of an automatic shutoff valve to close Failure of a level / flow sensor	Catastrophic failure - fireball and flash fire or pool fire. Localised failure of a pressure vessel - jet flame and flash fire and possible explosion. Pipe failures BLEVE of vessels Vaporiser leak jet fire, flash fire, explosion. Leak inside cylinder filling plant - confined explosion.

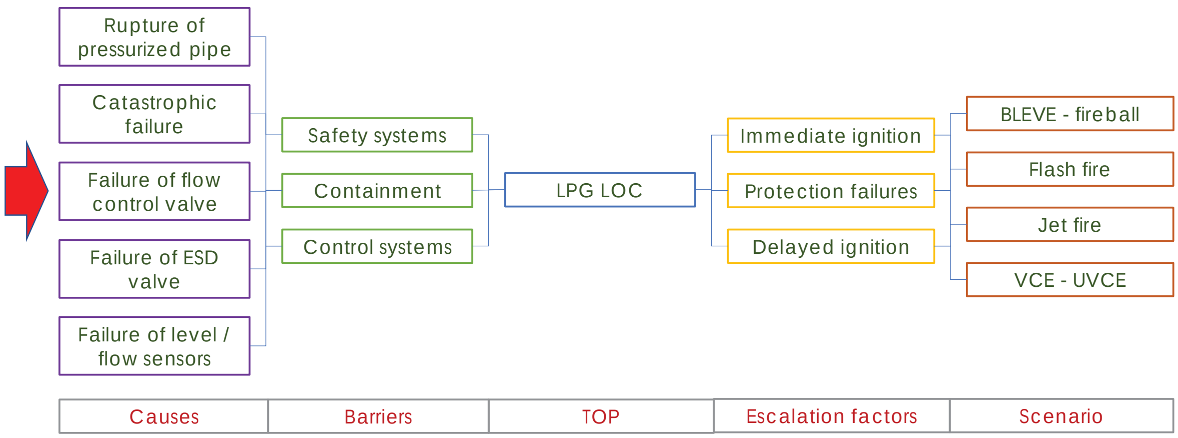
Dynamic risk assessment

Landslide triggered Events on LPG storage – Initiating event



Dynamic risk assessment

Landslide triggered Events on LPG storage – consequence assessment



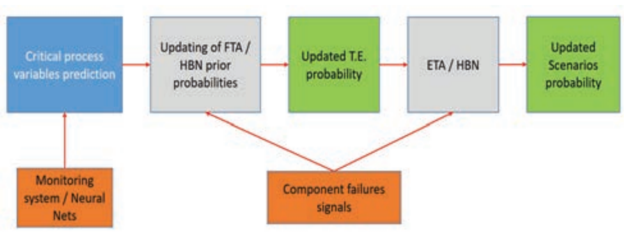
Integration

Dynamic risk assessment

The causes of an LPG Loss of containment, coming from the risk assessment, are:

- Rupture of pipe on a pressurized storage system
- Sudden catastrophic failure of vessels
- Failure of an excess flow control valve on demand
- Failure of an automatic shutoff valve to close
- Failure of a level / flow sensor

Dynamic Risk Assessment Framework (Vairo et al., 2022)

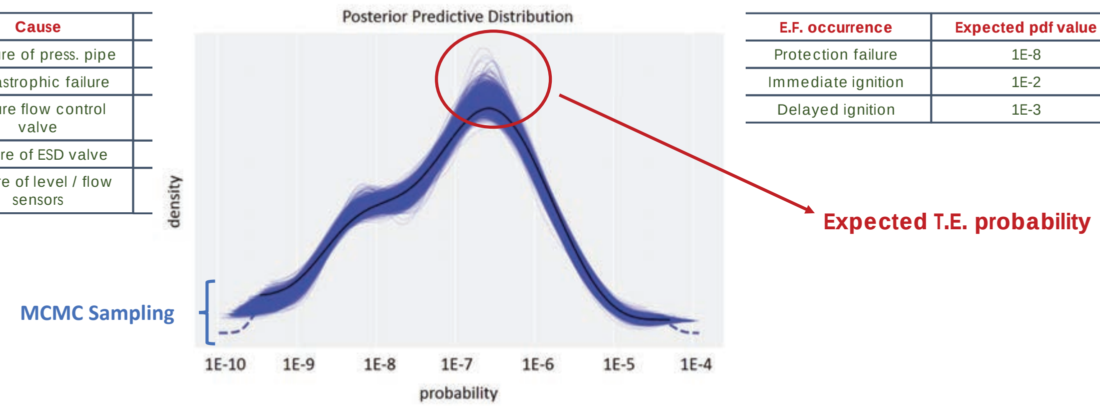


Integration

Dynamic risk assessment

Each cause - barrier failure - escalation factor probability is updated at new observation...

Cause
Rupture of press. pipe
Catastrophic failure
Failure flow control valve
Failure of ESD valve
Failure of level / flow sensors



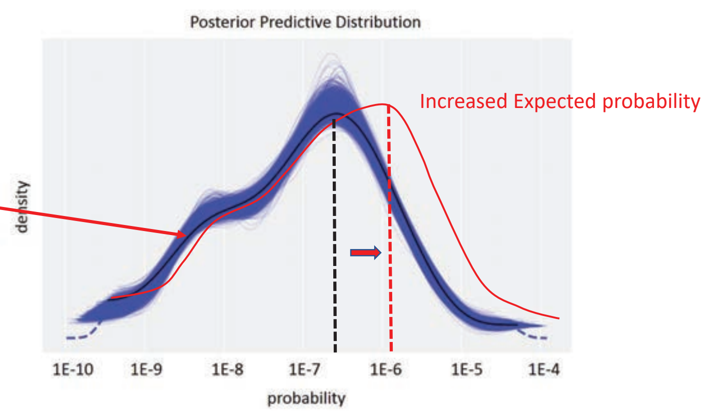
E.F. occurrence	Expected pdf value
Protection failure	1E-8
Immediate ignition	1E-2
Delayed ignition	1E-3

Integration

Dynamic risk assessment

Considering the landslide precursors...

Landslides prediction alert
>13 Events
6-13 Events
3-5 Events
1-2 Events



Conclusion

- The predictive model has, in general, a good accuracy →

```
Training accuracy: 0.9925
Testing accuracy: 0.9792
```

- The model showed a significant error in identifying type 3 events. 6 of these events were predicted as type 1 events. This underestimation must be improved
- It was shown that the prediction of landslide event has a considerable impact on the posterior predictive probability of top events
- The dynamically updated PPD represents a relevant safety parameter, which allows an early detection of a potential threat
- further investigation of the tuning parameters of the predictive model is underway, under a wider range of situations and configurations, for improving the detection of early warning signals.

True label \ Predicted label	1	2	3	4
1	1781	14	1	0
2	5	12	0	0
3	6	1	3	0
4	0	0	0	2

Thank you!

Tomaso Vairo
Stefania Magrì
Bruno Fabiano

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Na-Tech Risk: a New Challenge for Local Planners.

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Abstract

Natech accidents are a class of cascading events that occur when natural and technological hazards collide. In the process industry, where multi-hazard substances are used in large quantities, failures due to natural events can bring simultaneously or sequentially events of acute toxicity, fire, and explosion, which might impact on the population and the environment, also provoking economical losses. The common methodology for risk-analysis adopted by Seveso industries often led to the exclusion of scenarios related to Natech events due to their low probability, however the increasing effects of Climate-change are producing variations on the recurrence of severe unexpected natural events, that will deeply modify the foreseen frequency for NaTech events. For this reason, it is fundamental that the local authorities in charge for Civil protection and Planning are adequately aware and informed on the potential NaTech risks on their territory, in order to include them in the provisions of emergency and urban plans.

This paper proposes a Natech planning tool dedicated to local planners to estimate the Na-Tech risk, presenting its application on the case study of a plant producing lubricant oil additives located in an Italian municipality in Piedmont. A previously validated questionnaire was used to identify the potential vulnerable industrial assets and hazardous substances detained, aiming to classify the potential Natech vulnerability of the plant and identify potential critical situations to be further investigated. The results allowed the planners to obtain an early warning system about the potential Na-Tech risk of the municipality, increasing their awareness and preparedness. Further research is required to integrate this kind of analysis with diverse current methodologies for characterizing Natech events within territorial and multi-risk approaches.

Keywords: Index, Natech, Seveso plant, vulnerability.

Autonomous Mobile Robot (AMR) operating in internal material handling systems – problems of obstacle detection in various operational conditions

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Abstract

The paper is focused on the issues of internal logistics process automation. Such operational processes' performance needs appropriate systems to ensure safety and reduce the likelihood of undesirable situations occurrence. Especially, the problem of different external conditions influence on obstacle detection systems in AMR needs extensive development in relation to internal material handling systems operation. As a result, the paper presents the results of the conducted tests for simulating environmental factors limiting AMR functionality. The carried out research tests focused on investigating temperature changes, the effects of temperature and humidity changes, and dust and mist influence on the operation of scanners and cameras used in AMR performing in the internal material handling systems.

1 Introduction

Recently, there has been a significant development of internal logistics systems based on partially or fully automated solutions. An example of such systems are huge distribution warehouses (e.g. Amazon Robotics), which use autonomous mobile robots (AMR) whose task is to locate, identify, pick and transport loads between selected locations. Ensuring an adequate level of availability and safety of such robots requires the investigation of obstacle detection problem.

In the known literature, different classifications of AMR safety issues can be found. The authors present the summary of conducted research in this area in work [1] and report [2]. Based on the conducted research, one can divide the known literature into three main categories:

- a safe workplace for human safety,
- development of collision avoidance systems, and
- risk management.

In this article, the authors focus on the second problem, the development of anti-collision systems in the context of obstacle detection and the storage area problem. Especially, this problem is important, when the AMR performs in disrupting operating conditions, like, e.g., humidity, dust or significant temperature change.

The basic AMR safety solutions analysed in the literature take into account several performance parameters and safety indicators used, the infrastructure required for their implementation, or the type of robot used (service/industrial) [1]. Additionally, one of the most crucial aspects is the type of obstacle detected (static/dynamic). The report presents the classification of selected solutions to the robot obstacle detection problem [2]. Among others, aspects such as the inaccuracy of the obstacle location error (e.g. [3]) or the distance between the robot and the obstacle (e.g. [4]) were distinguished. However, despite meeting safety standards, unforeseen problems may arise due to the peculiarities of the different navigation systems and technical solutions used in robots. Some of these problems, with examples, are summarized in Table 1.

Table 1. Examples of obstacle detection problems

Obstacle detection problem type	Example	Reference
Changing the range of scanning zones	Minimising the range of scanner zones when the robot is close to the loading ramp	[5]
Influence of obstacle trajectory on detection speed	Faster detection of obstacles moving in front of the robot	[4]
Shape and colour of obstacles	Problems with detection of black obstacles	[6]
Obstacle surface texture	Delayed detection of an obstacle when its surface has many holes	[7]

Moreover, the obstacle detection methods and approaches are reviewed and summarized e.g. in works [2, 8]. However, based on the conducted literature review, the research focusing on investigation of different external conditions influence on obstacle detection systems in AMR needs extensive development in relation to internal material handling systems operation. Recently, e.g., in reference [9] the authors discussed in detail the effects of precipitation, fog, humidity, thunder, sun glint, and dust storm on various navigation systems based on LiDAR, RADAR, camera and ultrasonic scanner performance. The paper provides a descriptive comparison of various sensors by pointing out their advantages and limitations. The focus is on autonomous vehicles performance. A similar but more general comparison of the sensors is presented in [10], where cameras, LIDAR, RADAR, and ultrasonic sensor were compared based on spider charts in the context of FOV, range, accuracy, frame rate, resolution, colour perception, size, weather affections, maintenance, visibility and price. In another work [11], the authors focused on selecting a best fit sensor for robust autonomous navigation. The proposed methodology consisting of 12 layers starts with environment characteristics, which can negatively or positively influence considered laser sensor, vision sensor or sonar/radar. Additionally, in work [12] the authors provided an overview of the three primary categories of sensor calibration and reviewed existing open-source calibration packages for multi-sensor calibration and their compatibility with numerous commercial sensors. They compared three technical solutions based on camera, LIDAR and RADAR use.

However, based on the conducted literature review, the research focusing on investigation of different external conditions influence on obstacle detection systems in AMR needs extensive development in relation to internal material handling systems operation. The importance of this problem is summarized in work [13], where the authors proposed a three-stage method for assessing the relevance of environmental factors that interfere with sensor operation using fuzzy logic with occurrence, recovery and impact level consideration. The application of the method is presented on the basis of an autonomous forklift for indoor and outdoor use. Based on the research findings, the authors concluded that recently presented research works did not consider the sensory system comprehensively, but through the prism of its individual components. Moreover, the occurrence frequency of the external factor and the time for the system to return to full operability after the factor occurrence is not presented or ignored. As a result, the proposed paper presents the results of the conducted tests for simulating environmental factors limiting AMR functionality. There were investigated temperature changes, the effects of temperature and humidity changes, and dust and mist influence on the operation of scanners and cameras used in AMR performing in the internal material handling systems.

The paper is organized as follows. In Section 2 we have described the main assumptions for the carried out research. Section 3 summarizes and discusses the tests carried out in the climate chamber. Section 4 summarizes the entire work.

2 Autonomous Mobile Robot – main assumptions for the carried out research

Research on obstacle detection was carried out using AMR (autonomous mobile robot) designed to transport a load from point A to point B. The innovation of the task was to verify the selection of scanners (AMR navigation system) for outdoor (open) operational tasks performance. The AMR has to perform tasks partly in a closed environment (e.g.: warehouse hall) and open one (e.g.: manoeuvring area). Therefore, in addition to operating under given, "fixed" conditions, the influence of variable conditions that may arise, for example, when moving from a closed to an open environment and vice versa is needed to be examined.

As part of the tests simulating temperature changes, the effects of temperature and humidity changes on the operation of scanners and cameras were identified. A short introduction of the main assumptions for performed tests is provided in the next sub-sections. More information can be found in [2].

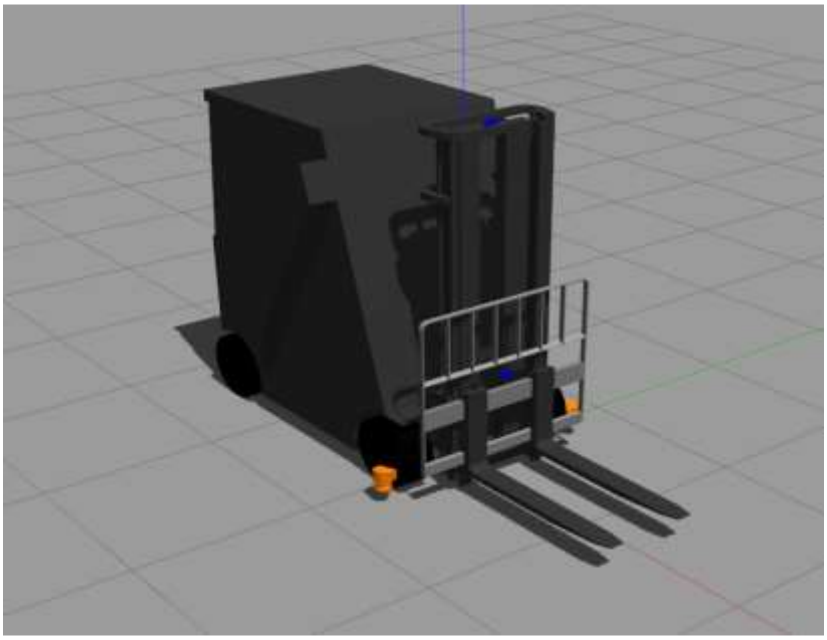
2.1 Sensors layout and navigation system

In order to carry out the tests, the sensors' layout on the platform was planned in the first step. For this purpose, a simulation model of the Gazebo environment was developed with layouts defined accordingly.

Various options were analysed to select the best solution for navigation system structure in terms of both the number of devices used and the largest area scanned by these devices. The analysis was carried out in the Gazebo Sim and Rviz environments. It was decided to use the aforementioned tools because they work with ROS, which is responsible for controlling the mobile platform. Gazebo is a simulator that allows to prepare a future working environment, with a faithful representation of the physics of objects. It can run a robot, controlled from the ROS, which will run exactly the same algorithms that will be found on the physical robot. After the initial determination of the sensor placements, simulation tests were started, which were then transferred to the real object. Rviz, which is a graphical overlay for the ROS system, was used to visualise the sensory data. A selected (example) configuration of the deployment of the vision systems that were analysed is presented in Figure 1. This option used:

- 3 lidar devices:
  - left
  - right
  - rear
- 3D cameras
  - front camera (ambulance)
  - front camera (internal mast)
  - rear camera.

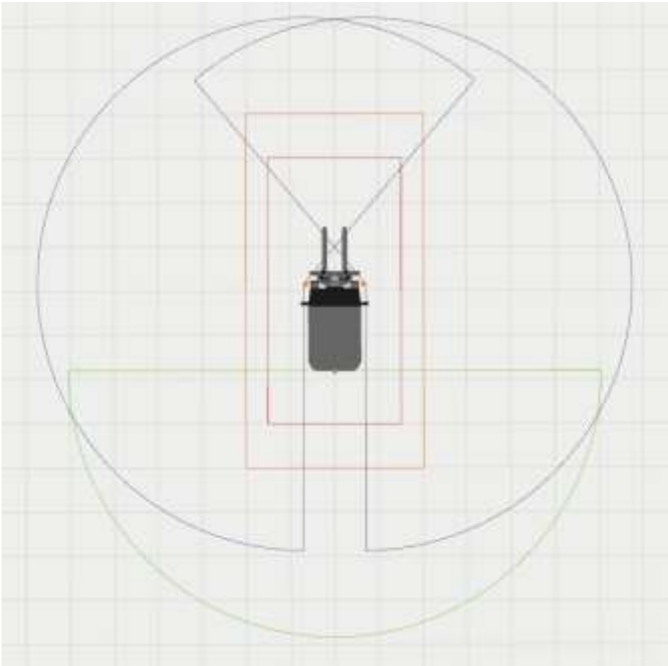
Figure 1. Model in the Gazebo Sim environment.



Source: [2]

The presented location of the scanners (Fig. 2) allows 360-degree coverage of the area around the robot, together with zones partially covered by 2 scanners simultaneously. The figure does not indicate the field of view of the 3D cameras, which are positioned in such a way as to allow observation of the environment in front of the pallet and directly behind the robot when reversing.

Figure 2. Lidar field of view: left (blue), right (purple) and rear (green) with safety zones.



Source: [2]

Figure 3 shows the layout of the scanners on the robot in the real system.

Figure 3. Positioning of scanners on the AMR.

Source: [2]

3 Tests in the climate chamber

The construction and functional analysis makes it possible to select robot components that potentially react to environmental factors limiting their functionality. The most important climatic exposure factors included parameters such as:

— temperature,

— humidity, fog, water spray, sublimation,

— rain/snow (IP65),

— surface condition (water, snow, ice, dust, pollution),

— air dustiness, transparency,

— insolation, brightness, glare/reflectivity,

— wind pressure.

The main parameters that are sensitive to the influence of operational conditions include:

- heat balance (efficiency),

- power,

- durability,

- insolation,

- transparency of optical components,

- dew point (condensation)/freezing,

- viscosity of oils, lubricants.

The tests carried out in the climate chamber made it possible to assess the influence of selected atmospheric factors on the behaviour of the robot's navigation system. The technical parameters of the climate chamber in which the tests were carried out are shown below. Figure 4 presents a photograph of the work carried out in the chamber.

Research parameters of the climate chamber:

- dimensions 5.2x5x4 m (L/W/H).

- temperature range - 20 °C to + 50 °C (for intermittent temperatures up to +60 °C).

- humidity control from 5 to 20 g/m3 (above 10 °C).

- simulation of insolation up to 1,000 W/m2 (with 3m2 of illuminated area).

- For tests at variable temperature, temperature gradient of 0.25 K/min. over the full temperature range (1 K/4 min.). For constant-temperature tests a temperature stability of +-0.5K.

Figure 4. Photo from the climate chamber, with the system under test.

Source: [2]

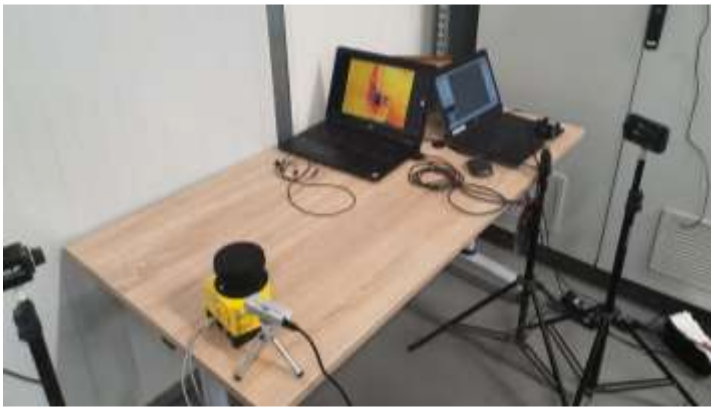
3.1 Testing the effect of temperature variation on the level of navigation system performance

The test was carried out as described. The system (computer and scanners) was introduced into the chamber for a set period of time. The test started at 5 min with increments of 5 min in the next iteration. Among other things, the temperature of the computer was analysed during the test. Each time the system under test was removed from the chamber, its recovery time to the initial temperature was analysed and its signals were analysed. Rviz software was used for this purpose. Figure 5 shows the test station used to verify the equipment warm-up and recovery times.

The temperature outside the climate chamber was verified using a weather station. Among other things, it allowed the temperature and humidity in the room to be read.

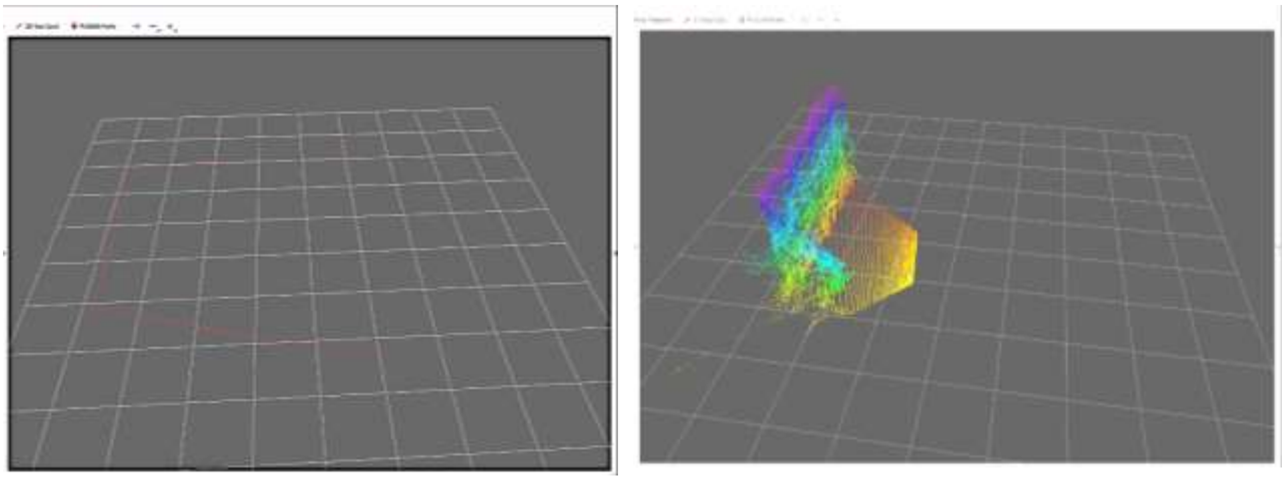
The most important test from the point of view of sensor selection was to check to what extent "frosting", i.e. condensation of water vapour on the measuring devices, occurs and to what extent this affects the operation of these scanners. The results of the measurements are presented in Figures 6 and 7 respectively.

Figure 5. Photo from the climate chamber, with the system under test.



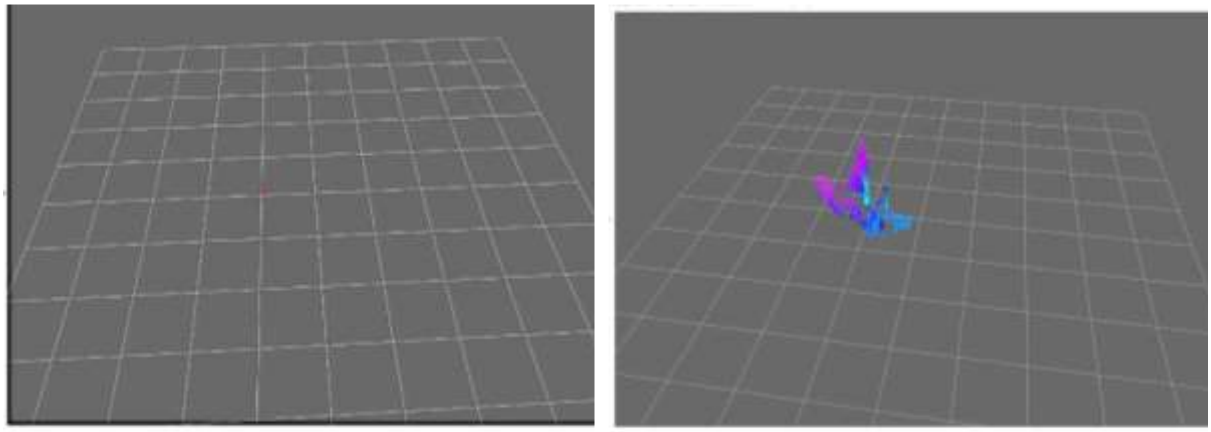
Source: [2]

Figure 6. View from the 2d scanner (left) and 3d camera (right) (visualisation from Rviz software) during the tests in the climate chamber



Source: [2]

Figure 7. View from 2d scanner (left) and 3d camera (right) (visualisation from Rviz software) after removal of the system from the climate chamber.



Source: [2]

The problem of frosting presented in Fig. 7 can arise when the robot is moved from an outdoor environment to an indoor hall. When the temperature of the measuring equipment (scanners) reaches below zero, condensation occurs on the surface of the scanners after moving to a room with a higher temperature. This causes the scanners to be 'blinded' and prevents them from functioning correctly. At a room temperature of 21 Celsius degrees, the time required to achieve full recovery is more than 15 minutes, making it basically impossible to operate the robot properly.

In order to eliminate the occurrence of water condensation, it was proposed to carry out additional maintenance activities during the operation of the robot. The solution analysed was to cover the scanner with a hydrophobic layer. The use of a layer of e.g.: wax can significantly reduce the described phenomenon. Figure 8 presents a view of the scanner. The solution analysed was to cover the scanner with a hydrophobic layer. The use of a layer of e.g.: wax can significantly reduce the described phenomenon. Figure 8 presents a view of the scanner. On the right there is presented the part covered by the protection layer. On the left, there is the layer of condensed water vapour.

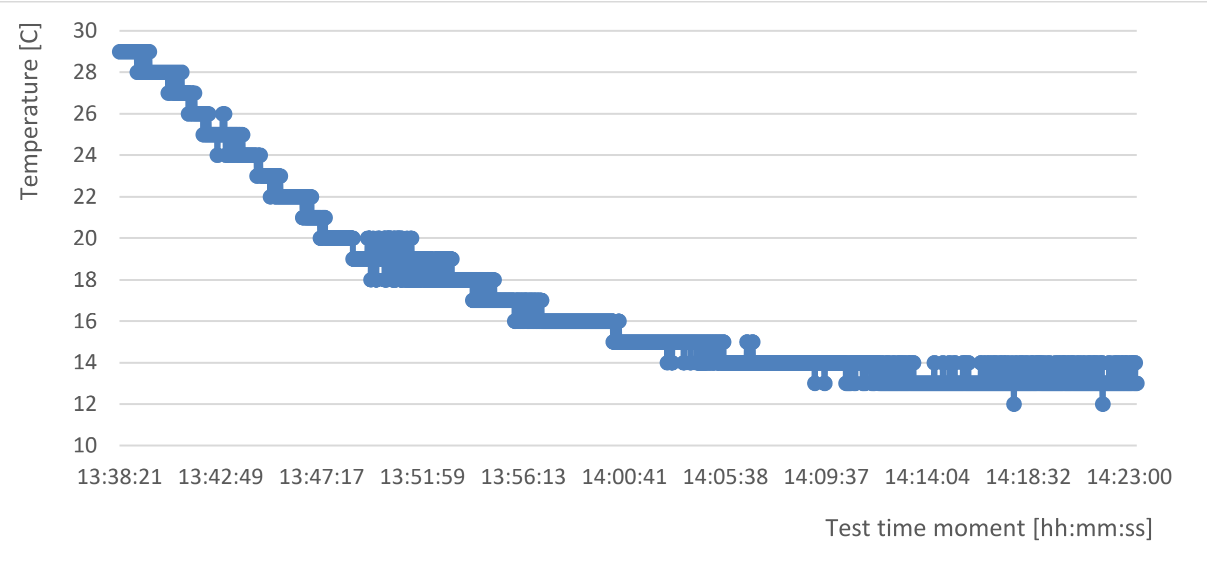
Figure 8. Scanner frosting (layer of condensed water steam prevents measurement)

Source: [2]

3.2 Testing the effect of temperature variation on the operation of computer and the scanner data transfer devices

The study investigated the effects of humidity and temperature variation on the operation of the computer and the scanner data transfer devices. Based on the study, it was determined that the temperature of the system (at a minimum of -20 degrees Celsius) drops to 13 degrees Celsius and does not fall below this temperature limit, despite the change in the time of exposure of the measurement system to temperature conditions. The course of the temperature change during the test is presented in the graph shown in Figure 9. The time taken to change the temperature from 29 degrees to reach 13 degrees took about 20 minutes on average. The return of the temperature from 13 degrees to about 29 degrees took the system up to 15 minutes on average (with an average temperature of about 21 degrees inside the room). The average was determined on the basis of more than a dozen tests with different exposure times for the system. The designed plastic component box proved to be airtight, and the increase in humidity was not recorded inside the cover.

Figure 9. Example of computer temperature change in the climate chamber at [-20 C].



3.3 Testing the effect of visibility level and air transparency on the level of navigation system performance

In addition to verifying the effects of temperature factors on sensor performance, the effects of dust and mist on sensor performance were also analysed.

A device for generating artificial fog was used to study the effect of mist. The output of the device was 215m3/min. It was used in a room with a volume of 90m3. Already after 20 seconds of operation of the device, the amount of fog generated limited the operation of the security system, built based on the SICK S300 Advanced scanner, to an area with a radius of 500mm. Outside this circle, the sensor could see absolutely no objects scattered around it. The ultrasonic fog generation device could also be used for this purpose. However, due to the conditions in the room where the test was conducted, the fog generated under such conditions would quickly dissipate, only increasing the humidity of the air. Therefore, water with a glycol mixture was used for the test. Figure 10 presents the measuring station.

Figure 10. Measuring station for testing the effect of mist on the performance of scanners.

Source: [2]

In addition, the station described above was used to verify the effect of mist on the performance of scanners. The purpose of the test was to verify whether the size of dust grains mattered in the measurement made by the scanner. The study used flour of different weights, which was poured in front of the scanner in a certain amount per unit time. The flour was fed in a 100mm diameter stream at a speed of 2 to 10g/s. This caused, in addition to the formation of a jet, visible to the naked eye, a hardly discernible dusting, which, however, interfered with the measurement sensors.

In both studies (both the effect of mist and the effect of dust), clear conclusions were obtained. In both cases, particle size was not significant from the point of view of the scanners. On the other hand, the number of particles, suspended in the air, per volume of air is important. This means that an increase in dustiness/ haze limits the field of view of the sensors. Such a situation is presented in Figure 10. The scanner measurements were narrowed to about 60 cm.

4 Conclusions

The conducted studies were focused on verification of the selection of the scanner to perform tasks in outdoor (open) conditions. This aspect is especially important for AMR operating in changing conditions. In this area, the effect of temperature and humidity changes on the operation of scanners and cameras has been identified as part of a study simulating temperature changes. The AMR is to perform tasks partly in a closed environment (e.g., warehouse hall) and an open environment (e.g., manoeuvring yard). Therefore, in addition to operating in given "fixed" conditions, the influence of variable conditions that may arise, among other things, when moving from a closed environment to an open one and vice versa, was examined with tests in a climatic chamber.

The most important study from the point of view of sensor selection was to check to what extent the phenomenon of "frosting", i.e. condensation of water vapour on measuring devices, occurs and to what extent this affects the performance of these scanners. In addition, the effects of dust and mist on sensor performance were also analysed to verify the effect of temperature factors on sensor performance.

Clear conclusions were obtained in both studies (both the effect of fog and dust). In both cases, particle size was not significant from the point of view of the scanners. On the other hand, the number of particles suspended in the air per volume of air is essential. This means that an increase in dustiness/ haze limits the sensors' field of view. The scanner measurements were narrowed to about 60 cm.

Acknowledgements

This research has received funding for a research task from the funds of the pro-quality subsidy for the research potential development of the Faculty of Mechanical Engineering of Wroclaw University of Science and Technology in 2022; Research task title: Predictive maintenance method for autonomous mobile robots (AMR) and from POIR.01.01.01-00-0691/19 Development and validation in real conditions of an autonomous forklift truck dedicated to operations in an open external environment.

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Autonomous Mobile Robot (AMR) operating in internal material handling systems – problems of obstacle detection in various operational conditions

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Sylwia Werbińska-Wojciechowska
Alicja Dąbrowska

HR EXCELLENCE IN RESEARCH

Wrocław University of Science and Technology

Outline

I. Introduction
- research motivation
- AMR studies
- obstacle detection problems

II. Experiments under selected operational conditions
- 3D camera, laser scanner and internal computer testing

III. Results

IV. Summary

2

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INTRODUCTION
Research motivation

Fundusze Europejskie Inteligentny Rozwój | Rzeczpospolita Polska | Narodowe Centrum Badań i Rozwoju | Unia Europejska Europejski Fundusz Rozwoju Regionalnego

- POIR.01.01.01-00-0691/19
- research project with total cost 8 110 632,21 PLN (about 38M EUR) funded by the Polish National Centre for Research and Development

Development and validation in real conditions of an autonomous forklift truck dedicated to operations in an open external environment

- application of the designed forklift: transport tasks within **a mixed work environment**, mostly indoor, but with outside possibility

INTRODUCTION
Scientific experience

- **Area of interest:** autonomous mobile robots, simulation modeling, waste management
- PROJECT MANAGER
    1. Development of an autonomous forklift navigating in a changing environment
    2. Predictive maintenance method for AMR.
    3. Method development for modelling waste collection time
- MAIN CONTRACTR IN 7 RESEARCH PROJECTS

Introduction

Experience:

cooperation with Lean-tech company.

Lean-Tech is a company offering material handling systems.

12 years of experience in designing and constructing intralogistics systems and construction of intralogistics systems.

INTRODUCTION

Robotization development

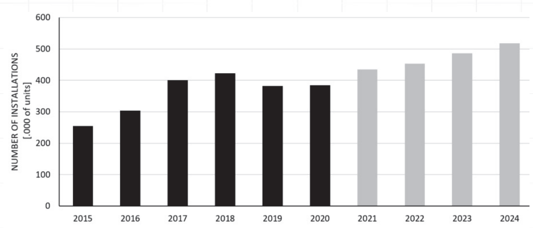

Fig. 1. Annual installations of industrial robots 2015-2020 and 2021-2024 forcast [World Robotics 2021]

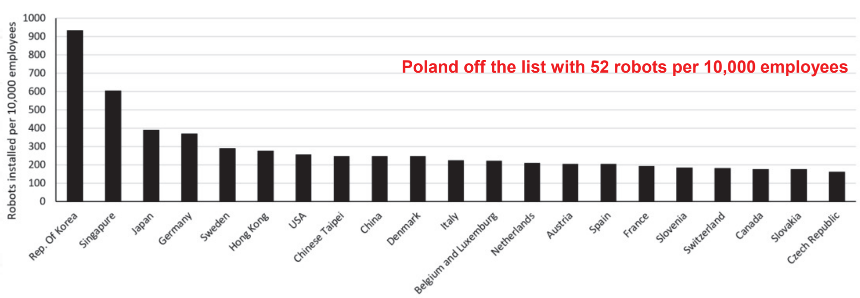

Fig. 2. Robot density in the manufacturing industry 2020 [World Robotics 2021]

INTRODUCTION

Autonomous mobile robots (AMRs) research

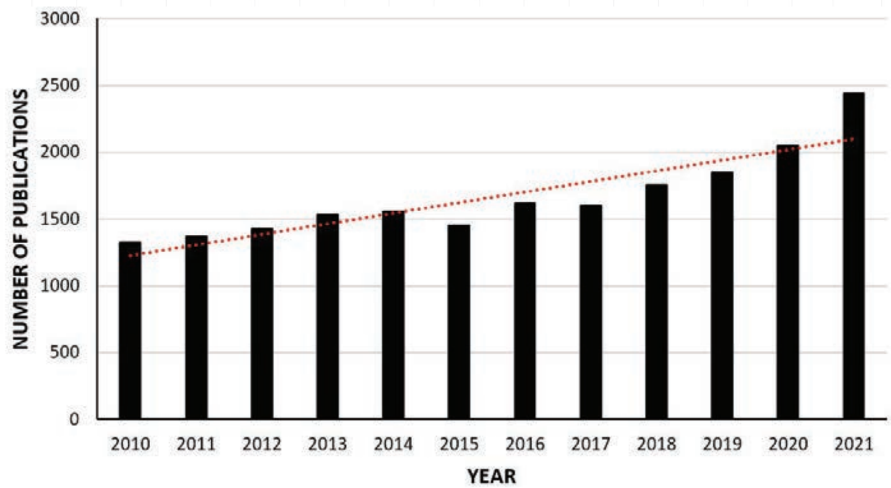

Fig. 3. Number of publications concerning AMR between 2010 and 2021 (based on Google Scholar database).

7

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INTRODUCTION

Autonomous mobile robots (AMRs) research

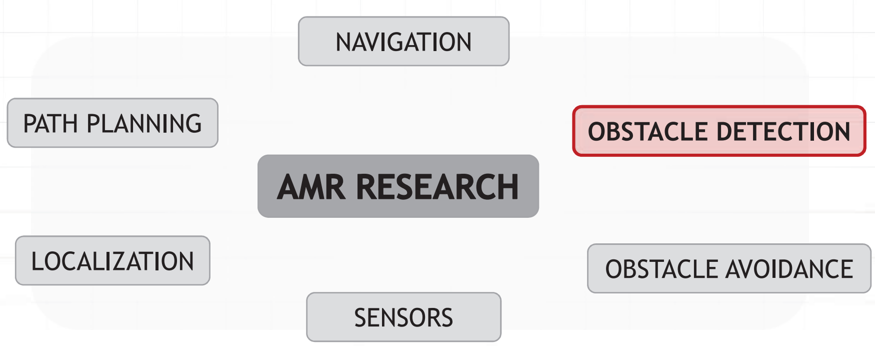

Fig. 4. AMR research areas
(Niloy et al. 2021, Alatise and Hancke 2020)

8

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INTRODUCTION

Obstacle detection problems

OBSTACLE FEATURES

- color
- size
- shape
- material structure
- position
- static/dynamic

SENSORS' LIMITATIONS

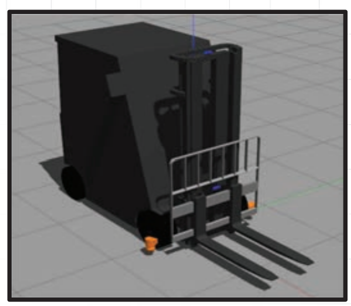
- detection accuracy
- field of view range
- required work enviroment
- placement

OPERATIONAL CONDITIONS

- temperature
- humidity
- dustiness
- light
- fog, rain, snow etc. (only outdoor)
- ground features
- human presence

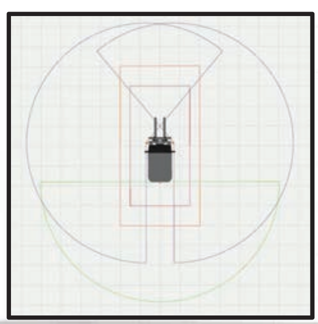
EXPERIMENTS UNDER SELECTED OPERATIONAL CONDITIONS

AMR characterizaton



- an autonomous forklift performing transport tasks within a mixed work environment, mostly indoor, but with outside possibility

- sensors for obstacle detection:
  - three Intel Realsense 435i 3D cameras
  - three SICK S300 Advanced laser safety scanners



EXPERIMENTS UNDER SELECTED OPERATIONAL CONDITIONS

Study background

1st group of experiments

- objective:
to define sensors' limitations under selected operational conditions
- obstacle type:
static (wall)
- performance measure:
ability to detect obstacle

Experiment #1, #2, #3

2nd group of experiments

- objective:
to validate AMR navigation in terms of obstacle avoidance
- obstacle type:
dynamic (human)
- performance measure:
obstacle avoidance due to route modification

Experiment #4, #5

11

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EXPERIMENTS UNDER SELECTED OPERATIONAL CONDITIONS

Study background

1st group of experiments

- objective:
to define sensors' limitations under selected operational conditions
- obstacle type:
static (wall)
- performance measure:
ability to detect obstacle

Experiment #1, #2, #3

2nd group of experiments

- objective:
to validate AMR navigation in terms of obstacle avoidance
- obstacle type:
dynamic (human)
- performance measure:
obstacle avoidance due to route modification

Experiment #4, #5

12

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EXPERIMENTS UNDER SELECTED OPERATIONAL CONDITIONS

Study background

1st group of experiments

- objects under study:
  - 3D camera Intel RealSense D435i
  - laser scanner Sick S300 Advanced
  - internal computer in plastic cover

AMR key elements for obstacle detection

- selected operational conditions:
  - temperature, humidity, dustiness, fogging

13

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EXPERIMENTS UNDER SELECTED OPERATIONAL CONDITIONS

Experiment #1

- study on temperature and humidity
- climate chamber use
- temperature range from – 20 °C to + 50°C, humidity from 5 to 20 g/m3 (above 10 °C)

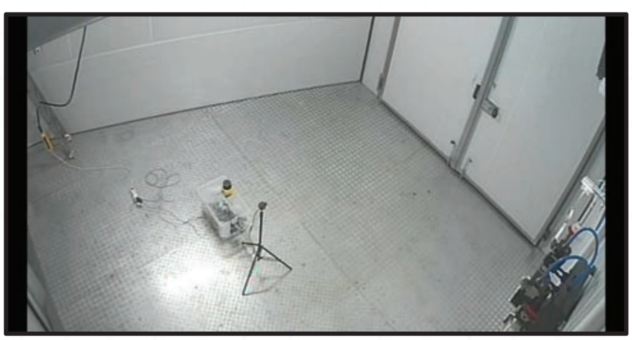

Fig. 5. Used climate chamber with objects under study

14

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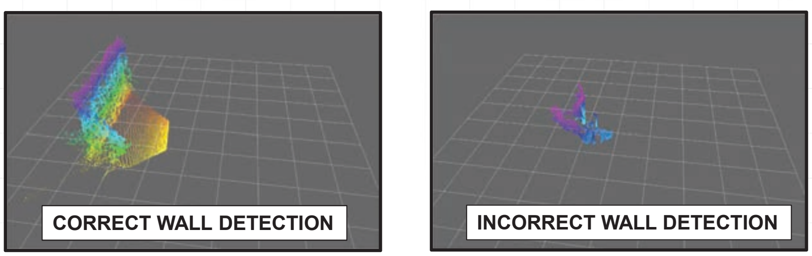
Experiment #1 results [SENSORS]

- sensors placed in the climate chamber lowered their temperature to ambient temperature (verification based on measurements from a thermal camera)
- despite the temperature drop, the sensors were working properly
- no differences in signals coming from sensors placed in different temperatures
- problem turned out to be each time the device was taken out of the climate chamber

Experiment #1 results [SENSORS]



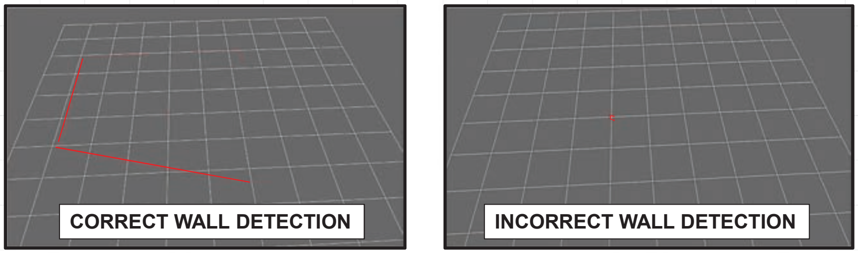
(a) (b)

Fig. 6. 3D camera view (from Rviz 3D visualizer for ROS)
(a) at room temperature (b) at room temperature after being in subzero temperatures

- **loss of ability to detect an obstacle**

EXPERIMENTS UNDER SELECTED OPERATIONAL CONDITIONS

Experiment #1 results [SENSORS]



(a) (b)

Fig. 7. Laser scanner view (from Rviz 3D visualizer for ROS)
(a) at room temperature (b) at room temperature after being in subzero temperatures

- **loss of ability to detect an obstacle**

17

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EXPERIMENTS UNDER SELECTED OPERATIONAL CONDITIONS

Experiment #1 results [SENSORS]

As a result of differences in the temperature of the surroundings and the measuring equipment, condensation of water vapor on the sensors' surface occurred every time (Fig. 6). Both the camera and the scanner lost their proper operation capabilities.

Fig. 8. Condensation of water vapor on the sensor's surface

The time of device inoperability lasted until the device was warmed up to room temperature and the water evaporated. At a room temperature of 21°C, the time required for full recovery was **over 15 minutes**.

18

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EXPERIMENTS UNDER SELECTED OPERATIONAL CONDITIONS

Experiment #1 results [COMPUTER]

The temperature of the computer (at a minimum of -20°C) drops to 13°C and does not fall below this temperature limit, despite staying in subzero temperatures

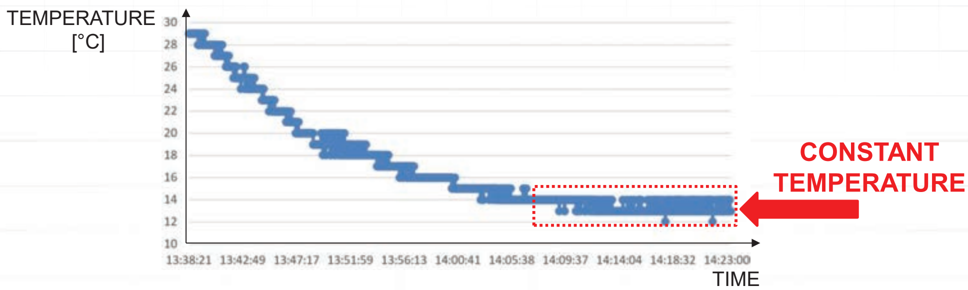

Fig. 9. Change in computer temperature during the test

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EXPERIMENTS UNDER SELECTED OPERATIONAL CONDITIONS

Experiment #1 results [COMPUTER]

- It took an average of about 20 minutes for the temperature to change from 29°C to reach 13°C
- It took up to 15 minutes on average for the temperature to return from 13°C to about 29°C
- Increase in humidity was not noted inside the cover

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EXPERIMENTS UNDER SELECTED OPERATIONAL CONDITIONS

Experiment #2

- study on dustiness
- dust imitated with flour of different grain size

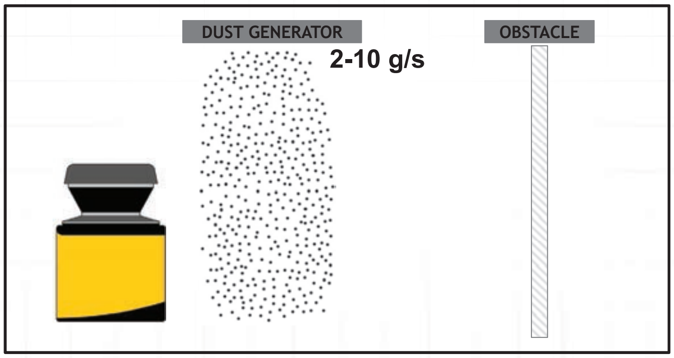

Fig. 10. Scheme of the measuring station

21

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EXPERIMENTS UNDER SELECTED OPERATIONAL CONDITIONS

Experiment #2 results

- regardless of grain size, a 100mm stream fed at a velocity of 2 to 10 g/s was identified by the scanner as a solid obstacle
- dust falling to the floor rose uniformly in all directions after a few seconds of testing. Even though the dust was practically invisible, it caused a clear performance limitation of the scanner
- an increase in dustiness limits the sensors’ field of view

22

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EXPERIMENTS UNDER SELECTED OPERATIONAL CONDITIONS

Experiment #3

- study on fogging
- artificial fog generation 215m3/min in 90m3 room

Fig. 11. Room for testing the impact of fogging

EXPERIMENTS UNDER SELECTED OPERATIONAL CONDITIONS

Experiment #3 results

- after 20 seconds, the amount of fog generated limited the scanner's operations to an area with a radius of 500 mm
- an increase in fogging limits the sensors' field of view

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EXPERIMENTS UNDER SELECTED OPERATIONAL CONDITIONS

Study background

1st group of experiments

- objective:
  to define sensors' limitations under selected operational conditions
- obstacle type:
  static (wall)
- performance measure:
  ability to detect obstacle

Experiment #1, #2, #3

2nd group of experiments

- objective:
  to validate AMR navigation in terms of obstacle avoidance
- obstacle type:
  dynamic (human)
- performance measure:
  obstacle avoidance due to route modification

Experiment #4, #5

25

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EXPERIMENTS UNDER SELECTED OPERATIONAL CONDITIONS

Study background

2nd group of experiments

- objects under study:
  - AMR equipped with sensors tested in the 1st group of experiments (three 3D cameras and three laser scanners)
- selected operational conditions:
  - human presence

26

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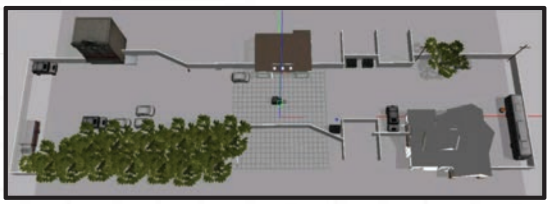
EXPERIMENTS UNDER SELECTED OPERATIONAL CONDITIONS

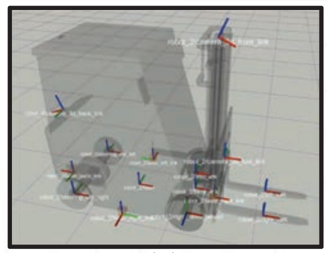
2nd group of experiments

Study background

- Gazebo - robot simulation environment
- Virtual world, simulated versions of robots, simulated sensors



(a)



(b)

Fig. 12. AMR study in Gazebo
a) External environment representation b) AMR with sensors

EXPERIMENTS UNDER SELECTED OPERATIONAL CONDITIONS

2nd group of experiments

Study background

- AMR navigation testing based on costmap

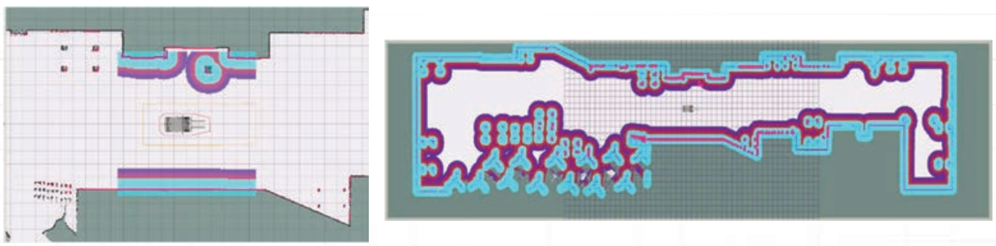
COSTMAP

- arises the combination of the AMR's pose (odometry data and IMU) and the perception of surrindings (cameras and scanners)
- a grid map, where each cell represents a value
- can be local or global

Study background

2nd group of experiments

- Global map – predetermined map, full path optimization
- Local map – details of immediate environment, optimization at close proximity, data from sensors

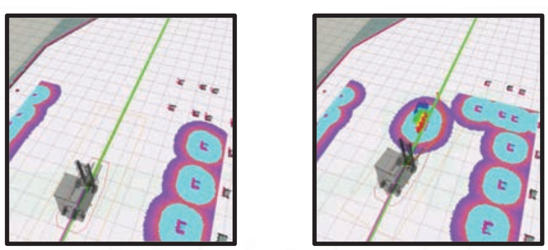


(a) (b)

Fig. 13. AMR cost map
a) local b) global

Experiment #4

- study on AMR's navigation
- dynamic obstacles appearing on the AMR's route



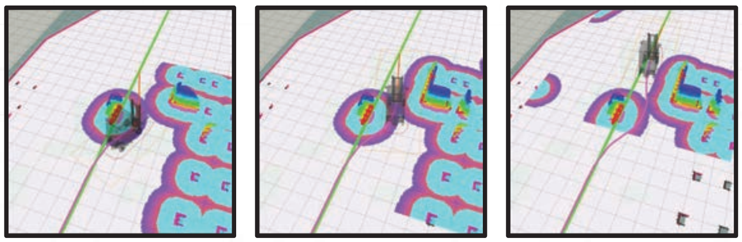
a) b)

Fig. 14. Gazebo simulation of human presence
a) path execution b) obstacle appearance

EXPERIMENTS UNDER SELECTED OPERATIONAL CONDITIONS

Experiment #4 - results

- AMR adjusted the local path and generated trajectories to ensure collision avoidance



a) b) c)

Fig. 15. Gazebo simulation of obstacle avoidance: a) route modification b),c) return to previous route

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EXPERIMENTS UNDER SELECTED OPERATIONAL CONDITIONS

Experiment #5

- study on system response in emergency case (sudden obstacle apperance)
- obstacles appearing in the warning and safety zones

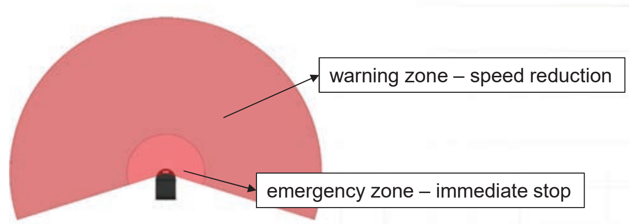

Fig. 16. Warning and safety zones of laser scanner

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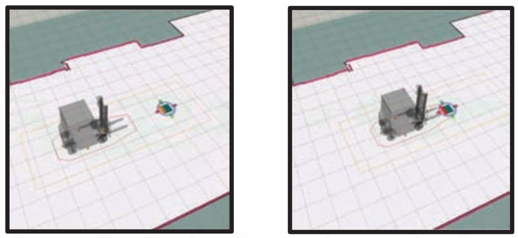
EXPERIMENTS UNDER SELECTED OPERATIONAL CONDITIONS

Experiment #5 - results

- obstacle in warning zone → AMR speed reduced by half and then stopping with braking distance 0.95m
- obstacle in emergency zone → AMR stoppage, braking distance 3.1 m in the worst case



a) b)

Fig. 17. Gazebo simulation of obstacle detection
a) obstacle in warning zone b) obstacle in emergency zone

Summary

- obstacle detection problems in various operational conditions were considered
- the effects of temperature, humidity, dust and human presence on the sensors performance were studied
- the problem of changing operating temperatures and the dust problem needs further consideration

Future steps

- modification of the designed AMR sensor system to protect it from identified problems
- protoype development of an autonomous forklift for use in a mixed environment (mostly indoor, but with outdoor possibility)

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Thank you for your attention

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A Game for Simultaneous Risk and Resilience Optimization

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Abstract

Risk and resilience are strongly correlated quantities, but an explicit description of the relationship between them is hard to find. Critical infrastructure protection typically involves tasks such as reducing risk and increasing resilience at the same time. This requires a way of dealing with quantities that does neither treat them as independent nor use an (over-)simplified model of dependency, as this may yield misleading results. A multi-objective game-theoretic model enables optimization of multiple quantities simultaneously without the need to explicitly model the interdependency between them, except for priority relations or importance weighting. Such a model can be used in the context of risk and resilience optimization to identify optimal actions in a worst-case scenario, i.e., the game-theoretic optimization helps to determine the best defence against worst case scenarios.

1 Introduction

This paper aims to demonstrate how to simultaneously minimize risk and maximize resilience without explicit modelling of the relation between risk and resilience. It investigates one of the threats considered in the PRECINCT (Preparedness and Resilience Enforcement for Critical Infrastructure Cascading Cyber-Physical Threats) project [1], namely a flooding that affects a European city.

The goal of the game-theoretic analysis is to identify strategies that provide optimal protection in the sense that they minimize the risk and simultaneously maximize the resilience [2]. Setting up such a game-theoretic model requires the following information:

1. The number of players
2. The possible actions that players can take (for their own revenue or against one another)
3. The payoffs for both players under all combinations of actions (from point 2).

In the context of critical infrastructure protection, we consider two players:

- A defender: an organization (e.g., a coordination centre or governmental bodies) that tries to protect one or more critical infrastructures and several threats that are of interest.
- An attacker: a rational entity that selects among the considered threats. The attacker can be a person or a group of people (e.g., in case of an APT) or nature (despite being irrational, i.e., without its own incentive. We let the second player defend against an artificial attacker, putting less weight on why the threats are there and more on how to defend.

Game theory assumes rational players, which is most likely not fulfilled in the case of an artificial attacker. Lacking knowledge about the opponents incentives, we may assume the attacker to have precisely opposite goals as the defender, corresponding to a worst-case scenario, and turning the game model into a zero-sum game ("my pain is your gain") [3]. The practically (much) more likely case of deviating rationales or even just "nature" as an entirely irrational opponent will then only improve the defender's situation, in the sense of experiencing less damage than expected. This conservative analysis avoids generally unreliable assumptions about the nature of attacks and the motives of adversaries, which may be practically unverifiable and to some degree speculative.

The strategies of the attacker are the considered threats and the strategies of the defender contain all the actions that can be taken to react to these threats in such a way that it reduces the risk or increases the resilience (or ideally both).

The lists of n defence actions and m threat scenarios define an $n \times m$ tableau, the payoff matrix of the game. The cell at row i and column j contains information about what happens if defence action i is taken under threat scenario j. These payoffs need to be assessed for each goal, in our case once for risk and once for resilience. Classical game theory assumes that these payoffs are real numbers, i.e., it is possible to assess them precisely. However, data about incidents in critical infrastructures is sparse and threats change (e.g., due to climate change). Cascading effects due to interdependencies make precise predictions of loss even more challenging. Risk can be assessed through loss distributions and reducing this to a single number (such as an average or a median) sacrifices information contained in the loss functions. To avoid this, we apply games that optimize stochastic payoffs [4]. The remaining task is therefore to estimate the payoff distributions for each scenario for each goal of the game, in our case for risk and for resilience (section 2.3 describes ways to do this). In case the analysis should also consider the cost as another goal to be optimized, a third payoff matrix is needed to describe the game.

2 Threat analysis

This section describes the considered threat scenario in such a way that it can be incorporated in the game-theoretic framework described in Section 1 and afterwards evaluated.

2.1 Threats

As many other natural hazards, floodings have become more frequent and more severe in recent years. Besides the direct impact on a city, especially on the transportation infrastructure, there are many indirect impacts due to cascading effects, e.g., hospitals are harder to reach, emergency services face congestion, and sewer systems are affected.

For the upcoming analysis we consider two different severity levels:

- Heavy rain: a significant amount of rain in a short period of time. Such events happen regularly, and the resulting damage is usually moderate
- Flood: rain fall for a longer period of time. Such events happen less frequently, and the damage is typically higher (e.g., damage to buildings)

Other threats can be considered, but this increases the dimension of the payoff matrices which makes a clear presentation more difficult.

2.2 Counteractions

Possible actions that reduce the risk of damage due to flooding and/or increase the resilience against it are manifold and specific to the considered infrastructure. For the sake of illustration here use generic counteractions that apply to many infrastructures.

- Increase flood protection measures (e.g., build a wall)
- Install or improve failure warning system
- Increase availability of emergency resources
- Adapt or refine emergency plan

The game-theoretic analysis described in Section 3 provides information on how to choose between these possible counteractions. In the simplest case, the analysis identifies a unique strategy that should be used. In other cases, it is optimal to choose multiple strategies with different frequencies.

2.3 Estimation of risk and resilience

Given the strategies for attacker and defender the remaining task is assessment of the payoff matrices for each goal, in our case one for risk and one for resilience. This task is challenging for every game-theoretic model and especially in the case when we use stochastic payoffs. In collaborative projects where people have different background it is recommended to work with categorical distributions, e.g., using a scale form 1 (best) to 5 (worst) to describe the expected consequences of an incident. Experts can usually provide such qualitative information about the effects [5] of incidents, and even more important thy are able to compare situations and decide which one is more critical for them.

Risk can be measured in many ways. Actuarial science offers various statistical models for extreme events [6] whose parameters may be actively influenced by the defender, i.e., the defender can shape the loss distribution such that the likelihood of large losses is reduced. Depending on the considered threats it may be challenging to find suitable distributions for all cases, and it is therefore better to use qualitative risk estimation based on historical data or expert assessment. In some situations, the estimation of risk (in terms of loss) can be supported by simulations. By letting a scenario start with a threat incident and simulating the impacts of a defined countermeasure, we can compile a loss distribution from numeric data collected over a sufficient number of trial simulations. In the PRECINCT project, a Mealy automata model is used to describe how this state of a component (representing its 'health') changes due to a threat for each component. Based on this local dynamics, a simulation framework is applied to estimate the cascading effects on an entire network of infrastructures [7]. This simulation enables an estimation of the risk in terms of impact (i.e., damage or reduced availability). The game theoretic model does not include the likelihood of occurrence of the threats, as this is an output of the analysis, at least for strategic attackers. In cases the assessment is done without support form historical data or simulation tools it may make sense to use multiple risk categories to capture the complex nature of risk [8].

Resilience is understood and therefore measured in many ways, depending on the context [9–13]. An approach that proved useful in course of PRECINCT is to work with resilience indicators that focus on services provided by organisations, e.g., on the number of passengers transported in an hour or the accessibility of an infrastructure [14]. Such indicators can be combined to a resilience score described on a qualitative scale. Other resilience measures might be mapped or adapted to fit the format of the risk measures [15].

For the upcoming analysis it is necessary that the scales used to describe the payoffs are comparable, since they are combined to a single payoff through a weighted sum [16]. It is therefore crucial to adapt the scale used to measure resilience to that used to describe losses (e.g., choose 5 levels). Another issue is that in this game one goal is minimized and one maximized, but the weighted sum of all payoffs can only be optimized in one direction. To this end, it is necessary to reverse the scale of the resilience payoffs in such a way that we minimize the 'negative' (or at least converted) resilience instead of maximizing the original resilience values. A simple way of doing this is taking the maximum resilience value $Resilience_{max}$ and minimizing the converse quantity $Resilience_{max} - resilience_{current}$ that lives on the same scale as "resilience", but is whose minimum will maximize the current resilience as a system property. Letting both, risk and resilience, range on a scale from 1…5, with 1 being "low" and 5 being "high", we strive towards achieving "risk = 1" (low), and "resilience = 5" (high), of equivalently "6 – resilience = 1" (low), so that we can minimize both variables (hence, we have $Resilience_{max} = 6$ in this example). Having the same optimization goal for all variables (in the sense of all minimizing or all maximizing) is a matter of technical convenience when using optimization algorithms off the shelf.

If we consider resilience as a system property that negatively correlates to risk (intuitively, higher resilience will mean lower risk and vice versa), we can simultaneously optimize the two goals by a scalarization. This means to optimize the weighted sum $w \cdot risk + (1 - w) \cdot (Resilience_{max} - \mathrm{resilience}_{current})$ with $0 < w < 1$ being a quantity to describe the "magnitude" of how strong risk and resilience correlate (setting $w = 0$ would ignore all risk and just optimize resilience; setting $w = 1$ would conversely focus all optimization on risk minimization, and the middle $w = 0.5$ may be a choice in lack of better knowledge to treat both goals "equally"). This modeling has the intuitively expected effect that any decrease of risk will need an increase of resilience and, conversely, reduced resilience will result in increased risk.

Payoff matrices with artificial data (to avoid leaking of real data) inspired by discussions with project partners are shown in **Figure 1** and **Figure 2**. We assumed that damage due to a flood is generally higher than in the case of heavy rain and that planning activities (failure warning system, refined emergency plan) are suitable to reduce damage and increase resilience. The ability to change the availability of emergency resources may be limited (simply due to limited resources of firefighters and similar resources).

Figure 1. Payoff matrix for gaol 'Risk'

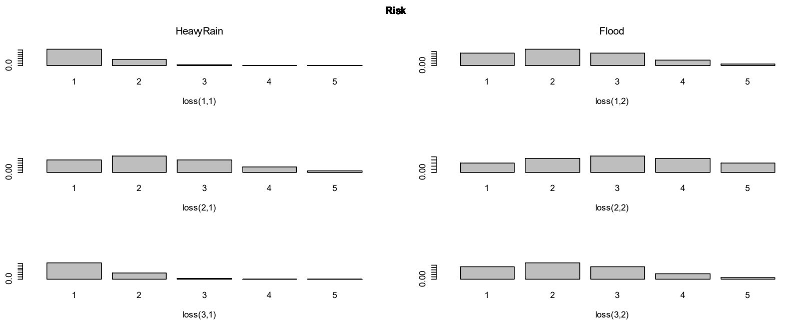
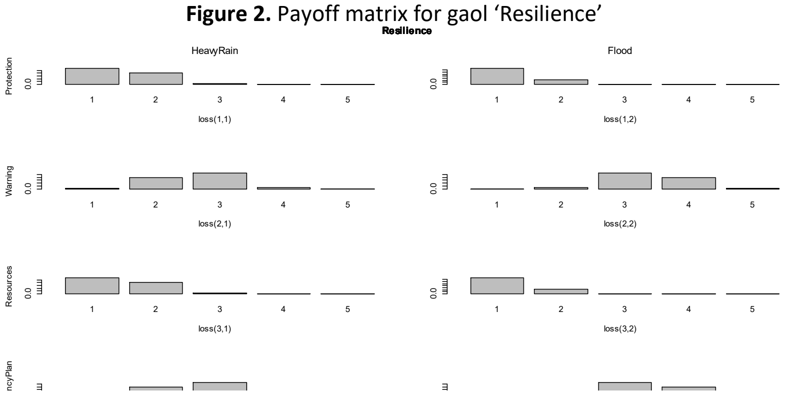


Figure 2. Payoff matrix for gaol 'Resilience'



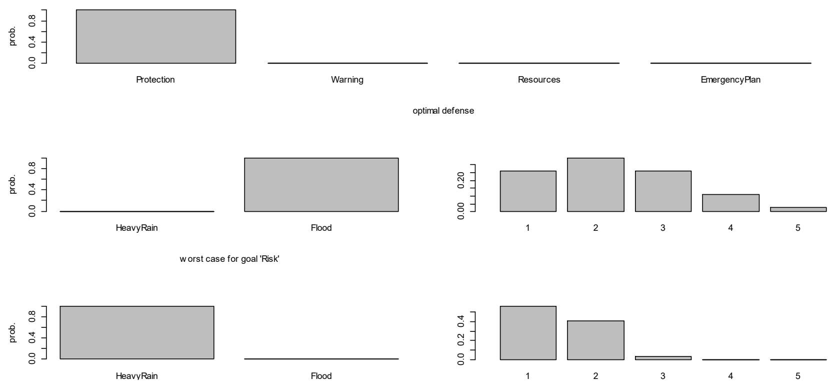
3 Identification of optimal strategies

The game specified in Section 2 is analysed using an implementation in R [17]. The HyRiM package account for categorical data in the following sense (described in terms of loss). The players are assumed to act "as best as they can against each other", to mutually optimize the largest loss category. That is, the defender seeks to minimize chances for the highest possible losses, while the (hypothetical) adversary attempts to maximize the probability for losses of the largest category to occur. Once this optimization is done, the analysis proceeds by letting the defender minimize the probability for the "second-largest loss" category, while retaining its defence to further guarantee the minimum probability of the largest possible loss. That is, the optimization in the second-highest loss category should not invalidate the current action profile that optimizes the largest possible losses already. This process is repeated for all loss categories until the smallest on the scale (as a typical example, these may be five loss categories, ranging from "negligible" < "low" < "medium" < "high" < "very high").

If the losses are categorized in multiple dimensions, for example, damage of infrastructure, loss of human lives, or similar, the game assigns a number to each dimension reflecting its importance relative to the other goals. The optimum defence resulting from this scalarization is such that there any attempt to improve the defence in one aspect would necessarily lead to a decrease of protection quality in another dimension (Pareto-optimality).

For the game described in Section 2, the result is shown in **Figure 3**. The algorithm identified the strategy 'increase flood protection measures' as the optimal category, which is not surprising as both payoff matrices indicate that in this case the loss is reduced, and the resilience increased. Things may change, if costs are explicitly considered as a third goal, but we assume that only affordable strategies are considered).

Figure 3. Optimal strategies for defender and attacker.



4 Conclusions

A multi-objective game-theoretic model allows simultaneous optimization of risk and resilience without the need of an explicit model of the dependency between risk and resilience. It provides a mixed strategy to react to a set of considered threats.

Acknowledgements

This work was done in the context of the PRECINCT project (www.precinct.info) which was funded by the European Union's Horizon 2020 research and innovation programme under Grant Agreement No 101021668.

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PRECINCT

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TOMORROW TODAY

A GAME FOR SIMULTANEOUS RISK AND RESILIENCE OPTIMIZATION

Focus on Interdependent Critical Infrastructures

Sandra König, Stefan Rass, Stefan Schauer

ESReDA Seminar, October 2022

PRECINCT

MOTIVATION

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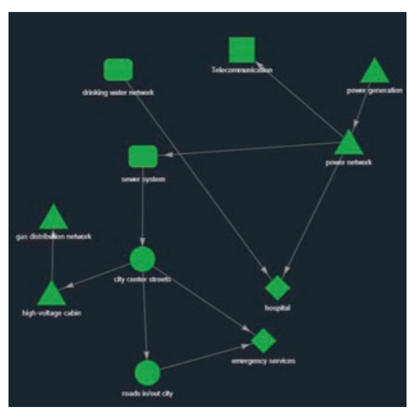
- Risk and resilience are correlated
  - Explicit description hard to find

PRECICNT project:

- Interdependency graph of CIs
- Cascading effects simulation
- Use case: flooding of a city
  - Cascading effects
  - Protect CI network
- Game for optimal protection



PRECINCT

SECURITY AS A GAME

Consider a threat as an 'attack' that causes damage

a) Player
   - Attacker – Human (cyber-attack), nature
   - Defender – CI, coordination centre, …

   Assumption: zero-sum game

b) Strategies: actions for players

c) Payoffs: impact (loss, damage, …)
   - Qualitative scale: 1 (minimal), …, 5 (massive)
   - Likelihood of occurrence not required as input, output of analysis

PRECINCT

FLOODING SCENARIO

- Player: attacker and defender (zero-sum)
- Strategies: actions for players
  - Attacker
    1. Heavy rain
    2. Flood
  - Defender
    1. Increase flood protection measure (e.g., wall)
    2. Improve warning system
    3. Adapt emergency plan
- Payoffs: probabilistic impact on scale 1 (minimal), …, 5 (massive)
  - estimate through simulation, resilience framework, experts assessment

PRECINCT

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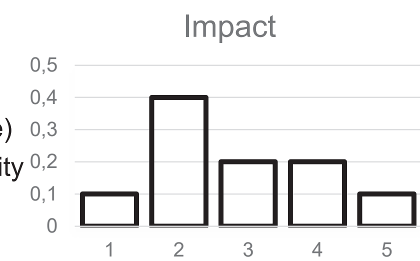
PROBABILISTIC PAYOFFS (1)

How to measure impact?

Your choice, but we recommend:

- Qualitative scale: 1 (minimal), …, 5 (massive)
- Probabilistic due to uncertainty and complexity

→ Distribution over possible losses



How to estimate impact?

- Historical data (rare)
- Expert assessment → include uncertainty

Table 4: Distribution over all states depending on impact and likelihood

Impact/Likelih.	Very Low	Low	Medium	High
Negligible	(1,0,0)	(1,0,0)	(1,0,0)	(1,0,0)
Moderate	(1,0,0)	(1/3,1/3,1/3)	(1/3,1/3,1/3)	(0,1,0)
Major	(1,0,0)	(1/3,1/3,1/3)	(0,2/3,1/3)	(0,0,1)
Severe	(1,0,0)	(1/3,1/3,1/3)	(0,2/3,1/3)	(0,0,1)

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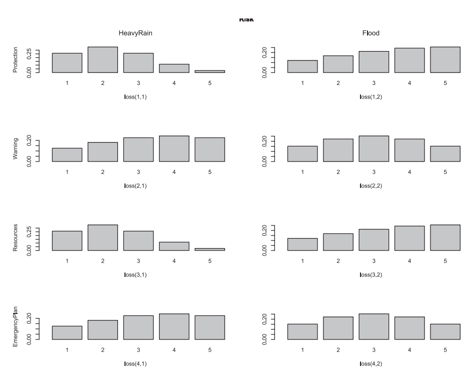
PROBABILISTIC PAYOFFS (2)

- Probabilistic payoffs instead of numbers
  - Define ordering between distributions
- Discrete case → lexicographic order
- Interpretation:
  - Minimize probability of maximal loss
  - Maximize probability of maximal resilience

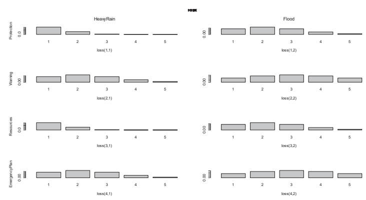


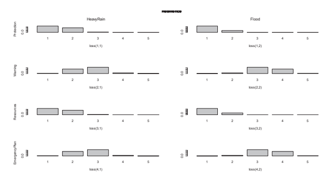
PRECINCT

MULTI-OBJECTIVE OPTIMIZATION

Goal: simultaneously optimize multiple goals may be dependent

- Determine payoffs for each goal
  - One payoff matrix for each goal
- Use same structure (set of strategies) and same scale





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PRECINCT

RISK AND RESILIENCE GAME

Goal: simultaneously minimize risk and maximize resilience

- Goal 1: minimize risk
  - Measured in terms of loss (1 = very low, …, 5 = very high) → min
- Goal 2: maximize resilience
  - Measured on same scale (1 = very low, …, 5= very high) → max
  - Adapt score such that minimizing as well, e.g., $Res_{max} - Res_{current}$

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SOLVING THE GAME

- Payoffs are combined to one

$$P_{tot} = w_1 P_1 + w_2 P_2$$

  - weights w_i representing the importance of goal i

- Game is solved with Fictitious Play algorithm
  - Adapted to probabilistic payoffs

- Implementation in R: package ‘HyRiM’ [FP7 project]
  - Interpretation for discrete distributions: lexicographic ordering

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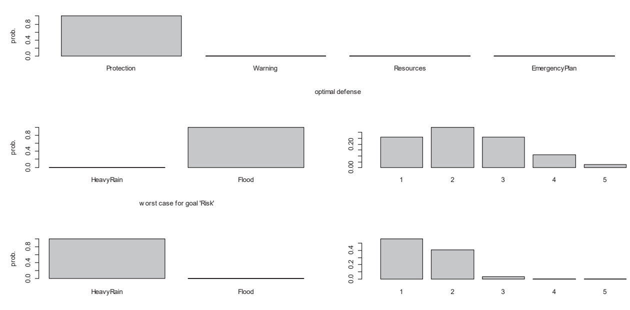
EQUILIBRIUM

- Optimal strategies
  - Defender
  - Attacker (for each goal)
  - Mixed strategies possible
- Worst-case risk and resilience for each goal (assurance)



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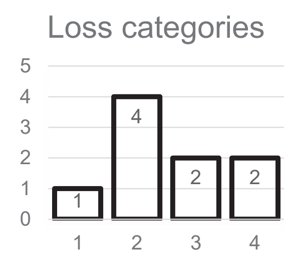
PRECINCT

ALTERNATIVE INTERPRETATION

- Payoffs not random, but multi-dimensional
  - Risk measured in multiple categories [ESReDA May 2022]
    - A. Humans
    - B. Property
    - C. Economy
    - D. Environment
  - Resilience in different phases [Marcelo Masera]
  R0, R1, R2, R4
- Compare with lexicographic order (priorities)



PRECINCT

FUTURE DIRECTIONS

Potential future work:

- Precinct Use Cases
  - Cyber and physical attacks (and combined), flooding, targeted attack to CIs
- Compare with empirical results from serious games
- Incorporate resilience framework (partners)
  - Further investigate how resilience is understood in different domains
- Investigate how pessimistic the worst-case is (far in the future…)

PRECINCT

PRECINCT PARTNERS

PRECICNT Project:

- *European Union's Horizon 2020 research and innovation programme,* grant agreement No 101021668
- More at
  - https://www.precinct.info/en/about/#about_the_precinct_project
  - Linkedin
  - Twitter

PRECINCT

AIT AUSTRIAN INSTITUTE OF TECHNOLOGY

TOMORROW TODAY

QUESTIONS?

Sandra König, 22.09.22

ESReDA | European Safety, Reliability & Data Association

Politecnico di Torino

61st Seminar on Technological disruptions triggered by natural events: identification, characterization, and management

September 23rd 2022, Turin, Italy

Advances in Natech Risk Management

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2

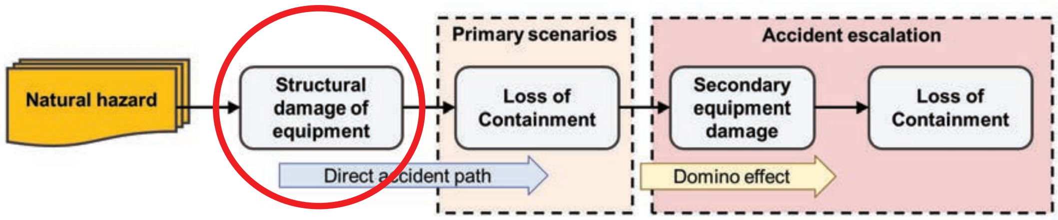
Outline of the presentation

- Definition and occurrence of Natech accidents
- The conventional paradigm for quantitative assessment of Natech scenarios
- Cornerstone accidents not captured by the conventional paradigm
- An innovative paradigm for Natech assessment
- The ITER to advanced Natech risk management
- Examples of new paradigm implementation:
  - ✓ Identification of indirect Natech scenarios
  - ✓ Assessment of safety barrier performance
- Conclusions and perspectives

Natech Event: definition

- Natural events (earthquake, floods, etc.) may cause damage to industrial installations and infrastructures
- Damage caused by natural events may start the release of hazardous substances triggering a technological accident
- These cascading events are defined "Natech" scenarios (Natural hazard triggering Technological disasters)
- NaTech scenarios are potentially high impact – low probability (HILP) events

The current paradigm for Natech assessment



- The current paradigm for the quantitative risk assessment of Natech scenarios is based on the assumption of a loss of containment caused by structural damage of equipment
- The natural event is assumed to cause the structural damage of process or storage equipment containing dangerous substances

The current paradigm for Natech assessment

5

Quantitative Risk RA of Natech events

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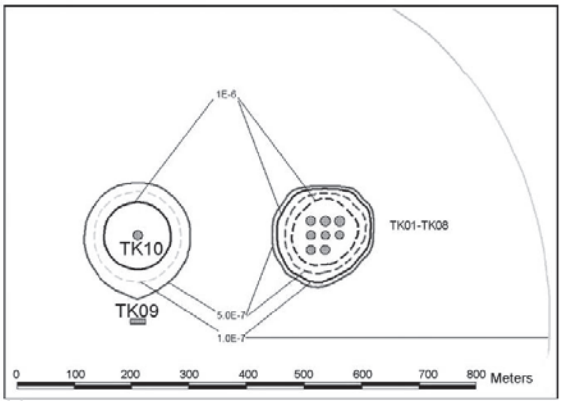
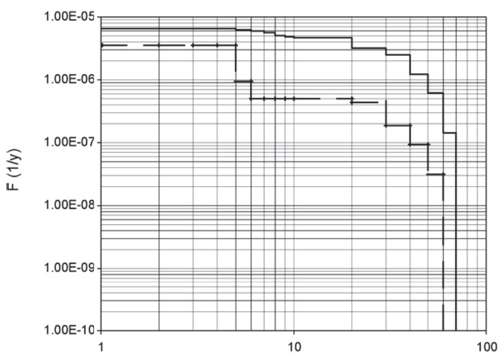




First complete QRA of a Natech event was published in 2007

G. Antonioni, G. Spadoni, V. Cozzani: A methodology for the quantitative risk assessment of major accidents triggered by seismic events. J. Hazardous Materials 147 (2007) 48–59

Early studies date back to 2003 and 2005:

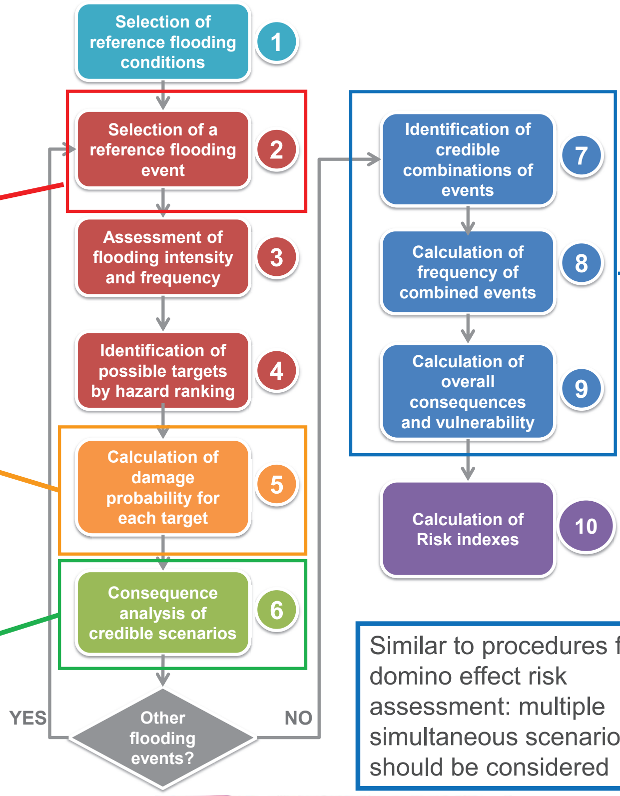
G. Fabbrocino, I. Iervolino, F. Orlando, E. Salzano: Quantitative risk analysis of oil storage facilities in seismic areas, J. Hazard. Mater. 123 (2005) 61-69

Natech QRA

A simplified description of the natural event is needed: intensity - time of return pairs

Vulnerability models for equipment are required

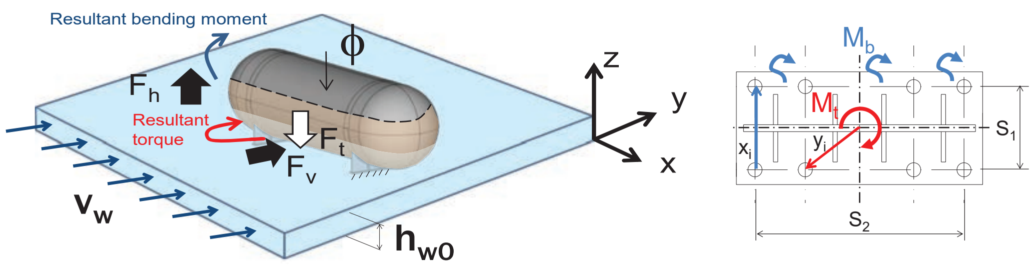
Specific event trees may be needed to capture Natech specific scenarios



Similar to procedures for domino effect risk assessment: multiple simultaneous scenarios should be considered

Key Enabling Models for RA and RM Tools

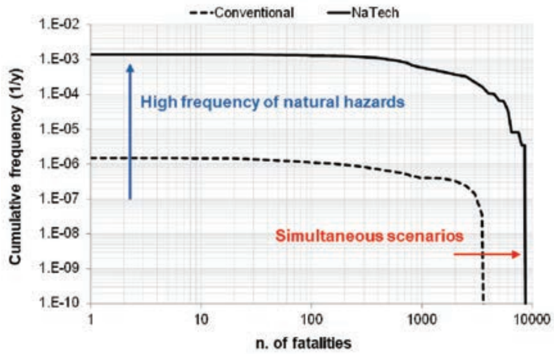
- All the methodologies for RA and RM are based on "**Key Enabling Models**" (**KEM**) for equipment damage
- KEM are empirical **probabilistic** models providing equipment damage probability in cascading events
- KEM require extremely **low computational effort** compared to FEM/CFD

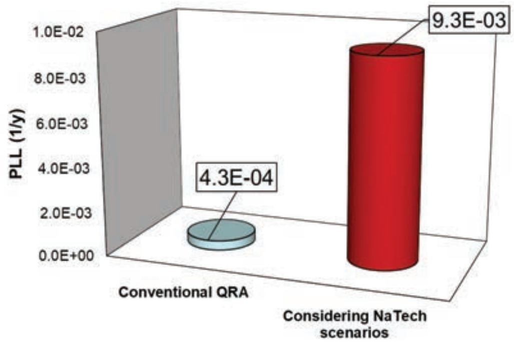


Natech Events: specific features

9

- ❑ Natech events go beyond "conventional" technological accidents
  - ➢ Multiple simultaneous failures
  - ➢ Cascading events: elevated possibility of escalation
  - ➢ Impact on safety systems, utilities and lifelines
  - ➢ Complex emergency management





The current paradigm for Natech assessment

10

- The current paradigm was verified in several Natech events
- However, **some recent severe accidents evidence that this is not the only route to Natech scenarios**

- *The **failure of utilities** (electric power, cooling water, etc.) as a consequence of intense natural events was evidenced as a **possible cause of technological scenarios***
- *The possible degradation of safety systems and safety barriers due to the action of natural events is also a key element to consider in Natech scenarios*

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MTO analysis of cornerstone Natech events

11

- MTO (Man, Technology and Organization) analysis is a well-known accident investigation method originally developed in the nuclear sector
- Representing the accident through a MTO analysis worksheet allows highlighting how human, technical and organizational factors contribute to accident progression

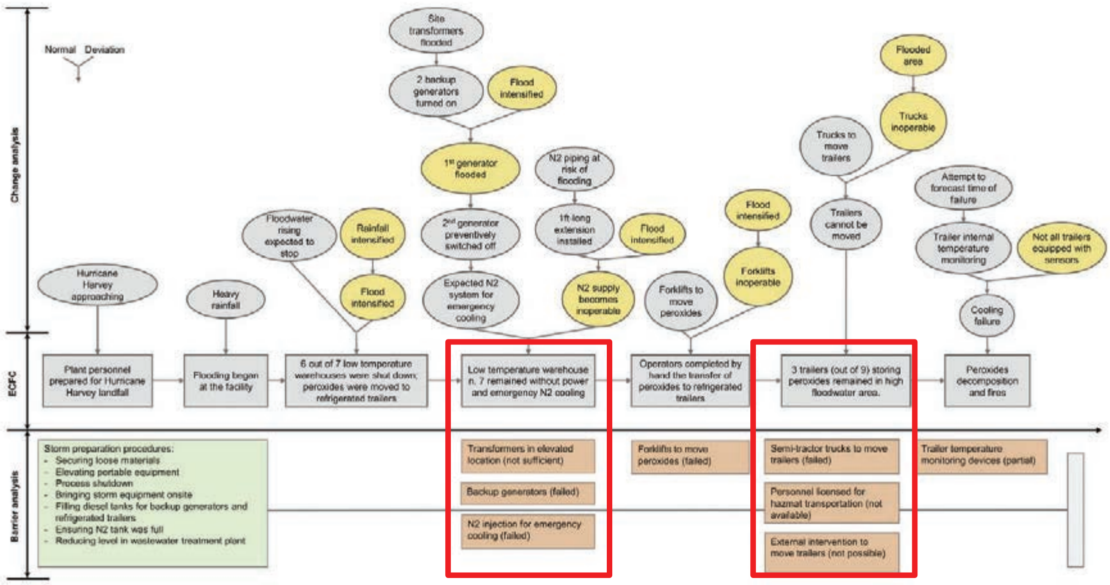
- *Two cornerstone Natech events were analyzed with MTO analysis:*
  - ✓ *The Arkema accident, Crosby, Texas, US (2017)*
  - ✓ *The Dai-Chi NPS accident, Fukushima, Japan (2011)*

Hurricane Harvey - Arkema Accident

12

- ✓ Occurred: **August 26-31, 2017**
- ✓ Site: **Arkema site in Crosby, Texas, producing organic peroxides**
- ✓ Cause: **Flood du to hurricane Harvey impact on the site**
- ✓ System affected: **peroxide refrigeration units, emergency power generators, inert gas system, peroxide storage units**
- ✓ Impacts: **Explosion and fire causing damage to storage tanks and processing units**
- ✓ Outcomes: **Economic losses, 2 policemen intoxicated by fumes, 1.5 mile radius evacuation area**

MTO analysis of Arkema plant

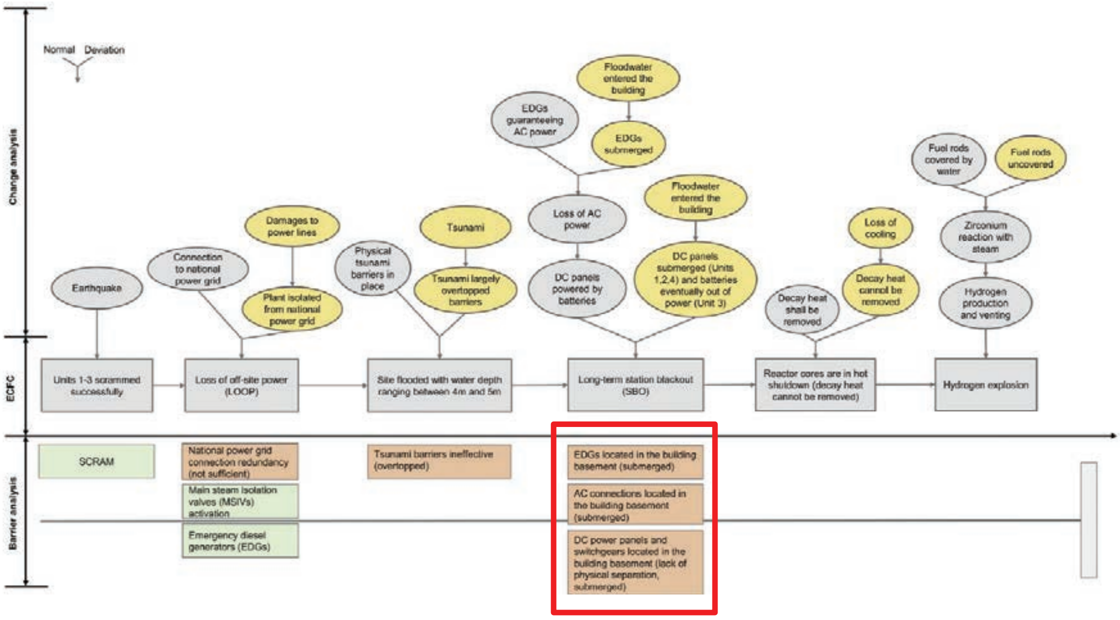


- ✓ *ECFC: Event and Causal Factor Chart*

Dai-Chi NPS accident, Fukushima

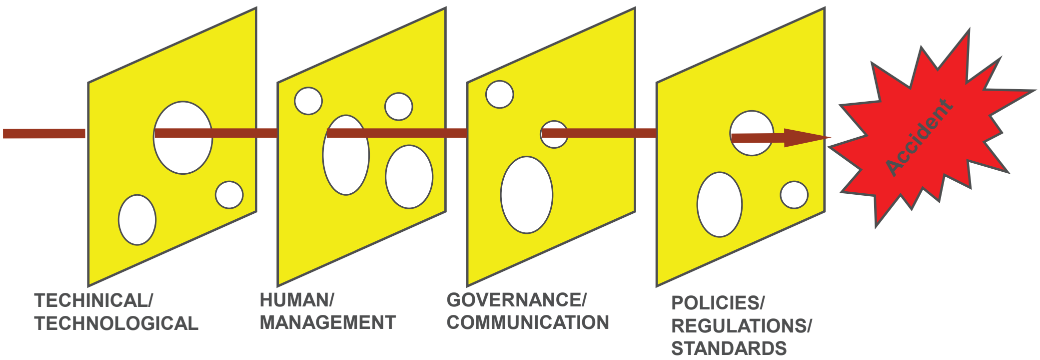
- ✓ Occurred: **March 11th, 2011**
- ✓ Target: **Dai-Chi Nuclear Power Station, Fukushima, Japan**
- ✓ Cause: **tsunami**
- ✓ System affected: **electric power supply, emergency power generators, control rooms, reactors, buildings**
- ✓ Impacts: **core meltdown in reactors 1-3; release of radioactivity and of contaminated cooling water**
- ✓ Outcomes: **huge economic losses: complete loss of the site, long-lasting actions to contain radioactivity; no onsite direct fatalities due to tsunami and explosions**

MTO analysis of Dai-Chi NPS

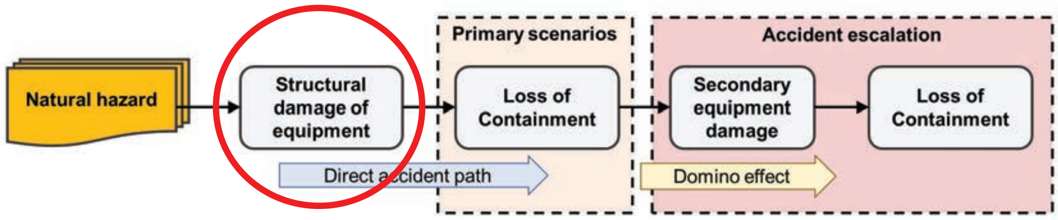


Results of MTO

- The **critical event** leading to the loss of containment in both accidents is caused by the **loss of electric power**
- The **failure** or **degradation** of **safety barriers** due to the impact of the natural event resulted a relevant factor in the unfolding of the chain of events leading to the accident

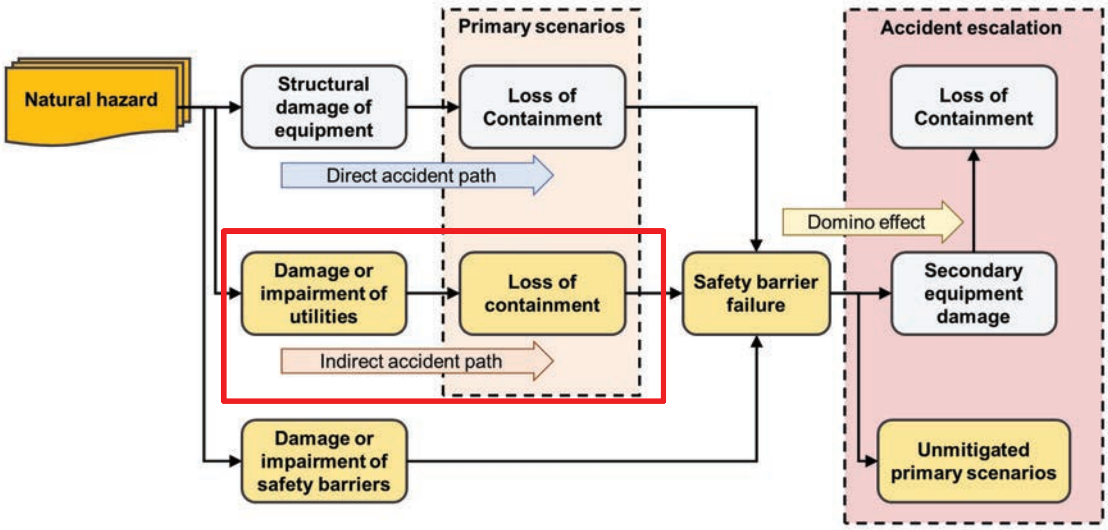


The current paradigm for Natech assessment



- The current paradigm **is not able to capture** accident scenarios as those occurred at the Arkema plant in Crosby and at Dai-Chi NPS
- The possible indirect route to Natech events needs to be considered the assessment of Natech risk
- An improved paradigm is needed for the management of Natech risk

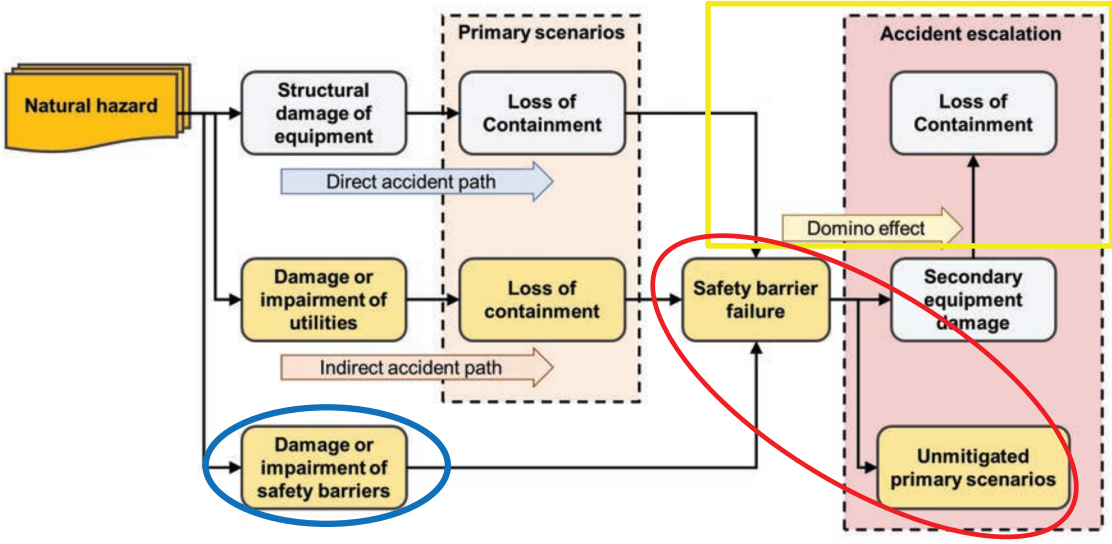
A new paradigm for Natech risk assessment



- The new paradigm introduced considers two alternative routes leading to Loss of Containment (LOC)
- LOCs caused by the failure of utilities are specifically addressed

(Misuri and Cozzani, Proc. Saf. Env. Prot. 52:338-351, 2021)

The new holistic paradigm for Natech



- The role of safety barriers impairment or degradation in the escalation of the consequences of primary accidents is specifically addressed
- The paradigm also addresses the effect of barrier impairment on cascading events triggered by domino effects

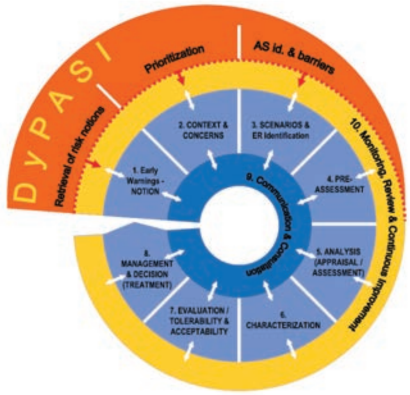
Paradigm implementation: approach

A challenging ITER towards the advanced risk management of Natech events:

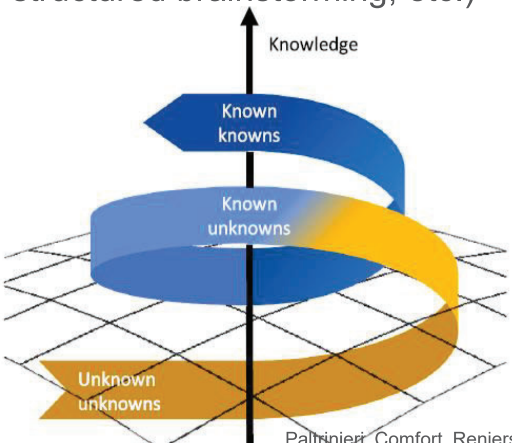
1. **Identification**: horizon screening and collection of weak signals and early warnings in key-industrial sectors affected by inherent hazards
2. **Tools for Risk Assessment and Risk Management**: development of specific tools to progress in the assessment and management of cascading events
3. **Enhanced Protection and Prevention by Design**: foster risk based design concepts and include safety drivers since early design
4. **Resilience**: resilient systems are required to manage risk of exceedance and HILP cascading events

1. Identification

- **New techniques:** dedicated to capture early warnings or scattered notions by the use of **AI** and **big data**
- **Integration:** creating synergies by the integration of complementary HazId techniques (indicators, structured brainstorming, etc.)



Paltrinieri et al., DyPASI: a new systematic HAZID tool. J.Loss Prev.Proc.Ind. 26:683-695 (2013)

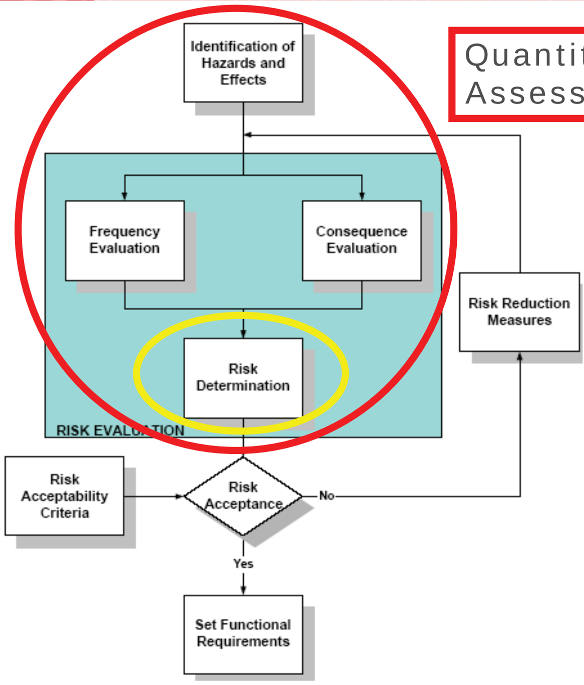


Paltrinieri, Comfort, Reniers, Learning about risk: Machine learning for risk assessment. Saf. Sci. 118, 475–486 (2019)

2. Tools for RA

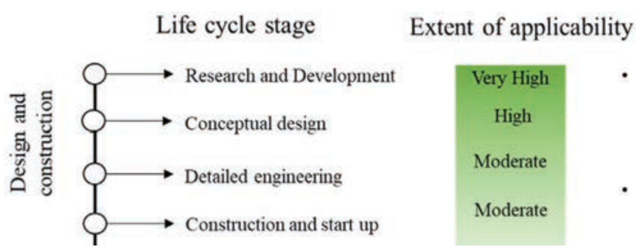
Early studies afforded the extension of Quantitative Risk Assessment (**QRA**) to cascading events as Natech

Quantitative Risk Assessment



3. Enhanced Protection and Prevention by Design

- Conventional protection and prevention by design based on static/deterministic problem description needs to be updated
- **Inherent safety drivers** need to be **embedded** in process and plant design (including structural elements, utilities and services)
- **Risk-based design** may be useful to define the level of protection by design, defining the residual functionality of **critical units** (not all equipment items need protection)

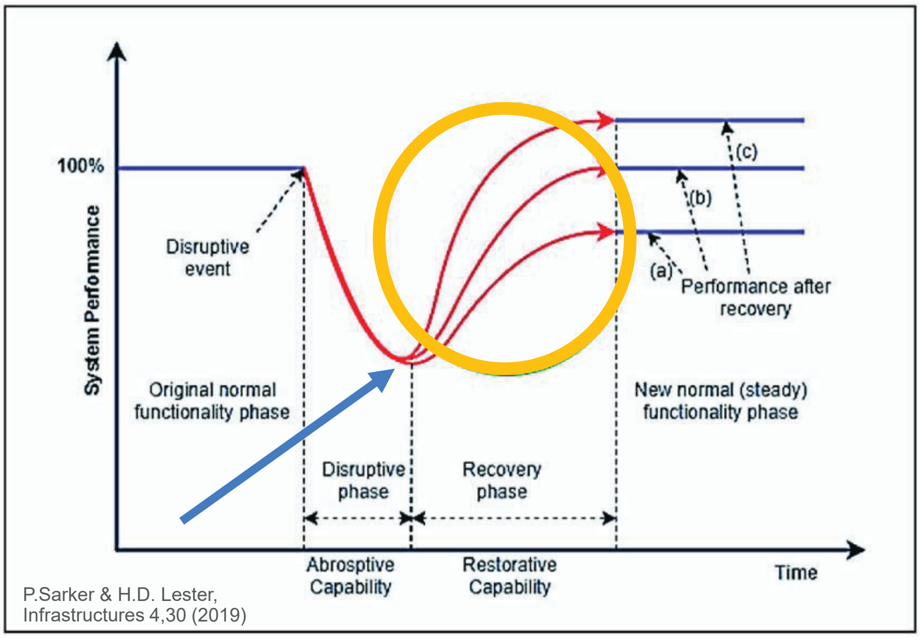


Y. Di Martino et al., Innovative decision-making framework to incorporate technological and non-technological Inherently Safer Design (ISD). J. Cleaner Prod. 296:126421 (2021)

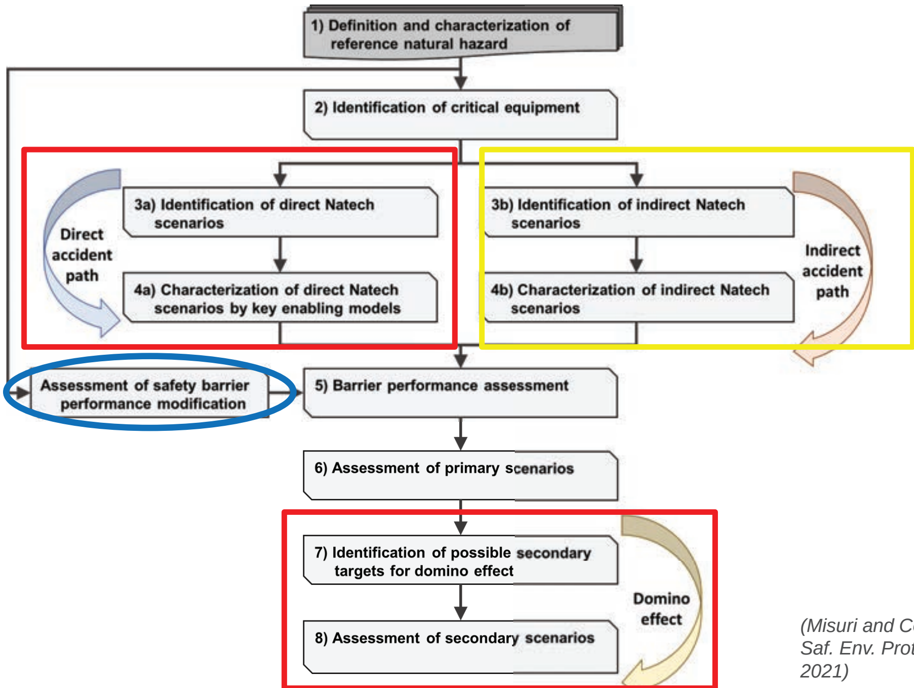
4. Resilience

- Resilience to cascading events is of utmost importance to manage the risk of atypical scenarios
- Modelling of system resilience to cascading events still needs to be consolidated
- Resilience modelling may be coupled to risk-based design to manage effectively the risk of exceedance
- Dynamic system sub-models for disruption and recovery during cascading events specific for the process industry are still missing
- Severe cascading events may cause effect beyond system boundaries and/or local community level

Resilience in Natech events

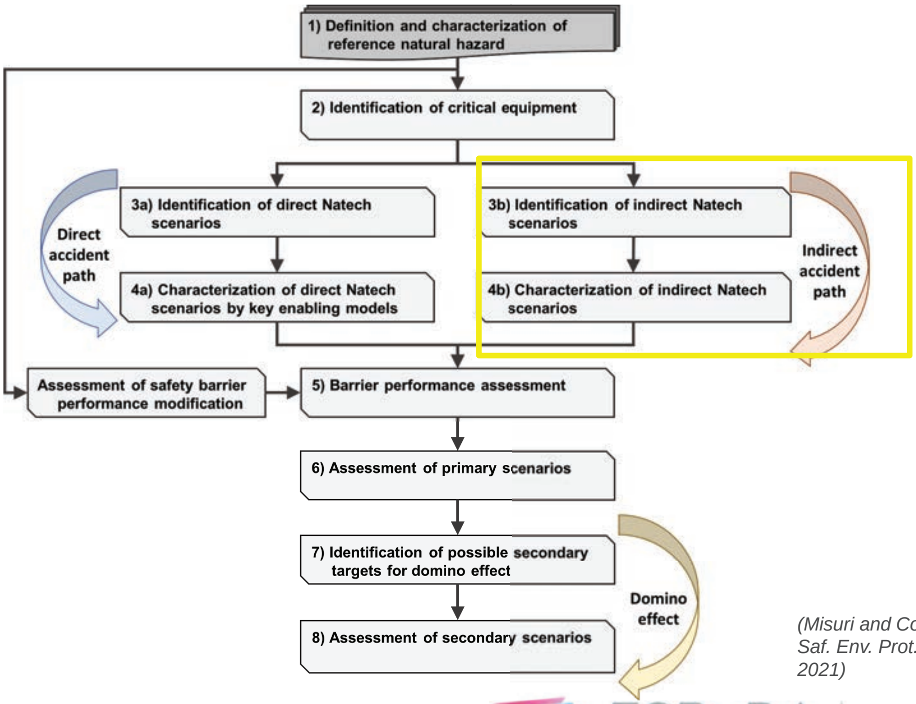


2. Improved RA tools for Natech: the new paradigm



(Misuri and Cozzani, Proc. Saf. Env. Prot. 52:338-351, 2021)

Step 3b – Identification of indirect scenarios



(Misuri and Cozzani, Proc. Saf. Env. Prot. 52:338-351, 2021)

Step 3b – Identification of indirect scenarios (1/3)

Evidence from the analysis of past accidents:

- The failure of power supply was responsible of several Natech accidents, in particular in the case of flooding
- Other critical utilities may fail due to the impact of the Natech events
- Failure of critical utilities may cause LOC events only for specific categories of substances
- Temperature sensitive, self-reacting or water reacting substances resulted the more critical categories

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Step 3b – Identification of indirect scenarios (2/3)

- *Reference list of potentially critical utilities:*
  - ✓ ***Electricity***
  - ✓ ***Cooling water***
  - ✓ ***Cooling fluids (brine, glycol-water solutions, refrigerants, etc.)***
  - ✓ ***Steam (energy vector for heat supply)***
  - ✓ ***Heating fluids (heating oil, molten salts, and other energy vectors for heat supply)***
  - ✓ ***Nitrogen gas (for purging and blanketing)***
  - ✓ ***Instrument air (compressed air for pneumatic actuators)***

Step 3b – Identification of indirect scenarios (3/3)

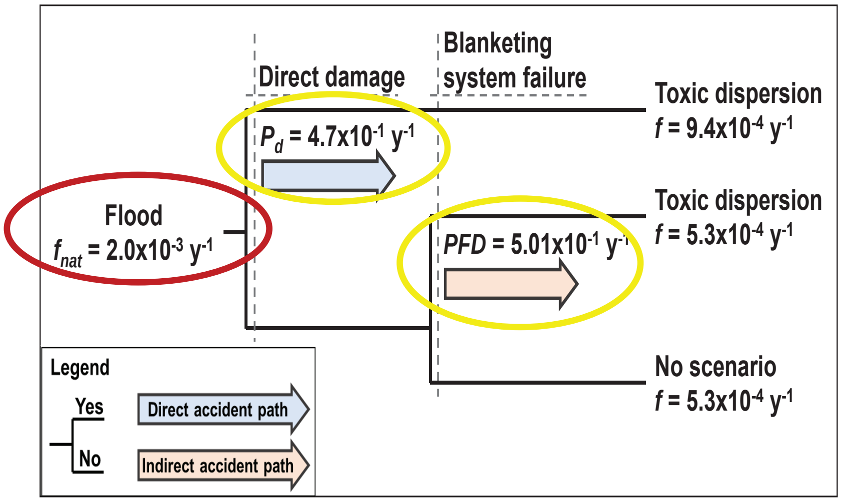
- **Critical categories of substances:**

ID	Description	GHS/CLP Hazard statements and codes	Reference scenarios
R01	Heat sensitive substances	Self-heating; may catch fire **(H251)** Self-heating in large quantities; may catch fire **(H252)**	Fire
		Heating may cause an explosion **(H240)** Heating may cause a fire or explosion **(H241)** Heating may cause a fire **(H242)** Risk of explosion if heated under confinement **(EUH044)**	Explosion/Fire
		May react explosively even in the absence of air **(H230)** May react explosively even in absence of air at elevated temperature and/or pressure **(H231)**	Explosion/Fire
R02	Substances reacting with water	In contact with water releases flammable gases which may ignite spontaneously **(H260)** In contact with water releases flammable gas **(H261)**	Flash Fire
		Reacts violently with water **(EUH014)**	Toxic dispersion/Fire
		Contact with water liberates toxic gas **(EUH029)** Contact with acids liberates toxic gas **(EUH031)** Contact with acids liberates very toxic gas **(EUH032)**	Toxic dispersion
R03	Substances reacting with air	Catches fire spontaneously if exposed to air **(H250)**	Fire
		May form explosive peroxides **(EUH19)**	Fire

31

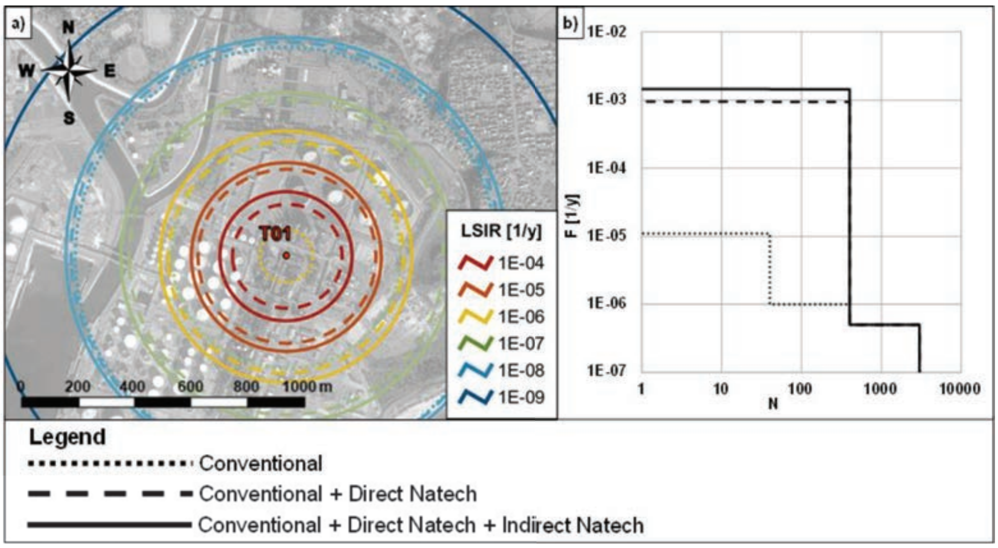
Notional case-study: Indirect Natech scenario

- Horizontal tank storing 40 ton of $SiCl_4$ at 3.5bar
- $SiCl_4$ is classified as EUH014 (Reacts violently with water) and releases HCl (toxic gas) upon reaction
- Inert gas is used to ensure safe storage conditions



32

Indirect Natech scenario – risk modification



- ✓ *Both individual and societal risk increase due to indirect scenarios*
- ✓ *Relevance of indirect scenarios depends on PFD of utilities and safety systems*

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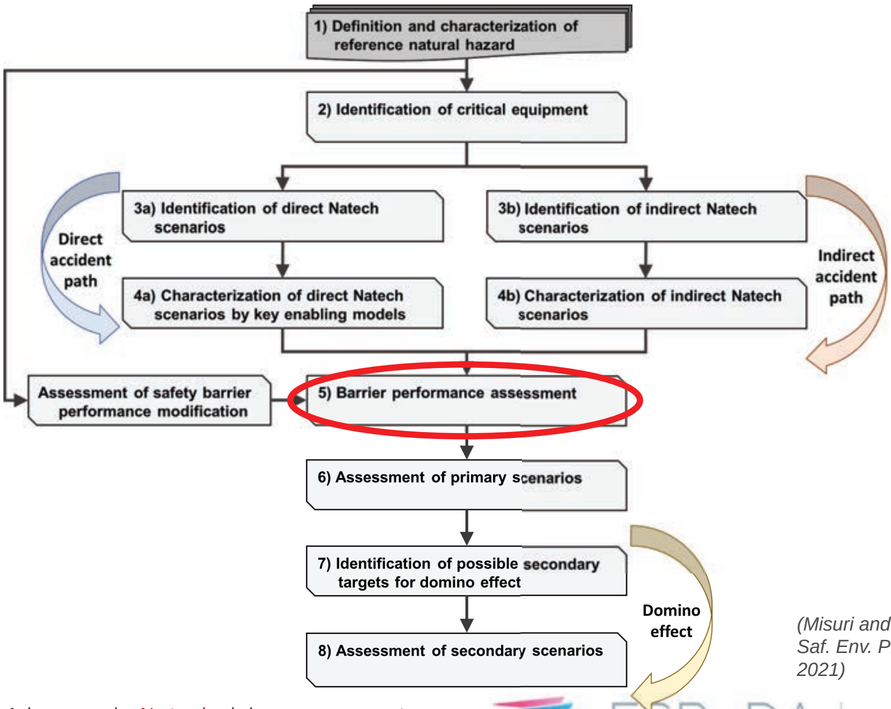
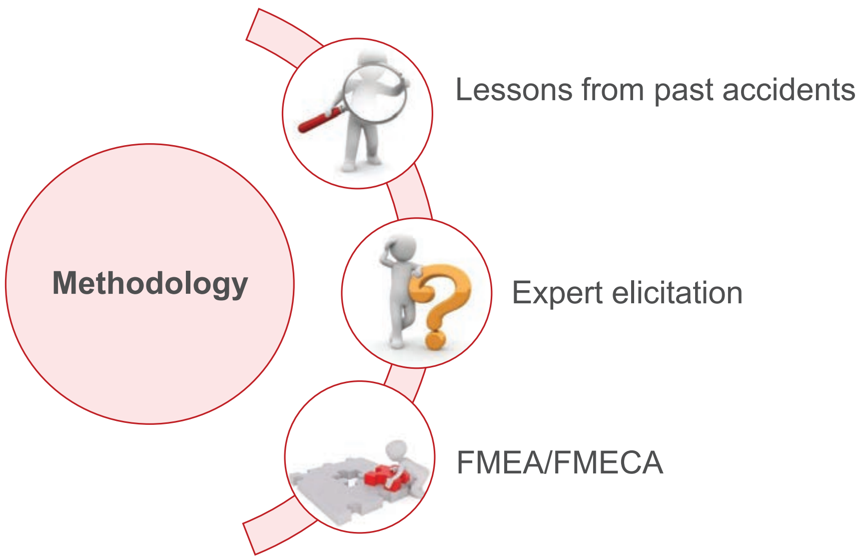
Step 5: Integration of barrier analysis in QRA



(Misuri and Cozzani, Proc. Saf. Env. Prot. 52:338-351, 2021)

Safety barrier performance in Natech events

Is barrier performance degraded in Natech events?



Lessons from past accidents

Hurricane Harvey (Texas, 2017)

- About 100 chemical releases. **Power outage** was experienced in many cases. Massive release from shutdown and emergency flaring. (*Misuri et al., 2019*)*
- Arkema peroxide plant was flooded. **Power outage** interrupted the refrigeration units. **Inert gas system not available**. **Backup generators submerged.** Violent explosions. **Emergency intervention was hindered by floodwater**. *(CSB)*

Vltava River Flood (Czech Republic, 2002)

- Electrolysis plant was flooded. **Emergency retention sumps were flooded**. 80000t of chlorine were released in air and water. *(eMars)*

Hurricane Katrina (Louisiana, 2005)

- At Murphy Oil, one crude oil tank (95m diameter) was dislodged (*Godoy, 2007*), spilling more than 3000m3 of oil. **Containment dikes were submerged and damaged**. Part of oil spread in residential area. (*NOAA*)

San Jacinto River Flood (Texas, 1994)

- During flooding, 8 hydrocarbon pipelines ruptured (other 29 were undermined), releasing LPG, gasoline, crude oil, diesel fuel and natural gas. Fire developed in multiple areas. 545 injuries by smoke. **Manual interruption valves were submerged**. **Operator intervention hampered**. *(NTSB)*

(Misuri et al., Reliability Eng. Sys. Saf., 2019, in press, https://doi.org/10.1016/j.ress.2019.106521)

Lessons from past accidents

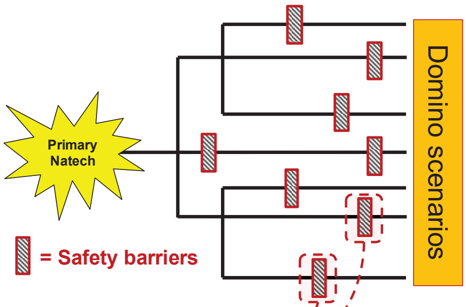
- Power outage is recurrent in accidents triggered by flood
- Research on natural hazard impact on power grid reported power outage in the totality of investigated flood events. *(Karagiannis et al., 2017)*
- From major accident database *(Cozzani et al., 2010)*:
  - Main item mostly involved: atmospheric storage tanks (~56%)
  - Dangerous substance mostly involved: liquid hydrocarbons (~67%)
  - Recurrent scenarios: environmental contamination and fire

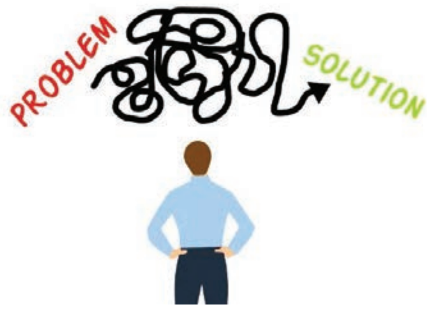
↓

These findings influence how to prioritize
some types of barriers in the analysis!

Step 5: Assessment of barrier performance

- **Procedure for the assessment of barrier performance:**



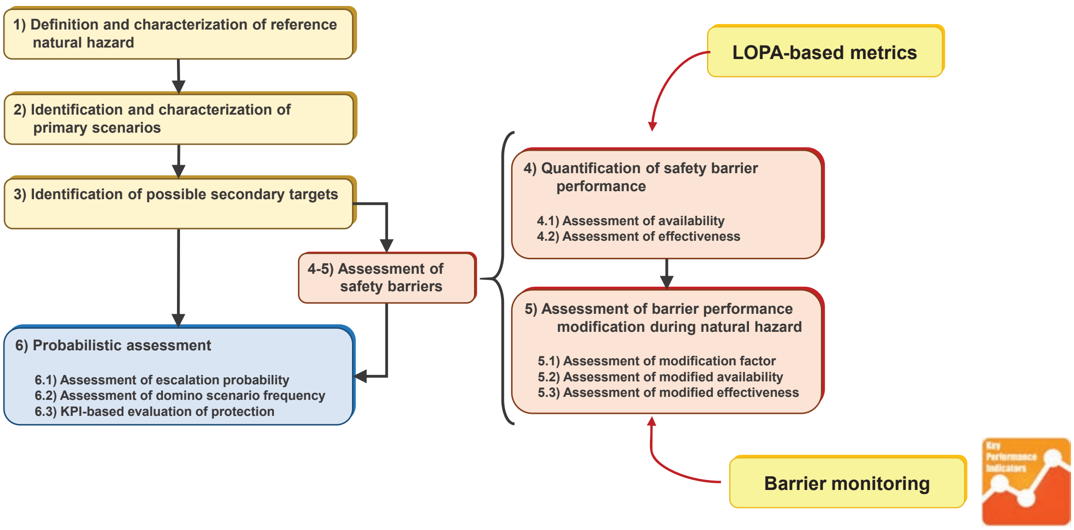


The performance of safety barriers is critical in determining the likelihood and the magnitude of accident escalation!

How does the impact of natural hazards modify overall risk figures?

Step 5: Assessment of barrier performance

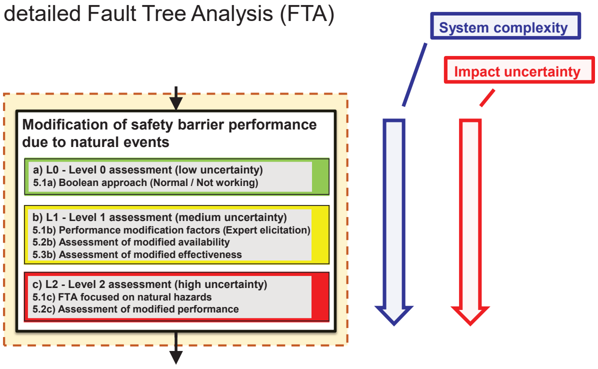
- **Quantitative assessment of barrier performance:**



(Misuri et al., Reliability Engineering System Safety, 205:107278, 2021, https://doi.org/10.1016/j.ress.2020.107278)

Step 5: Integration of barrier analysis in QRA

- A multi-level approach to barrier assessment was included in the two methodologies
  - Level 0: Low uncertainty, Boolean approach to be used
  - Level 1: Medium uncertainty, φ for reference barrier systems
  - Level 2: High uncertainty, detailed Fault Tree Analysis (FTA)



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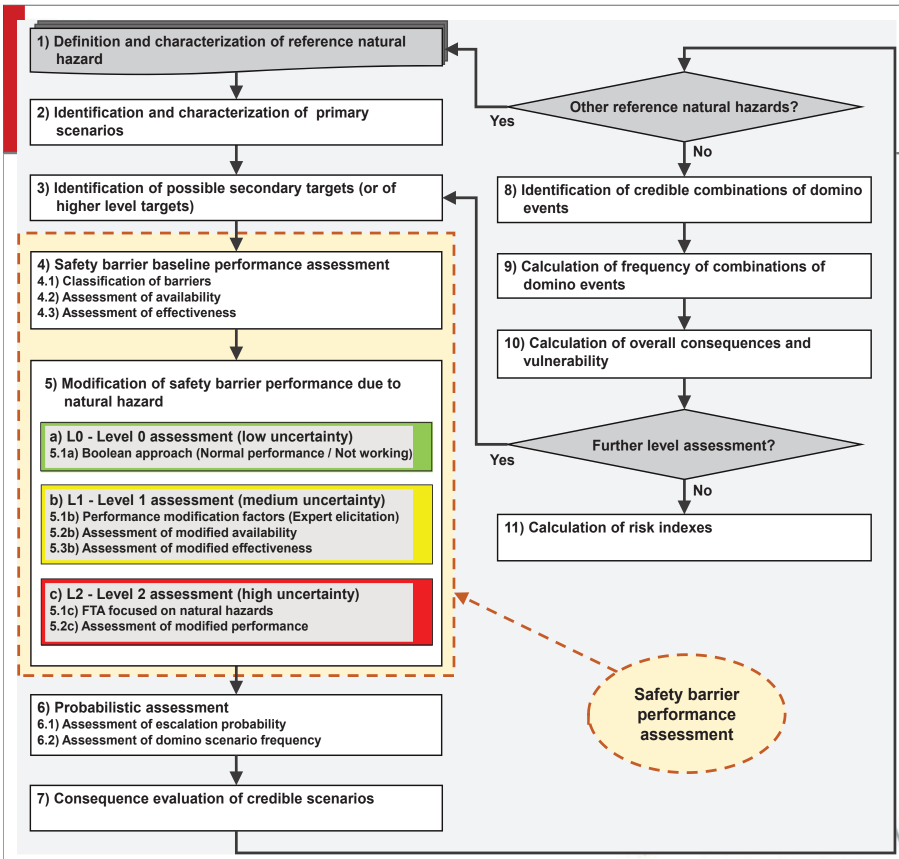

QRA Results including depleted barriers

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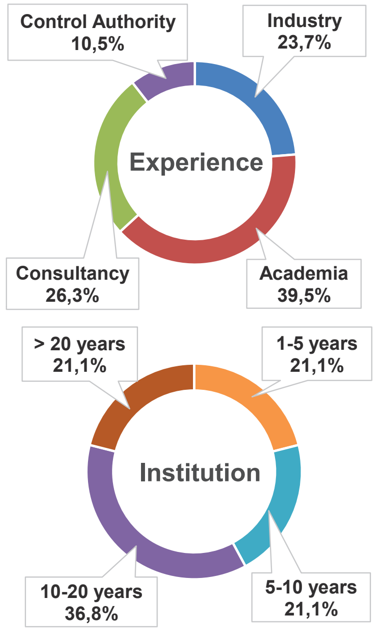
Expert elicitation: Survey

- 16 safety barriers (active and passive)
  - Inert gas blanketing system
  - Rim-seal fire extinguisher
  - Fixed/semi-fixed foam systems
  - WDS/Water curtains/Sprinklers
  - Hydrants
  - Fire activated valves
  - Fire and gas detectors
  - SDVs
  - BDVs
  - Fire walls
  - Blast walls
  - Fireproofing
  - Bunds/Catch basins
  - EBD line to flare
  - Mounding tanks
  - Burying tanks

9 active barriers

7 passive barriers

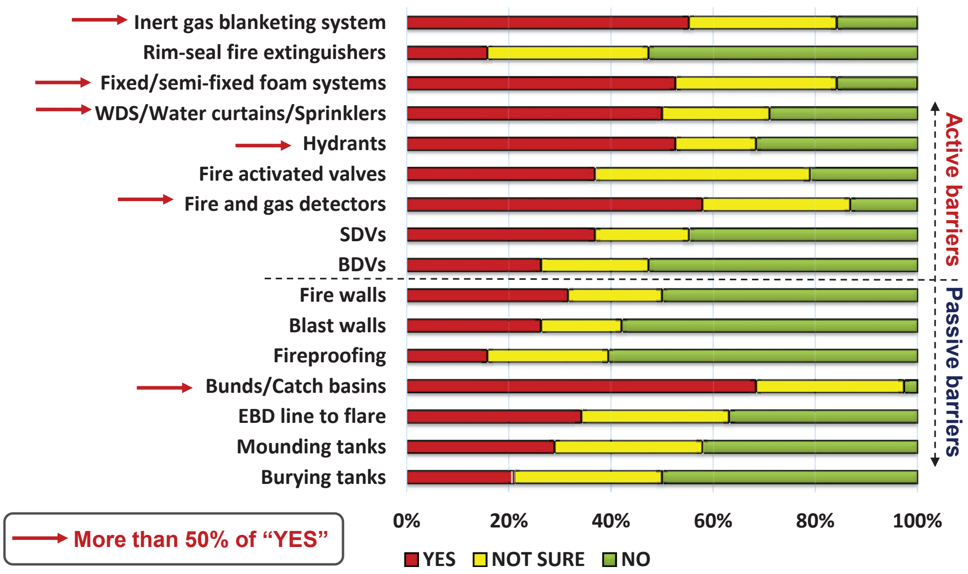
- More than 40 experts involved
- Online questionnaire



(Misuri et al., Reliability Eng. Sys. Saf., 2020, https://doi.org/10.1016/j.ress.2019.106597)

Expert elicitation - results

Will the barrier fail in case of flood?



Level 1 barrier assessment

Vulnerable systems highlighted

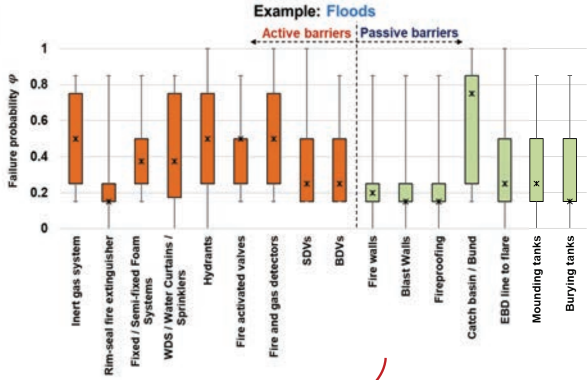
Floods

- Blanketing systems
- Fixed/semi-fixed foam systems
- WDS/water curtains/sprinklers
- Hydrants
- Fire and gas detectors
- Catch basins and bunds

Earthquakes

- Blanketing systems
- Rim-seal fire extinguishers
- Fixed/semi-fixed foam systems
- WDS/water curtains/sprinklers
- Hydrants
- Fire and gas detectors
- SDVs
- Fire walls
- Blast walls
- Catch basins and bunds
- EBD line to flare

Barrier performance parameter elicited



φ

Performance modification factors

(Misuri et al., Reliability Engineering System Safety, 2193:106597, 2020)

Expert elicitation – results

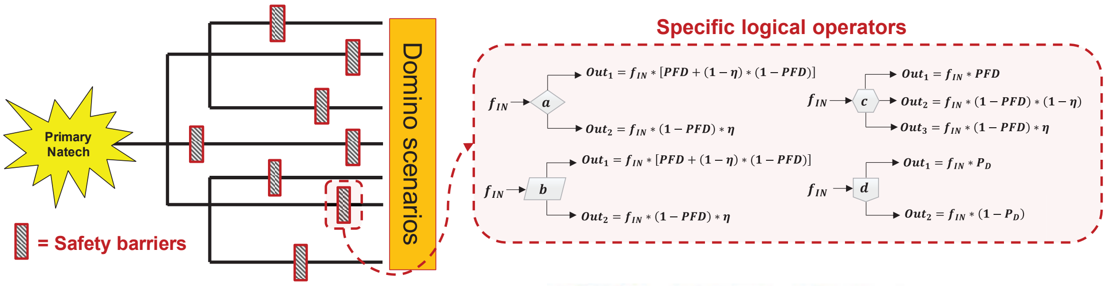
Safety barrier	ϕ_f	$[Q_1, Q_3]_f$	ϕ_e	$[Q_1, Q_3]_e$
Inert-gas blanketing system	**0.5**	[0.25, 0.75]	**0.625**	[0.5, 0.85]
Automatic rim-seal fire extinguishers	**0.15**	[0.15, 0.25]	**0.5**	[0.25, 0.75]
Fixed / Semi-fixed foam systems	**0.375**	[0.25,0.50]	**0.5**	[0.5, 0.75]
WDS / Water Curtains / Sprinklers	**0.375**	[0.18, 0.75]	**0.75**	[0.5, 0.85]
Hydrants	**0.5**	[0.25, 0.75]	**0.5**	[0.25, 0.75]
Fire activated valves	**0.5**	[0.25, 0.50]	**0.375**	[0.25, 0.69]
Fire and gas detectors	**0.5**	[0.25, 0.75]	**0.5**	[0.25, 0.75]
Shut down valves	**0.25**	[0.15, 0.50]	**0.5**	[0.25, 0.50]
Blow down valves	**0.25**	[0.15, 0.50]	**0.25**	[0.15, 0.50]
Fire walls	**0.2**	[0.15, 0.25]	**0.5**	[0.25, 0.75]
Blast walls	**0.15**	[0.15, 0.75]	**0.25**	[0.25, 0.50]
Fireproofing	**0.15**	[0.15, 0.25]	**0.25**	[0.15, 0.44]

(Misuri et al., Reliability Engineering System Safety, 205:107278, 2021)

Level 1 barrier assessment

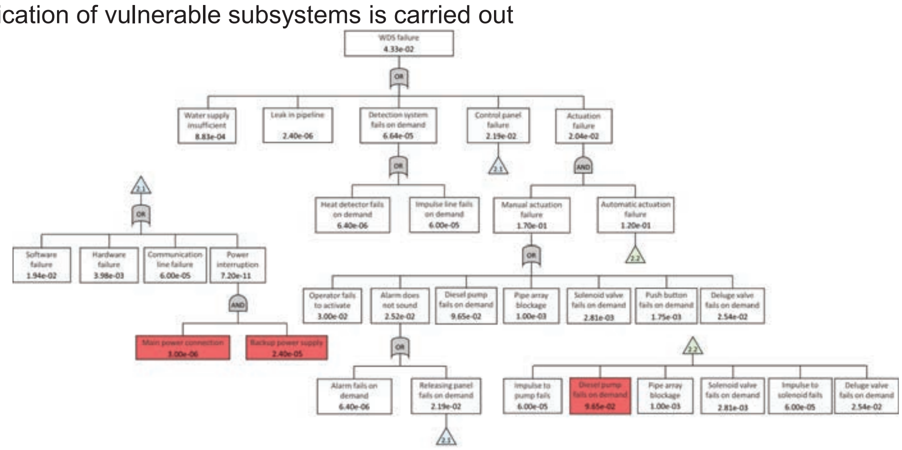
- LOPA-based metrics for barrier performance characterization
  - Probability of failure on demand (PFD_0) (active and procedural barriers only)
  - Effectiveness (η_0)
- Barrier performance during natural hazards
  - Active barriers: $PFD = 1 + (\boldsymbol{\varphi} - 1)(1 - PFD_0),\ \eta = \eta_0$
  - Passive barriers: $\eta = (1 - \boldsymbol{\varphi})\eta_0$

  $\boldsymbol{\varphi}$
- Modified Event Tree Analysis (ETA)



Level 2 barrier assessment

- A tailored FTA is applied
- Identification of vulnerable subsystems is carried out

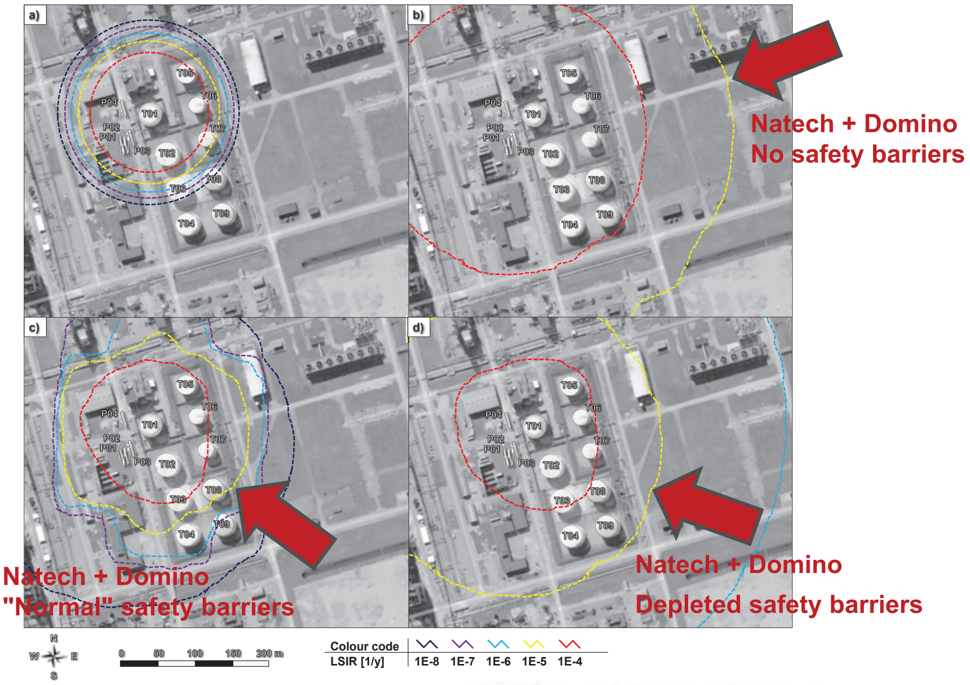


- Barrier probability of failure is updated accordingly

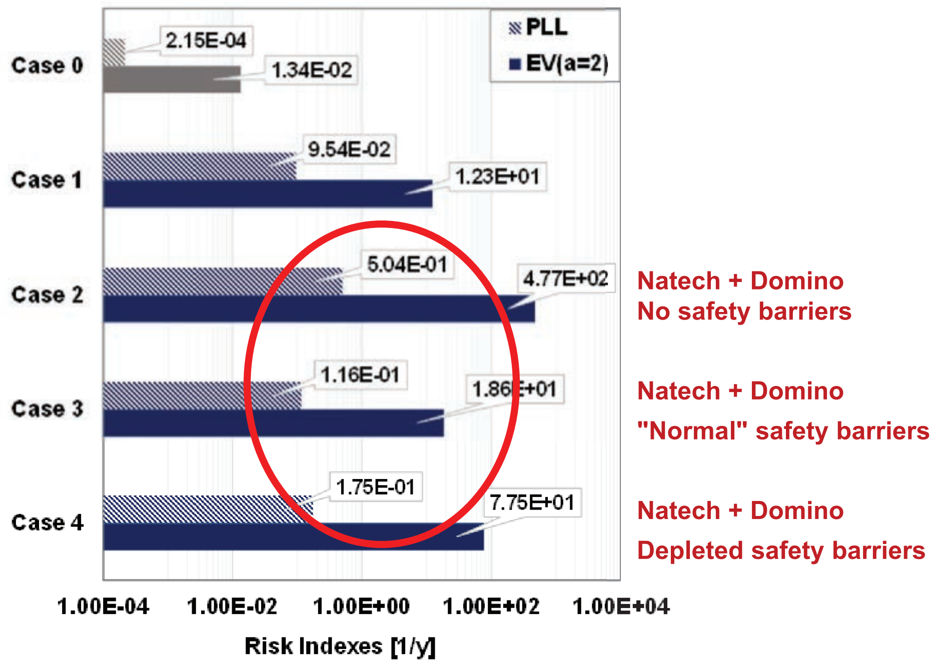
$$Q_j(MCS_{m,k}) = \prod_p \left(q_{p,0} + \delta_{p,j}(1 - q_{p,0})\right)$$

$$PFD_{j,k} = 1 - \prod_m (1 - Q_j(MCS_{m,k}))$$

Effect of barrier degradation



Effect of barrier degradation



Advances in Natech risk management
V. Cozzani, University of Bologna, Italy
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September 23, 2022

49

Conclusions

- Natech events are High-Impact Low-Probability (HILP) that may provide a relevant contribution to the overall technological risk present in process and chemical plants
- Past accident analysis evidenced the presence of indirect routes leading to Natech events not considered in conventional Natech assessment procedures
- A new paradigm and a roadmap for its implementation is proposed for the assessment of Natech events
- Routes involving the failure of utilities and the impairment of safety barriers proved to provide an important contribution to the overall risk of QRA scenarios
- An ITER needs to be established for the improved management of risk in Natech events

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50

Acknowledgments

- Results presented were obtained by the research group of **LISES – Laboratory of Industrial Safety and Environmental Sustainability** of University of Bologna: Alessio Misuri, Federica Ricci, Fabiola Amaducci, Giacomo Antonioni, Sarah Bonvicini, Valeria Casson Moreno, Alessandro Tugnoli, Ernesto Salzano

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61st Seminar
September 23, 2022

Thank you for attending!

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Development of fragility models to support security vulnerability assessment in the framework of multi-risk analyses

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Abstract

Natural events may impact on industrial facilities triggering accidents with potential severe consequences [1]. These events are known as NaTech (Natural-Technological) events. Climate change is exacerbating these phenomena, which have become more frequent and more severe in recent years. Natural events are complex to describe: two or more events can present themselves in a simultaneous and cascading way, see the Fukushima disaster in 2011. Multi-hazard and multi-risk approaches have therefore been developed in order to account for the complex dynamic of external natural events [2].

Intentional attacks to chemical facilities can also be seen as external threats leading to cascading events. Available analyses of intentional attacks occurred in recent years reveal that physical and cyber-attacks are indeed a credible threat for process facilities [3] [4]. Global affairs show that the risk of attacks at industrial infrastructures and chemical facilities is ubiquitous as part of violent conflicts in highly industrialized regions. For these reasons, the inclusion of security issues in multi-risk approaches is an urgent task.

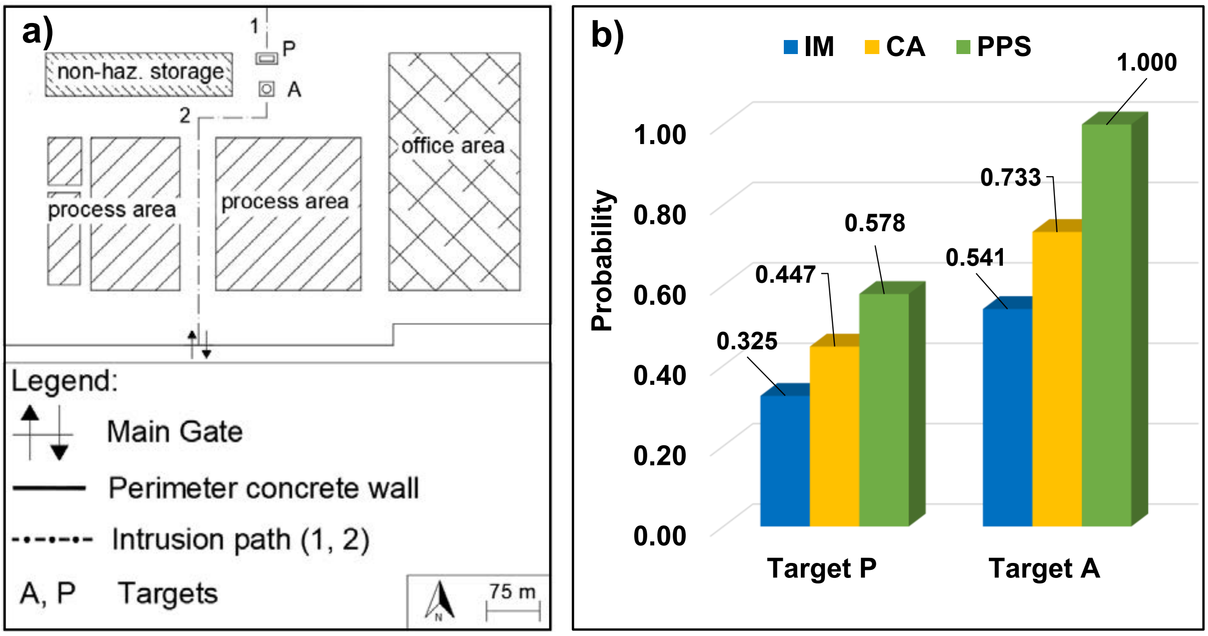
Global and regional efforts were made to address security issues. Facility owners in the USA are required to prepare a facility security plan according to the prescriptions of the Chemical Anti-Terrorism Standards (CFATS). On the other hand, the European SEVESO III Directive does not yet address the need for a security analysis of facilities storing and processing hazardous chemicals. Still, international security standards are available for the evaluation of security risk and vulnerabilities [5] [6] and can provide guidance to analysts and plant managers. Current approaches do however present some criticalities. In particular, the methodologies offer at-most semi-quantitative metrics; the development of quantitative techniques may help to identify weaknesses of process facilities and to develop multi-risk-based strategies for plant management.

This works aims at developing a quantitative methodology for Security Vulnerability Assessment (SVA) to support the inclusion of security issues in multi-risk assessment. Vulnerability is defined as a weakness that can be exploited to successfully perform an attack [5]. Therefore, vulnerability will be seen in this work as a proxy for attack success likelihood. Two levels of weakness have been considered for SVA. The first one is the performance of Physical Protection Systems (PPS), i.e., security barriers. Three actions from PPS can be identified: detection of the intrusion, communication to the emergency response team and intervention of the emergency response team to neutralize the attacker [7]. All three actions need to be accomplished in order to stop the attacker, meaning that if either one actions fails, then the threat will successfully carry out the attack. This statement supports the definition of the probability of failure of PPS by binding the necessary actions with a logical AND gate.

The second level of weakness has never been explicitly taken into consideration in SVA and is related to the structural resistance of targets to certain attacks. Vulnerability assumes in this perspective the meaning of fragility, and fragility models are used to quantitatively assess the physical damage to targets. Out of 26 well-documented cases of intentional attacks to chemical and petrochemical facilities, more than half included the use of explosives [3]. For this reason, this work focused on the development of an improved fragility model for explosive attacks. Approaches from literature have been combined to create a comprehensive procedure, which can be used for both military and improvised explosives and accounts for the possible mitigative effect offered by dikes and bunds.

The vulnerability assessment of an industrial case study was carried out to test the potentialities of the present approach. In Figure 1 a) the layout of the plant is shown. Two possible targets of explosive attacks have been identified (P and A in Figure 1 a)). Two exemplifying attack paths (1 and 2) have been considered to conduct the SVA. Figure 1 b) shows the results. Firstly, vulnerability using the improved fragility model was evaluated (IM in Figure 1 b)). Then, vulnerability obtained by using conventional approaches was evaluated. The first approach only includes PPS failure probability (PPS in Figure 1 b)); the second one neglects the mitigative effect of the dike (CA in Figure 1 b)).

Figure 1. a) Layout of the demonstrational case study; b) results of vulnerability assessment. IM = vulnerability with improved models, CA = vulnerability with conservative approach, PPS = failure probability of PPS



The results in Figure 1 b) show that the application of the methodology significantly leads to a reduced value of vulnerability, meaning that dikes can act as integrated barrier for safety and security. The development of improved facility models can therefore lead to a more accurate estimation of vulnerability with respect to conventional approaches. Still, the performance of PPS remains a critical issue (see PPS in Figure 1 b)): studies on possible attack paths and more precise performance data are needed to identify critical scenarios and improve the analysis.

In conclusion, this work focused on the development of a quantitative methodology for Security Vulnerability Assessment. Given the credibility of intentional attacks to process facility, this methodology is the first step towards the integration of security issues in multi-risk assessment techniques to guide managers in a comprehensive and integrated plant management. Future works include the development of fragility models for other security-relevant attacks modes, as well as in improvement of PPS performance data.

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ESReDA European Safety, Reliability & Data Association

The 61st ESReDA Seminar on Technological disruptions triggered by natural events: identification, characterization, and management – 22-23 September, Turin, Italy

Development of fragility models to support security vulnerability assessment in the framework of multi-risk analyses

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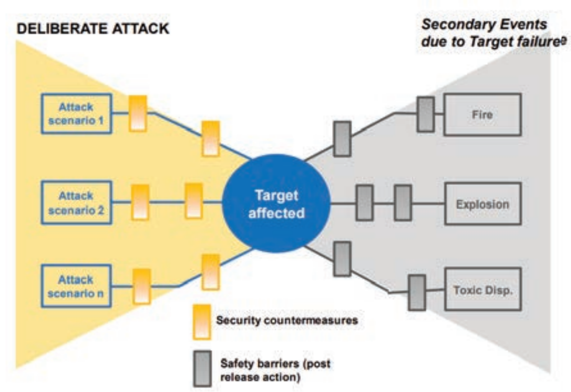
DICI DIPARTIMENTO DI INGEGNERIA CIVILE E INDUSTRIALE

Introduction [1]

- External events triggering cascading scenarios in process facilities:
  - Process upsets
  - NaTech
  - **Security events**

Domino effect: propagation of an accident to nearby units, ultimately causing the amplification of consequences.



Introduction [2]

- Intentional attacks to industrial facilities

(Iaiani et. al, 2021, Rel. Eng. Syst. Saf.)

373 security-related events in the process industry from 1954 to 2019

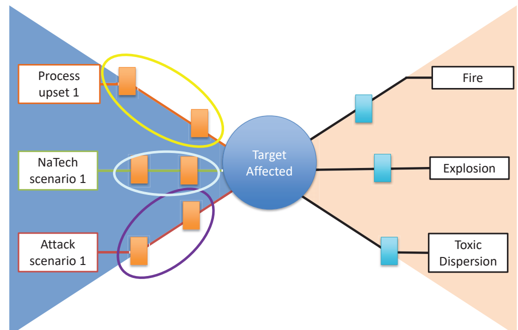
84 events specifically targeted Chemical&Petroleum processes

«The attackers intended to blow up the facility»

Militants attack storage tanks near Libya's Ras Lanuf oil terminal

- External threats:
  - Complex to describe
  - Dynamic escalation leading to potential *domino effects*

→ Security issues to be included in multi-hazard and multi-risk approaches



Introduction [3]

- **Security Risk and Vulnerability Assessment** – early work after 9/11
  - API, 2003, Security Risk Assessment Methodology (USA)
  - CCPS, 2003, Guidelines for analyzing and managing the security vulnerabilities (USA)
  - Störfallkommission (SFK), 2002
- **Regulation**
  - USA
    - Facility owners and operators are required to ***prepare a Security Vulnerability Assessment (SVA) and a facility security plan***, according to the prescriptions of the Chemical Facility Anti-Terrorism Standards (CFATS) *(DHS, 2007)*
  - European framework
    - Security issues contemplated for critical infrastructures and international port facilities
    - Security aspects are not explicitly mentioned in the SEVESO Directive
- **Limitations:**
  - Methodologies do not systematically account for geopolitical context → Interdisciplinary approaches to be developed
  - Qualitative or semi-quantitative methodologies → Quantitative approaches needed!
  - Do not explicitly account for *domino effects*

Likelihood

Threat

Attractiveness

$R = (T \times A) \times \mathbf{V} \times C$

Vulnerability

Consequences

Likelihood Assessment

- Attack likelihood: combination of threat and attractiveness → $L = T \cdot A$

(American Petroleum Institute, API Standard 780, 2013)

Threat: a person or group of people that could potentially carry out an external act of interference

↓

Threat assessment: identifying potential adversaries.

↓

Evaluation of attack frequency

(American Petroleum Institute, API Standard 780, 2013)

Attractiveness: perceived value of the target to a threat

↓

Attractiveness assessment: identifying high-value installations and assets

↓

Probability of choosing the installation as a target

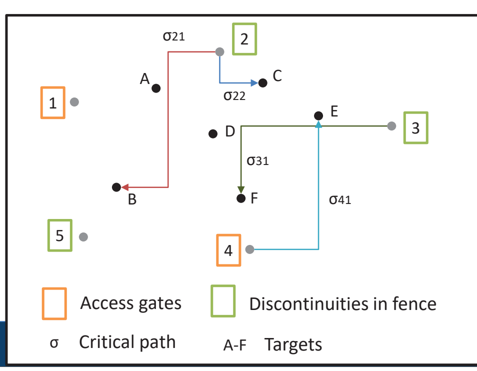
Vulnerability assessment [1]

- **Vulnerability**: weakness that can be exploited to successfully carry out an intentional act of interference

(American Petroleum Institute, API Standard 780, 2013)

→ Proxy for attack success likelihood

- Each process facility is characterized by several access points that can be exploited by an external agent
  - ➢ **Path analysis**: identifying all possible paths and screening critical ones



Screening methods based on:

- Distance between target and intrusion point *D*
- Number of security countermeasures along the path *n*
- Probability of failure of security countermeasures P_F

$$P_{\sigma j} = \frac{1 - D_{N,j}}{\sum_{i=1}^{n}(1 - P_{F,i})} \; j \neq i \qquad D_{N,j} = D_j / D_{max}$$

$$P_{\sigma j} \; critical \; if \; P_{\sigma j} > I_k \; \rightarrow k - th \; percentile$$

(Landucci et al., Physical Security in the Process Industry, 2020, Elsevier)

Vulnerability assessment [2]

- Security barriers

A **physical protection system** (PPS) integrates people, procedures, and equipment for the protection of assets or facilities against theft, sabotage, or other malevolent human attacks.

(Garcia M.L., The Design and Evaluation of Physical Protection Systems, 2008, Butterworth-Heinemann)

- Primary PPS functions:
  - Detection: discovery of the intrusion
  - Delay: slowing down the adversarys' actions
  - Response: action taken by the emergency team to stop the adversary
  - Deterrence: measures that rely on the perception by the adversary as too difficult to defeat

? → Difficult to consider - therefore not a reliable source of protection

Vulnerability assessment [3]

- Performance of PPS

Reference values can be retrieved from literature:
- Probability of interruption
- Probability of effective communication to the emergency team
- Reference delay times

(Garcia M.L., Vulnerability Assessment of Physical Protection Systems, 2006, Butterworth-Heinemann)

- Study based on expert elicitation:
  - Baseline probability of success for security typicals has been identified
  - Factors influencing baseline probability have been identified and quantified based on expert elicitation

$$P = P_0 \cdot \prod_{i=1}^{N} X_i \cdot r_i$$

(Argenti et al., Saf. Sci., 2017)

  - The presence of barriers can mitigate physical effects on potential targets:
    - A dike can mitigate the overpressure effect caused by explosives

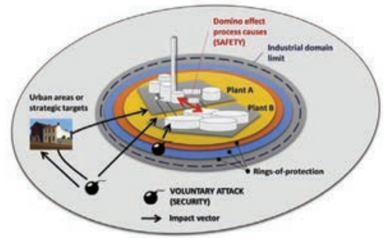
Safety barriers can mitigate or prevent security scenarios!

- Physical resistance of equipment → **fragility**

Characterize attack modes → Characterize damage phenomena → Develop probabilistic damage models

Consequence assessment

(Landucci et al., 2015, Rel. Eng. Syst. Saf.)



- Process facilities may be the direct or indirect target of intentional attacks
- Intentional acts of interference to process facilities may lead to:
  - Direct impact on sensible targets
  - Impact on process equipment leading to the escalation of consequences and potential domino effects

Explosive attacks can damage both humans and structures simultaneously

(Landucci et al., Physical Security in the Process Industry, 2020, Elsevier)

ANFO prills

TATP powder

- Types of explosives:
  - Military explosives like Trinitrotoluene (**TNT**)
  - Improvised Explosive Devices (**IED**) are home-made and their characteristics may vary depending on the substances used:
    - Ammonium Nitrate + Fuel Oil (ANFO) →
      - Lower detonation energy
      - Stable, can be accumulated in high quantities (tons)
    - Triacetone Triperoxide Peroxyacetone (TATP) →
      - Higher detonation energy
      - Unstable, maximum 50kg to be carried

Scope of the work and methodology

Quantitative methodology for security vulnerability assessment (SVA) that includes equipment fragility models

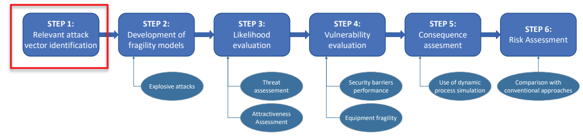
Implementation in a comprehensive process safety risk analysis

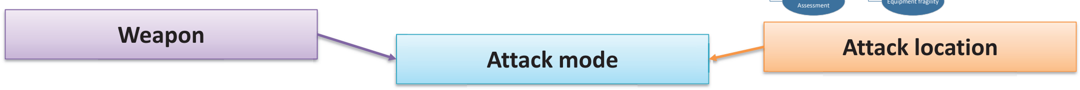
STEP 1: Relevant attack vector identification → **STEP 2:** Development of fragility models → **STEP 3:** Likelihood evaluation → **STEP 4:** Vulnerability evaluation → **STEP 5:** Consequence assesment → **STEP 6:** Risk Assessment

- STEP 2: Explosive attacks
- STEP 3: Threat assessement; Attractiveness Assessment
- STEP 4: Security barriers performance; Equipment fragility
- STEP 5: Use of dynamic process simulation
- STEP 6: Comparison with conventional approaches

Application to a demonstration case study

Methodology [1]

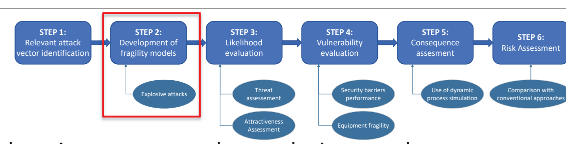




(Landucci et al.. 2017, Proc. Saf. Env. Prot.)

Attack mode	Weapon	Intrusion Required	Description
Deliberate misoperation	-	Yes	Deliberate acts involving simple operations without the use of instruments
Interference using simple aids	Tools present on site	Yes	Deliberate interference using tools and aids that are present on site
Interference using major aids	Heavy tools	Yes	Prepared destruction of installation parts by force using heavy tools Incendiary
Arson	Incendiary devices	Yes	Use incendiary weapon to damage equipment or pipelines to cause collapse of the target
Use of explosives	Explosives	Yes	Use explosives to blow up tanks and pipelines or to blow up load-bearing structures to cause the collapse of tanks
Use of vehicle bomb	Explosives	Yes	Use explosives to blow up tanks and pipelines or to blow up load-bearing structures to cause the collapse of tanks Interference
Shooting 1	Light firearm	Yes	Interference at close distance, using different types of weapons
Shooting 2	Heavy firearms	No	Interference at distance, using different types of heavy weapons
Vehicle accidents	Vehicle	Yes	Vehicle accident in the establishment aimed to release hazardous substances or damage/destroy important parts of the installation
Aircraft accident	Aircraft	No	Aircraft accident aimed to release hazardous substances or damage/destroy important parts of the installation

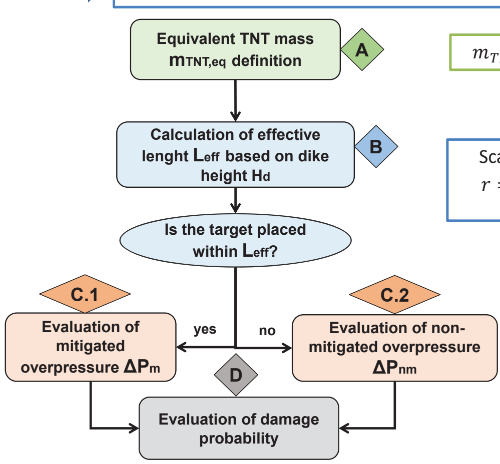
Methodology [2]



- Bunds and dikes can act as a protection for chemical equipment exposed to explosive attacks

(Miura et al. 2013, J. Loss Prev. Proc. Ind.)

Development of a fragility model for mitigated explosive attack



$$m_{TNT,eq} = \Psi \cdot \eta \cdot m_{IED}\ [kg]$$

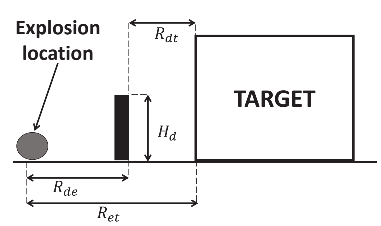
IED	Ψ	η
TATP	1.00	0.61
ANFO	0.50	0.23

Scaled distance:
$$r = R / m_{TNT,eq}^{1/3}$$

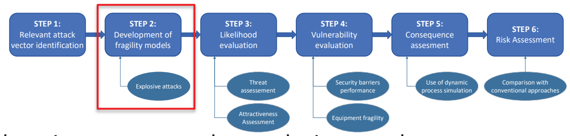
$$l_{eff} = (0.765 \cdot r_{de} - 0.366) \cdot h_d + 0.9$$

(Miura et al. 2013, J. Loss Prev. Proc. Ind.)

$m_{TNT,eq}, m_{IED}\,[kg]$
$r\ [m]$
$R\ \left[m / kg^{\frac{1}{3}}\right]$
$\Delta P, p\ [bar]$



12

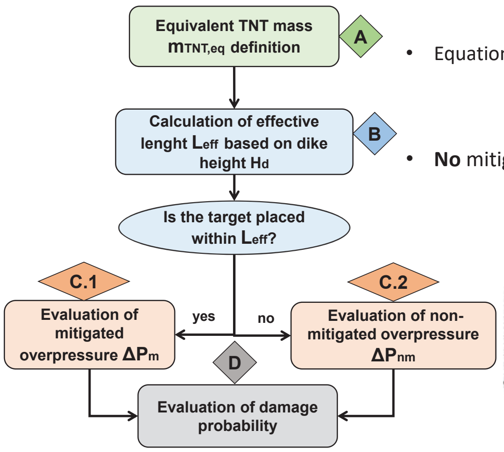


Methodology [3]

- Bunds and dikes can act as a protection for chemical equipment exposed to explosive attacks

(Miura et al. 2013, J. Loss Prev. Proc. Ind.)

➡ Development of a fragility model for mitigated explosive attack



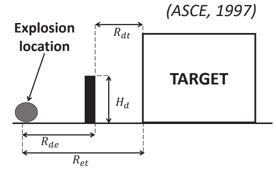
- Equation for overpressure:

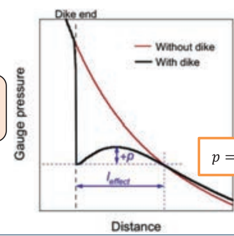
$$\Delta P = \frac{m_{TNT,eq}^{1/3}}{D} + 4.4\frac{m_{TNT,eq}^{2/3}}{D^2} + 14.0\frac{m_{TNT,eq}}{D^3}$$

(ASCE, 1997)

- **No** mitigative effect:

$$\Delta P_{nm} = \Delta P(R_{et})$$





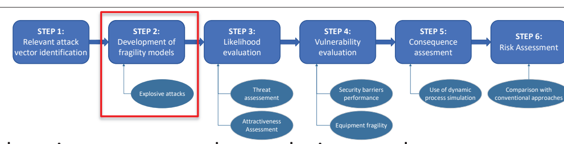
- **Mitigative** effect:

$$\Delta P_m = \Delta P\left(R_{de} + L_{eff}\right) + p$$

$$p = 31.87 \cdot r_{de}^{-4.59}\, exp\left(\left(-0.20 \cdot r_{de}^2 + 2.62 \cdot r_{de} - 8.33\right) \cdot h_d\right)$$

(Miura et al. 2013, J. Loss Prev. Proc. Ind.)

13

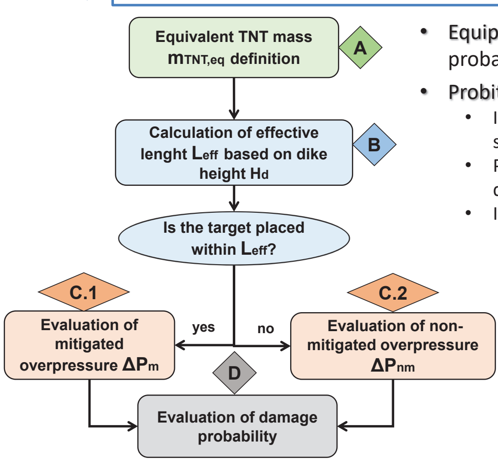


Methodology [4]

- Bunds and dikes can act as a protection for chemical equipment exposed to explosive attacks

(Miura et al. 2013, J. Loss Prev. Proc. Ind.)

➡ Development of a fragility model for mitigated explosive attack



- Equipment fragility: expressing a correlation among damage probability and dose of physical effect
- Probit models can be used as a probabilistic model:
  - Initially used in toxicology studies, but now spread to other fields of science.
  - Probit Y is a variable with mean 5 and variance 1 of a log-normal distribution
  - It can be used to model a dichotomous outcome variable

$$P = \frac{1}{(2\pi)^{1/2}} \cdot \int_{-\infty}^{Y-5} \exp\left(-\frac{u^2}{2}\right) \cdot du$$

(Finney D., Probit Analysis, 1952, Cambridge University Press)

- For damage caused by overpressure:

Atmosferic equipment: $Y = -18.96 + 2.44 \cdot \ln(\Delta P)$

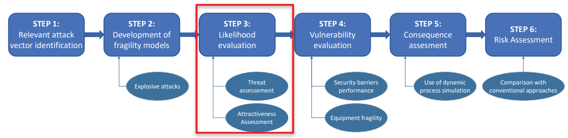
Pressurized Equipment: $Y = -42.44 + 4.33 \cdot \ln(\Delta P)$

→ P_{EqD}

(Cozzani and Salzano, 2004, J. Haz. Mat.)

14

Methodology [5]

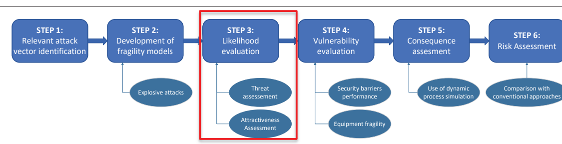


- Values of T can be retrieved from API/ANSI 780 according to a qualitative context description.

Threat assessment			
Ranking	**Descriptor**	**Description**	**Annual attack likelihood (attacks/year)**
1	Very Low	Little or no credible evidence of intent.	0.1*1/Λ
2	Low	Low threat against the asset or similar assets.	1/Λ
3	Medium	Possible threat to the asset based on similar assets' history.	0.1
4	High	Credible threat exists against the asset or similar assets.	0.2
5	Very high	Credible threat exists and Subject asset or similar assets are targeted or attacked on a frequently recurring.	1.0
Λ = facility expected life			

Systematic threat characterization based on context to be developed.

Methodology [6]



- Indicative value to be retrieved from API/ANSI 780:

Ranking	Descriptor	Description	Probability of asset choice
1	Very Low	Little to no level of interest.	0.0 to 0.2
2	Low	Some degree of interest, but not likely to be of interest.	> 0.2 to 0.4
3	Medium	Moderate degree of interest.	> 0.4 to 0.6
4	High	High degree of interest.	> 0.6 to 0.8
5	Very high	Very high degree of interest.	> 0.8 to 1.0

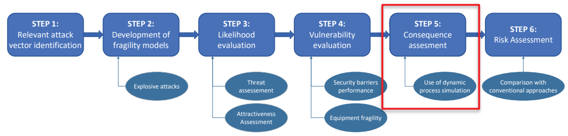
✓ Development of an attractiveness assessment method is for industrial facilities located in critical areas:

- Technical aspects:
  - Based on plant site specific hazards
  - Inventories of substances
  - Vulnerability of the surrounding areas

- Data easily available to plant staff
- Derived from plant base documentation

- Geopolitical, social, and strategic factors

Interdisciplinary approach

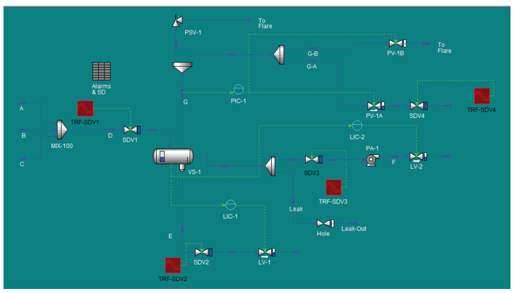


Methodology [9]

- Conventional consequence assessment is static but security-related accidents have a complex escalation

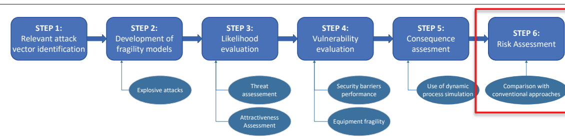
→ Need for dynamic and real-time approaches as well as a full characterization of security scenarios

- Exemplyfing application: specific template in UniSim® Design for a three-phase separator and storage tank



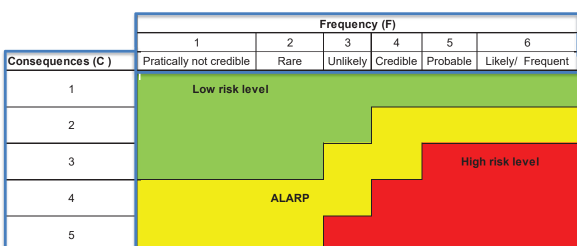
Simulation approach for security scenarios:

- Calculation of the source term of release *(Pannocchia and Landucci, 2014)*
- Calculation of jet fire and pool fire heat radiation *(Van Den Bosh and Weterings, 1997)*
- Conventional leak diameters adopted:
  - 1'' for minor release (i.e. firearms or sabotage)
  - 4'' for major release (i.e. explosive or arson) *(API 581)*
- Damage threshold approach
  - → 5 kW/m² → Irreversible damage threshold



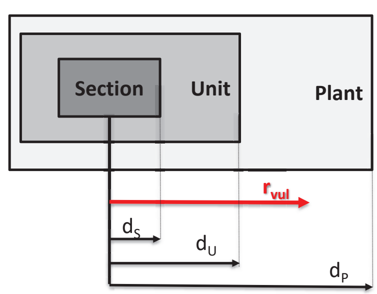
Methodology [10]

- Risk assessment follows a Risk Matrix Approach → Adapted from O&G practices *(Petrone et al., 2011)*

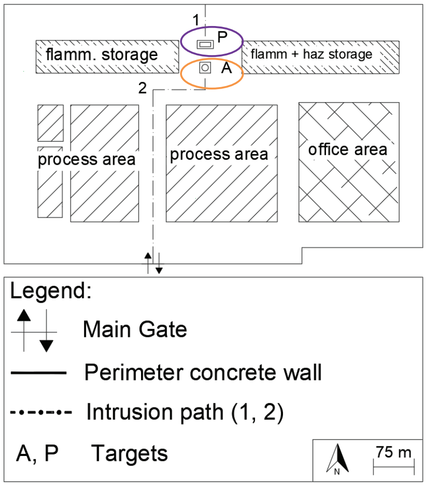


Qualitative Rating	Frequency interval
Pratically not credible	$f_i < 10^{-6}\ y^{-1}$
Rare	$10^{-6} \leq f_i < 10^{-4}\ y^{-1}$
Unlikely	$10^{-4} \leq f_i < 10^{-3}\ y^{-1}$
Credible	$10^{-3} \leq f_i < 10^{-1}\ y^{-1}$
Probable	$10^{-1} \leq f_i < 1\ y^{-1}$
Likely/ Frequent	$f_i \geq 1\ y^{-1}$

Qualitative Rating	Consequence severity
Slight effect	$r_{vul} < 1$ m
Effect inside the plant section	$1\ m \leq r_{vul} < d_S$
Effect outside the plant section & no interaction with other equipment/people	$d_S \leq r_{vul} < d_U$
Damages to other plant units & possible fatalities	$d_U \leq r_{vul} < d_P$
Damage outside the facility & multiple fatalities	$r_{vul} \geq d_P$



Case study



- **Facility storing and process petroleum products:**

Substance	Item [ton]
LNG-LPG	3010
Petroleum products	754046

- Residential areas nearby
- Located near other industrial complexes

- **Targets:**

ID	Content	Diameter	Height/length	Dike
		[m]	[m]	[m]
A	Gasoline	12	9	1.5
P	3phase separator	8	20	2.3

- **Attack modes:**

Path	Target	Attack mode	Task sequence
1	P	31 kg TATP	Trespass wall using 1 kg of the explosive and a sledgehammer; walk 60 m; place and detonate the rest of the explosive
2	A	15 kg TATP	Cross the main gate; walk 500 m; place and detonate the explosive

Results [1]

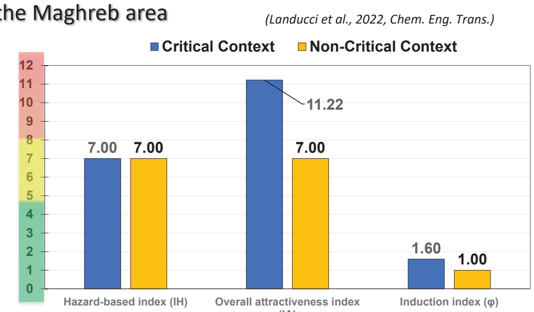
✓ Attractiveness of process facilities in critical contexts: the Maghreb area

- History of security threats in the area

- Impact of technical triggers:
- High hazardous materials inventory
- Facility located near residential and industrial areas

- Impact of non-technical triggers:
- Criticality of the context causes a **60% raise in attractiveness**

(Landucci et al., 2022, Chem. Eng. Trans.)



✓ Attractiveness of process facilities in non-critical contexts: Italy

- Impact of technical triggers are the same
- Non critical context → φ = 1

Assuming plant located in non critical context:

Very Low Threat:

T = 0.1*1/Λ = 0.1*1/30 = **0.0033** attacks/year

High Attractiveness

A = 0.8

Results [2]

- **Vulnerability assessment**
- PPS Performance
  - Scenario 1
    - Detection from roving guards because intrusion path does not cross process areas
  - Scenario 2
    - Detection from employees because intrusion path crosses process areas
- Equipment fragility
  - Scenario 1
    - Mitigative effect from dike present
  - Scenario 2
    - Mitigative effect from dike present

PPS Performance		
Scenario ID	1	2
P_D	0.80	0.89
P_C	0.95	0.95
P_T	0.55	0.00
P_{PPS}	0.58	1.00

Equipment fragility		
Scenario ID	1	2
$M_{tnt,eq}$ [kg]	18.30	9.15
R_{et} [m]	11.00	16.00
R_{dt} [m]	3.53	4.00
L_{eff} [m]	5.09	9.45
ΔP_m [bar]	0.59	0.19
ΔP_{nm} [bar]	0.68	0.23
P_{EqD}	0.56	0.54

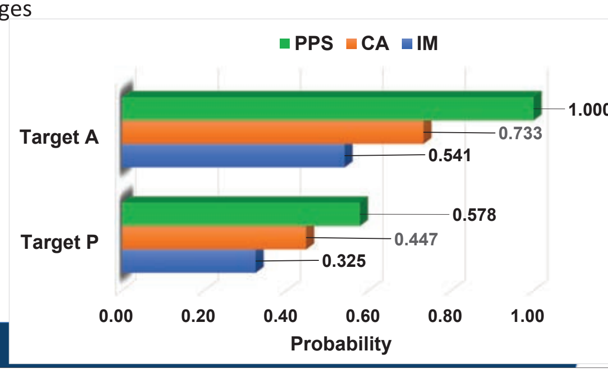
Results [3]

- **Vulnerability of the scenarios**:

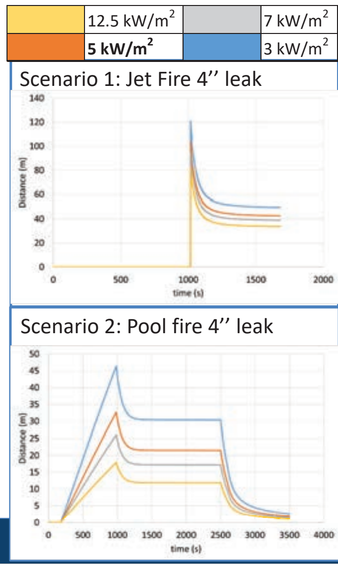
Vulnerability using improved models		
Scenario ID	1	2
V	0.32	0.54

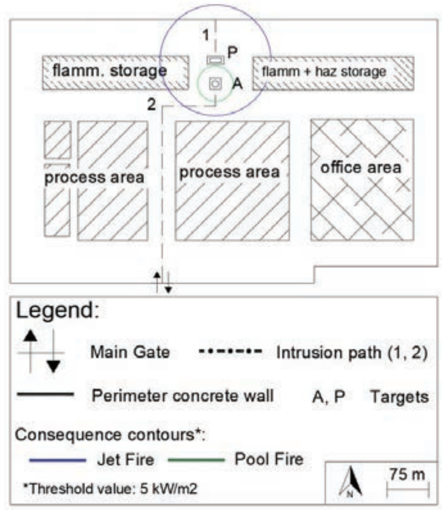
- Vulnerability obtained with improved fragility model has been compared with vulnerability using a conservative approach, i.e., neglecting the mitigative effect from the dike:
  - Equipment damage probability changes

Vulnerability using conservative approach		
Scenario ID	1	2
P_{Eq}	0.77	0.73
V	0.45	0.73



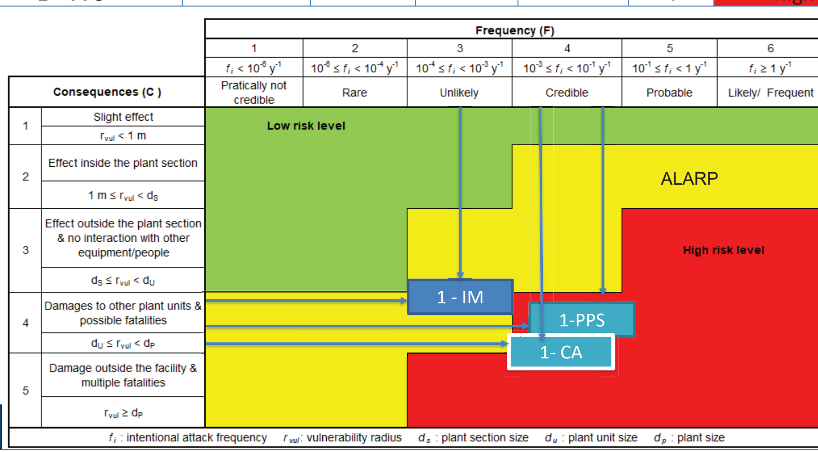
Results [4]





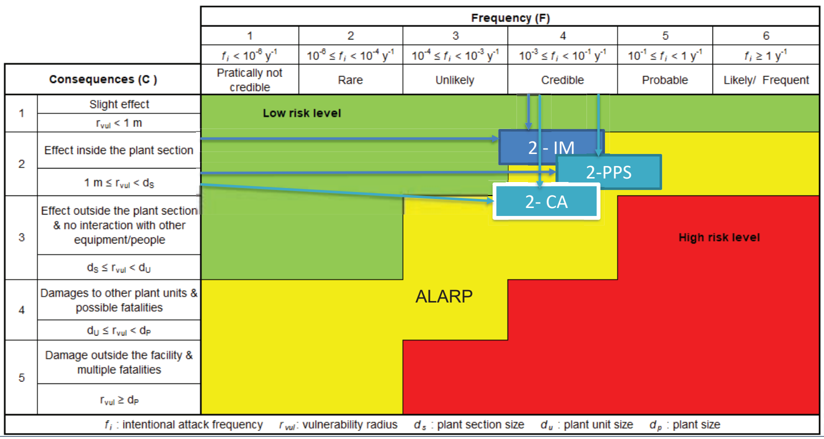
Results [5]

Scenario ID	T [a/y]	A	V	L_2	C	R
1 – IM	0.0033	0.80	0.32	8.66E-04	4	ALARP
1 – CA	0.0033	0.80	0.45	1.19E-03	4	High risk
1 – PPS	0.0033	0.80	0.58	1.54E-03	4	High risk



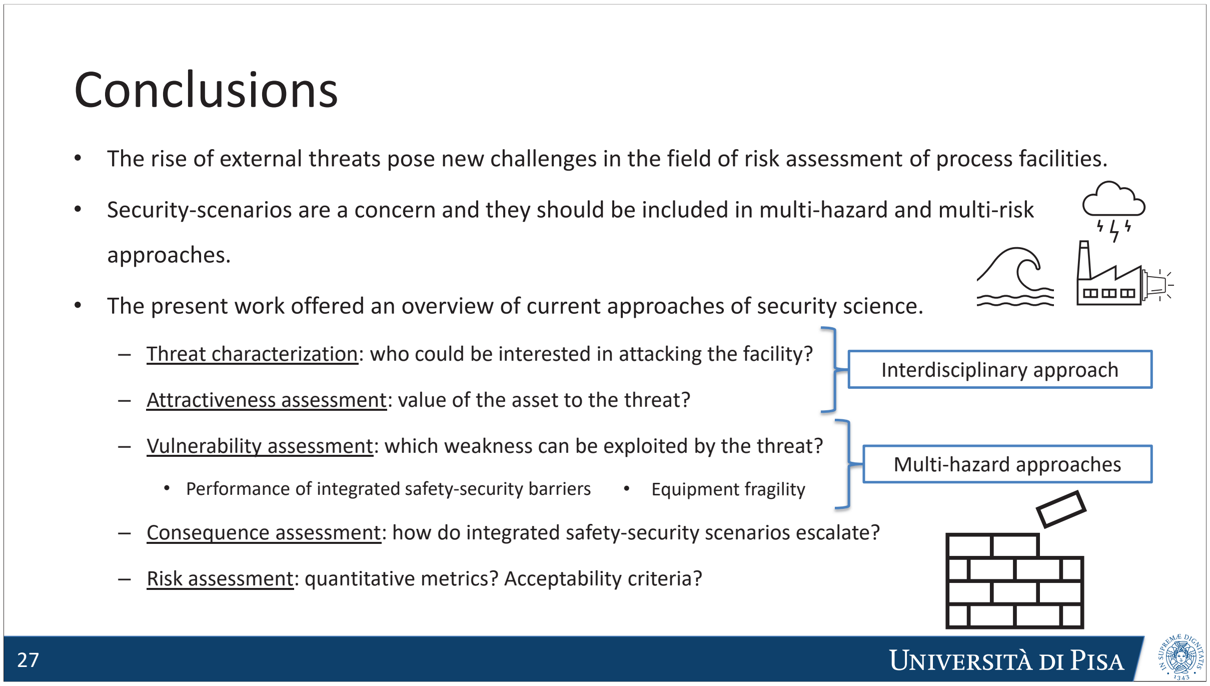
Results [6]

Scenario ID	T [a/y]	A	V	L_2	C	R
2 – IM	0.0033	0.8	0.54	1.44E-03	2	ALARP
2 – CA	0.0033	0.80	0.73	1.95E-03	2	ALARP
2 – PPS	0.0033	0.80	1.00	2.67E-03	2	ALARP



Discussion

- **Threat and attractiveness assessment**
  - Interdisciplinary approach based on technical and non-technical factors
- **PPS performance**:
  - PPS failure probability is always higher than 50% → Studies on possible intrusion paths and PPS placement are crucial
  - Emergency response is the most critical task
  - However, evaluation is based on literature data → Data gathering from the facility to improve the analysis
- **Equipment fragility:**
  - Can significantly reduce vulnerability → Dikes can be effective in reducing overpressure effects → They can act both as safety and security barriers
- **Security vulnerability assessment:**
  - Includes a wide variety of factors
  - Can be included in multi-hazard and multi-risk techniques
- **Risk assessment**:
  - Quantitative metrics to be developed to improve the analysis


Conclusions
The rise of external threats pose new challenges in the field of risk assessment of process facilities.
Security-scenarios are a concern and they should be included in multi-hazard and multi-risk approaches.
The present work offered an overview of current approaches of security science.
Threat characterization: who could be interested in attacking the facility?
Attractiveness assessment: value of the asset to the threat?
Vulnerability assessment: which weakness can be exploited by the threat?
Performance of integrated safety-security barriers
Equipment fragility
Consequence assessment: how do integrated safety-security scenarios escalate?
Risk assessment: quantitative metrics? Acceptability criteria?
Interdisciplinary approach
Multi-hazard approaches
27
Università di Pisa

Ecological Functionality and Landscape Sensitivity Assessment for Territorial Resilience and Sustainability

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Angioletta Voghera, Politecnico di Torino – DIST Department, angioletta.voghera@polito.it

Abstract

The contribution presents the application of assessment of ecological functionality and landscape sensitivity, through the use of indicators, to define strategies for improving territorial resilience. This methodology has found application in various experiences in the Piedmont region (Mappano and other Municipalities) but also in the areas of Central Italy, already compromised by the seismic events of 2009, 2016 and 2017.

In all cases considered, the indicators "Ecological functionality" and "Landscape sensitivity" describe the distinctive characteristics of the environment and territorial identity: the first indicator allows us to read the level of ecological integrity of the natural components and their ability to perform an adequate function for the health of ecosystems; the second makes it possible to evaluate the degree of landscape sensitivity on the basis of the percentage of territory considered most visible from several privileged points of view. The application of both indicators allows to bring out the most useful elements for territorial resilience, but at the same time also the most fragile and compromised elements.

In this perspective of action, territorial knowledge is the fundamental component for managing risks and for defining and implementing adaptation strategies to improve the resilience of the system. The integrated reading of these components allows to grasp the profound and virtuous interactions between them and to define a framework of territorial resilience that is not just a collection of specific projects but a coordinated, complex and shared set of planning strategies.

The work carried out is based on the idea of outlining a shared perspective, because it is based on theoretical acquisitions already given, but which required measuring oneself with the territorial dimension to guide them towards new hypotheses, methodologies and application directions. By dealing with urban planning, in particular, such an approach helps us to abandon the idea of relegating this activity within a single disciplinary area and to acquire the conviction of taking a look "beyond the borders", under penalty of reductivism and, consequently, of not being able to grasp the relevant threats on the territory due to the global changes in progress, the evolution of the same territorial and cultural processes and forms of government that characterize today's society.

All this allows us to go beyond the simple construction of autonomous and separate rules and projects, to grasp the values, objectives and interests on which to define common territorial transformation strategies.

These experimentations, already calibrated for the case studies considered, could represent a good practice to be replicated in other national and international cases, within the framework of the transition policies towards sustainability, promoted in recent years by numerous European agendas.

1 Introduction

Among the lessons that come to us from the health crisis from Covid-19 pandemic there is one, of fundamental importance, which concerns the role of biodiversity and landscape. The destruction of natural habitats and the pursuit of increasingly intensive models of agriculture, breeding and industry undermine the resources necessary for the well-being, health and economy of human communities and at the same time expose us all to serious biological risks. In particular, the dramatic crisis of biodiversity today is therefore one of the greatest challenges that deserves attention even for health reasons (Hooper 2005). It is in this sense that the massive reaction to the pandemic crisis implemented by the European Union and largely represented by the "Next Generation EU" programme should be read. This programme, confirming and adopting the sustainability of the Green Deal principles, demonstrates that the European Commission and the EU Member States, albeit through a difficult path of convergence, have at least in theory understood that it is really time to change and that the economic recovery must closely match environmental resilience and sustainability.

Since the 1970s, when the strong pressure of economic growth and demographic expansion of cities began to show in a concrete way, there was a need for mankind to find harmony with nature (United Nations Conference on the Human Environment, Stockholm Conference 1972): climate and global changes, land consumption, deforestation, intensive agriculture, pollution, ecological fragmentation are contributory causes of the disappearance of biodiversity and the destruction of ecosystems which are accompanied by the degradation of ecosystem services. The main challenges perceived by people today, in terms of risk and impact, are environmental ones (World Economic Forum 2020).

The reduction of biodiversity damages the resilience of natural systems and favours the transmission of pathogens from animals to humans (zoonoses) (IUCN, 2020). Many scientific data support that the emergence and re-emergence of zoonotic diseases are linked to the unnatural coexistence between wild animals and humans, as well as to the alterations of ecosystems and the subtraction of natural habitats from wild species due to uncontrolled urbanization (IPBES 2018; IPCC 2019).

The Covid-19 pandemic has highlighted the vulnerability to the reactions of nature and the poor ability to mitigate their impacts (preparedness), with serious damage to health, social cohesion and socio-economic well-being. It is therefore all the more important to account for current and potential economic costs, through a correct quantification of ecosystem services, deriving from the degradation of natural assets: the positive externalities for biodiversity and ecosystems must certainly be valued. Urban green space networks, together with natural and semi-natural ecosystems around cities, allow urban areas to be more sustainable and tackle many challenges including air pollution, noise, heat waves, hydrogeological instability and a better management of the water cycle, conservation of the resource through the strategy of green and blue infrastructures.

Therefore, since the Seventies, urban planning practices demonstrated the potential of ecological network to contribute to challenges such as health, species protection, biodiversity protection, climate change adaptation (Benedict and McMahon 2002). When understood as part of local ecological network, these and other emerging challenges and trends must be considered not just as obstacles to overcome, but as important drivers for investing the future urban planning choices (La Riccia 2015a and 2017).

The identification of the most suitable planning scale to trigger, starting from an ecosystemic vision, territorial policies aimed at the design of ecological networks is a question strictly connected to the definition of the concept of “local”, which cannot univocally coincide, according to a common name widely used in urban planning, with only the municipal planning area (Selman 2006). The ecological network in fact refers to an open system of territorial relations between the different biological and landscape elements that constitute it and cannot, therefore, be enclosed and delimited within strictly defined administrative limits. Thus, involving variously localized portions of the territory, the ecological network interacts with multiple scales and territorial planning tools. The urban planning scale that comes closest to the methodological perspective outlined for an adequate planning and management of ecological networks therefore seems to coincide with that represented by municipal and park territorial planning, which today have a more direct operation and a higher capacity of integration.

Ecological networks can be framed among planning strategies including an articulated set of territorial actions aimed at mitigating the effects of environmental fragmentation of anthropogenic origin at all levels of ecological organization. The main objective of this type of planning is, therefore, the conservation of biological diversity and dynamic processes that allow the maintenance of vitality and functionality over long periods of biological populations and communities, ecosystems, landscapes.

Being a set of territorial actions that refer to environmental sustainability policies, acknowledging EU and international guidelines, the priority given to nature conservation actions, beyond the intrinsic value attributed to biodiversity and the need for its protection, it implies a series of positive consequences also on a human level. These consequences can be of a social, cultural, aesthetic-perceptive nature, being the interventions, in general, aimed at improving the environmental quality and conserving resources, and their usability, for future generations.

To deal with the design of an ecological network it is important to have a cognitive framework relating to the basic ecological and landscape disciplines inherent to this problem (Antrop 2001 and 2004): the models of population structure and dynamics, the ecology of biotic communities, the ecology of the landscape, the study cultural and visual perceptive landscape, land uses, conservation biology.

For this reason, the maintenance of nature in the city seems to require a strong change of perspective, which has to be mediated by the concept of landscape through specific regulations of urban planning. In this case, it is necessary to overcome the conceptual reductionism, which has been traditionally used to describe nature and landscape components in urban systems, such as: open spaces, green spaces, green areas, ecological corridors, greenways, urban parks.

The choice of a concept among these almost always depends on the specific issues addressed by the planning, from the point of view of the scale (local or regional), the value of income and ownership (public or private green, park) or the spatial configuration (greenway and green belts).

This contribution therefore aims to demonstrate that the conservation of nature in the city is not possible without a broader consideration of the concept of the urban landscape, where the areas for nature conservation may play a central role for the new image and the territorial resilience of the city.

2 Multi-level territorial resilience

In this contribution two very different territorial scales are considered: the local scale of the Municipality of Mappano (Turin) and the supra-regional scale of 138 Municipalities in Central Italy, part of 4 Regions and 10 Provinces, affected by the seismic events of the 2009, 2016 and 2017. On the one hand, therefore, we have the experience of a Municipality, just recognized as such since 2013, called to draw up its first town plan; on the other hand, we have instead a very vast territory that still shows the scars of a series of catastrophic events. In both cases, the methodology presented below and the application of the two indicators (Ecological Functionality and Landscape Sensitivity) on these two experiences show the importance of multi-level territorial resilience for defining future planning strategies.

The community of Mappano was recognized as new Municipality by the Piedmont Regional Law no. 1/2013, called “Establishment of the Municipality of Mappano” (B.U.R. Piemonte – no. 5 of 31.01.2013). Since this is the town plan of a newly formed Municipality, the analyses carried out call for a historical reconstruction of the transformation of the territory with particular attention to the process of formation of the fractional settlement of Mappano as an unplanned sedimentation of fragmented and contradictory settlement choices, documented not only from the effects of the urban planning tools of the neighbouring municipalities (known as transferring municipalities) of Caselle Torinese, Borgaro Torinese, Leinì, Settimo Torinese, but also from the will of the population to search for a community identity, interpreted by the “Committee for Constitution of Mappano Municipality” (“Comitato per la Costituzione di Mappano Comune”), up to approval at the Consultative Referendum of 11 November 2012 (Traore 2021). The case study of Mappano is emblematic to demonstrate the role played by the supremacy of local identity or local interests despite the acknowledged importance of the key role played by soil everywhere (Pileri and Scalenghe 2016). The contradiction highlighted by this case raises discussion amid some crucial issues as to the role of local urban planning and the protection of soil, which cannot be fragmented or subject to local short-term interests. At the time of Covid-19, Mappano therefore found itself carrying out its first town plan in this period of profound health crisis: this certainly involved careful reflection on the interpretation of the territory as a synthesis of the relationship between person, community and environment. The following methodology describe a summary of the elaborations carried out in the framework of the collaboration agreement signed between the Politecnico di Torino (work carried out in coordination between the DIST and DIATI Departments and the Responsible Risk Resilience R3C Interdepartmental Center[1]) and the Municipality of Mappano, which has aimed at strengthening the planning role of the development lines of one’s own territory, including the analysis of those components that a modern multidisciplinary approach considers indispensable for urban growth, with the aim of creating an urban planning tool that enhances the building component, road, productive, social and cultural territory.

In the specific case of the area of the 4 regions of Central Italy, the territory is characterized by an urban framework of main cities and a set of medium and small villages that present, on the one hand, a significant wealth in terms of historical heritage. architectural and, on the other hand, negative socio-economic trends and

[1] Coordinators: Andrea Lingua (DIATI), Angioletta Voghera (DIST). Working group: DIST-R3C: Grazia Brunetta, Ombretta Caldarice, Luigi La Riccia, Ammj Traore, Giulia Matteucci, Mattia Scalas; DIATI: Stefano Angeli, Valeria De Ruvo, Paolo Maschio, Marco Piras.

great difficulties in rethinking and enhancing buildings and settlements, reducing consumption, favouring virtual and physical connections, in favour of a green transition.

The basin of the 2016 earthquake is characterized by a marked breadth and territorial heterogeneity. The 138 municipalities of the 2016 basin (distributed in 10 Provinces and 4 Regions) are mainly located in the Inner Areas of Central Italy and are characterized by a particularly complex territorial context due to its polycentric spatial organization, the persistent conditions of economic and demographic decline, widespread seismic hazard.

Improving the accessibility, inclusiveness and sustainability of cities and small villages requires substantial changes in the organization system of open spaces and the use of energy; in the ways of producing, moving and connecting people and businesses.

These territories face a series of increasingly frequent and violent extreme events that are the effect, on the one hand, of the specific conditions of natural ecosystems and the landscape and, on the other, of the progressive loss of social and economic capital. The prevention and response capacity of these territories in the face of these risks is found to be weak or almost nil and requires a strong transfer of knowledge, to promote a phase of innovation and radical change in response to crises, disturbances, pressures (Folke et al. 2021).

3 Ecological Functionality

Attributing ecological significance and therefore an ecosystem role, not necessarily secondary, to territory means reflecting on a general renovation of the urban planning paradigms, considering the importance of productive, business and policy interests. Therefore, a clear need to define the objectives, which avoid simple "territorial schemes" of new ecological corridors, maybe excellent in aesthetic terms, but lacking of all meanings from the point of view of biodiversity. For this reason, it is important not to stop to analyse only the state of naturalness and diversity at different scales, but it is necessary go further to give priority to the pursuit of ecological coherence of the whole territory: that is to say to link the network with the impacts deriving from human activities and, more generally, to define a framework for urban planning operability (La Riccia, 2015a).

In this context, several interesting experiences about this issue have been launched in the Piedmont region (Italy) with the aim to improve the overall ecological quality of the natural and landscape areas and specifically indicate the operational procedures to avoid the ecological fragmentation and the reduction of biodiversity (Voghera and La Riccia, 2016 and 2019). In the last years a specific research was carried on by Polytechnic of Turin in collaboration with the Metropolitan City of Turin and ENEA with the objective of defining a proposal for the implementation of the ecological network at the local level in some municipalities of Turin[2].

In the last two years, other experiments have been conducted in other municipalities (Mappano, Alpignano, Moncalieri) following the developed methodology, adapting it to different geographical contexts and taking into account new strategic objectives in the post-pandemic era. In Italy, in fact, the current reference given by the PNRR (National Recovery and Resilience Plan, 2021) is contributing with important funds deriving from the Next Generation EU and is pushing local governments to prepare new projects for the country's economic recovery. The goal is the ecological transition but also digitization, competitiveness, training and social, territorial and gender inclusion[3].

In these experiences, the approach proposed was reconsidered to guide local governments with specific measures to limit anthropogenic land use and, where possible, orient and qualify the conservation of ecosystem services. Habitats, natural areas and landscape have not been interpreted only by exclusively ecological point of view (a mosaic of ecosystems) but also considering a broader perspective that embraces cultural, social and economic aspects of the area.

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[2] Between 2014 and 2016 the research "Guidelines for the Green System of PTC2" (convention between Metropolitan City of Turin, ENEA and Polytechnic of Turin) and the "Operational proposals for the ecological network of Chieri" (Polytechnic of Turin and Comune di Chieri, Turin) were conducted with the objective of defining a proposal for the implementation of the ecological network at the local level firstly in two municipalities of Turin (Ivrea and Chieri).

[3] The six major areas of intervention (pillars) on which the PNRR focuses are: 1) Green Transition, 2) Digital Transformation, 3) Smart, Sustainable and Inclusive Growth, 4) Social and Territorial Cohesion, 5) Health and Economic, Social and Institutional Resilience, 6) Policies for the new generations, children and young people.

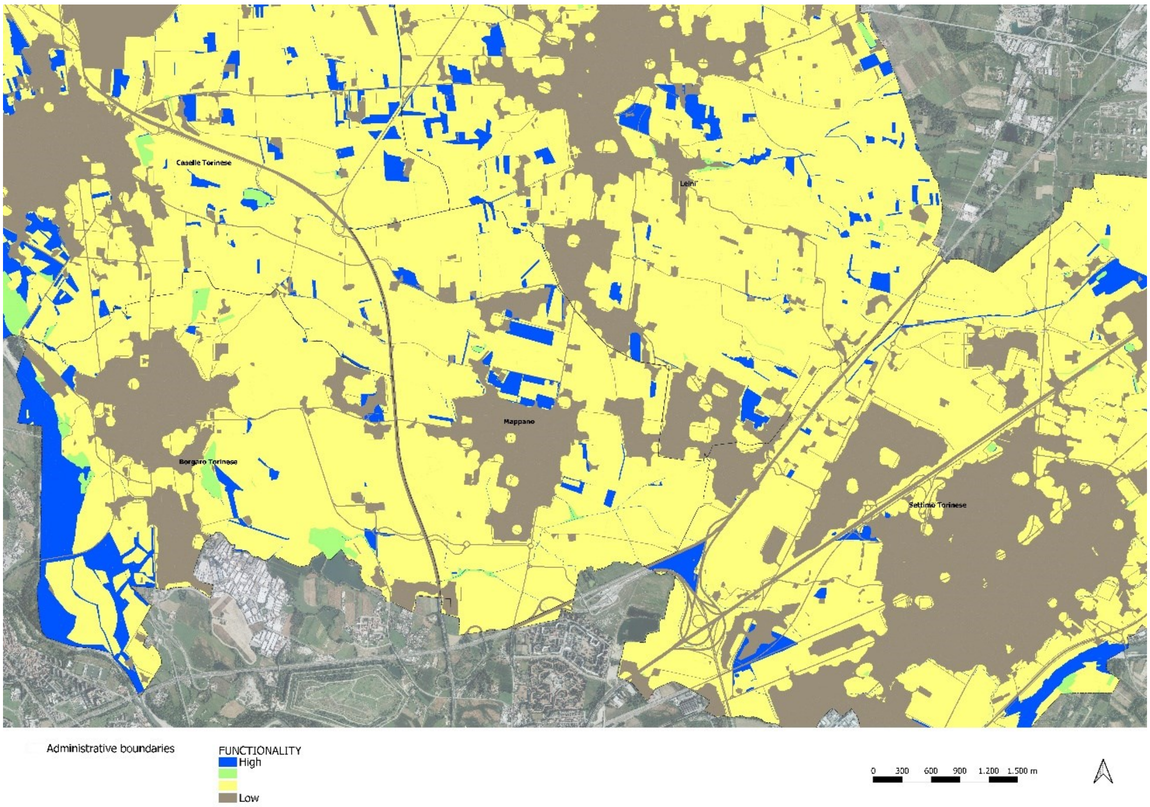

Figure 1 – Ecological Functionality Index representation in Mappano (Source: Voghera and La Riccia elaboration).

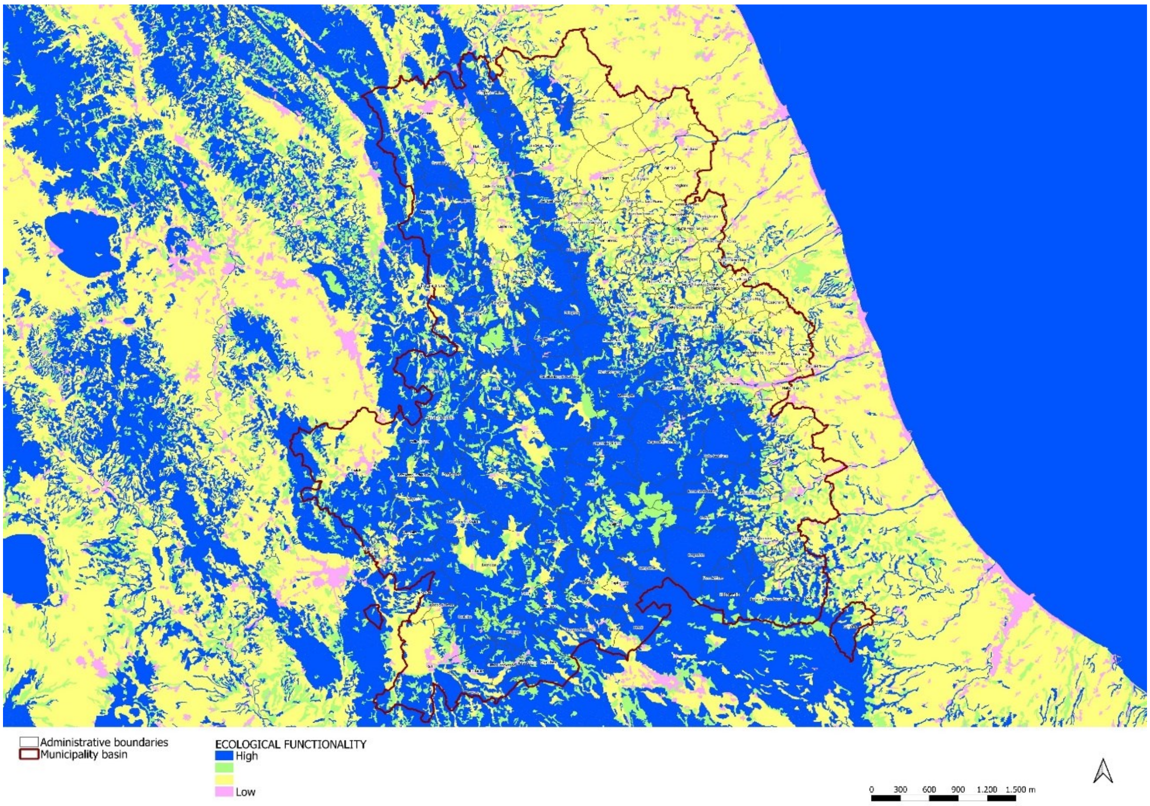

Figure 2 – Ecological Functionality Index representation in Central Italy (Source: Voghera and La Riccia elaboration).

The proposed methodology identifies the ecological character of the territory and defines the criteria for the evaluation of different types of land use: in Piedmont 97 types of use, according to Corine Land Cover database, were identified. Subsequently, we applied five key indicators for assessing the ecological status: Naturalness, Relevance for conservation, Fragility, Extroversion, Irreversibility (Voghera and La Riccia, 2016 and 2019).

Each element, structure, subsystem that works in a partially autonomous manner, overall allows to carry out movements that are the integration between the functions of the ecosystem elements (emergent properties). The combination of patches characterized by different levels of naturalness and relevance for conservation leads to being able define a zoning of the territory in terms of reticular value and ecological functionality (Figg. 1 and 2). The fundamental attributes which can lead to the reading of the actual ecological network are Naturalness and Relevance for the conservation.

For the creation of a local ecological network it is essential not only an analysis of the current geometry of the elements of naturalness capable of constituting an ecological network, but also their location within the transformation forecasts relating to the territory in question, both as a consequence of the inertial processes in progress (for example, advance of urbanization fronts, change in the prevailing crops, phenomena of abandonment of hilly-mountain areas), and of those resulting from the programmatic choices expressed by the various levels of government of the territory (general planning or sector and planned interventions). Only in this way will it be possible to prefigure an overall ecological network design capable of achieving its objectives, demonstrating compatibility with the objectives of the various sectors.

4 Landscape Sensitivity

Thus affirmed, among the aims of the ecological network, the priority of the conservation objective of biodiversity, one cannot fail to recognize the role that the landscape assumes in its design, implementation and management. As is well known, the complexity of the landscape brings into play a very wide range of components: physical, ecological, cultural, semiological, perceptive.

The study and design of the landscape, due to its specificity and complexity, therefore configures a relatively different and largely independent path from that of the design and construction of the ecological network. Nevertheless, the same primary objective of biodiversity conservation and the aim of the research to conceive the ecological network also as fruitive opportunities (cultural, perceptive, recreational, …) cannot exempt from placing the ecological network project in relationship with the landscape. In the first place, as the landscape constitutes the context in which the ecological network project is set and many of the processes and interactions that take place in it significantly influence biodiversity and therefore are an essential basis for the creation and management of the network itself. Conversely, the landscape benefits from the construction of the ecological network as it is oriented towards safeguarding the ecological relationship processes, which are a fundamental component of landscape functionality and diversification. Secondly, as the cultural and perceptive aspects of the landscape can constitute complementary elements of the ecological network, attributing additional values to the same components of the ecological network (cultural and perceptual values) or identifying other components and relationships to be preserved and enhanced, which amplify the role of the network itself by defining, in addition to an ecological value, others of a perceptive and user type, or even integrating it with other forms of landscape connection.

With the advent of ICT, the large use of geospatial data and the creation of DEMs (Digital Elevation Models) and DSM (Digital Surface Models), the development and implementation of new GIS methodologies help to determine visible areas in a more precise and automatic way (Travis 1975; Yoeli 1985; La Riccia 2015b, 2017; Chiesa and La Riccia 2016). The family of GIS software (GIS-science) can provide a spatial representation of the landscape elements, study the inter-visibility relationship between points which are more or less distant form each other, and define the overall landscape sensitivity. The aim of this analysis is to contribute to the field of town planning, taking into account the objective conditions and geometries of several points of analysis (formal features of the landscape scene, observation points, range and depth of vision, perceptual landmarks), assuming that they could be predictive of a subjective landscape experience.

The so-called viewshed analysis simulates the relationship between the landscape morphology and the territorial elements, and helps to calculate the coverage (visual space) with respect to the location and the visual horizon of a specific observer. On the basis of a model (DTM or DSM) it is possible to perform the analysis from individual positions (viewsheds), paths (incremental viewsheds) or areas (cumulative viewsheds). In all cases, the viewshed tool defines the visual space assumed as the portion of landscape that an observer can view. This process is not only based on the three-dimensional aspects of the space, but also on other conditions such as the observer's position (altitude, proximity, etc.), the view direction (azimuth and vertical angles), and atmospheric conditions (minimum and maximum visibility radius). The results is based on a concept of Boolean visibility and reported in binary code (1 = visible; 0 = not visible). A binary viewshed responds to a basic question: what portion of a landscape is visible from a given observation point? In performing this analysis it is important to include all kinds of information about, for example, other scenic elements or special points of interest (historic buildings, landmarks, natural environment, etc.) in order to evaluate the different intervisibility relationships.

Several conditions can influence the readability of a landscape, such as the position of the observer, the observation time, the movement and the speed (with consequences on the alternation of different sequences and the definition of the rhythm of the vision). In general, the physical forms of landscapes are those that primarily affect the syntax of this reading, although they may involve other cultural elements (social values of places, symbolic meanings, place names, etc.). In addition, the depth of the visual field also seriously affects perception together with the texture and the appearance of materials, the effects of light/shade and color, and the presence or absence of a foreground.

The use of GIS significantly speeds up the whole process of the individuation of the areas which are visible from a point or a defined scenic path, an operation that, traditionally, was previously done by hand requiring skilled sensitivity on the part of the territorial analyst.

The geometric characteristics of each selected scene are organized within a geographic database that includes several elements: altitude of the chosen viewpoint, height of the observer relative to the ground, height of a visual reference (landmark), width of horizontal and vertical angles, depth (radius) of the horizon of the view. The set of parameters that can be implemented by the GIS software (Fig. 3) is reported below:

- Spatial coordinates of the viewpoint;
- SPOT: altitude of the viewpoint
- OFFSET A: height of the observer with respect to the ground;
- OFFSET B: height of a different landmark or another point of interest;
- AZIMUTH 1 and 2: width of the horizontal angle;
- VERT 1 and 2: with of the vertical angle;
- RADIUS 1 and 2: minimum and maximum distances (radius) of the view.

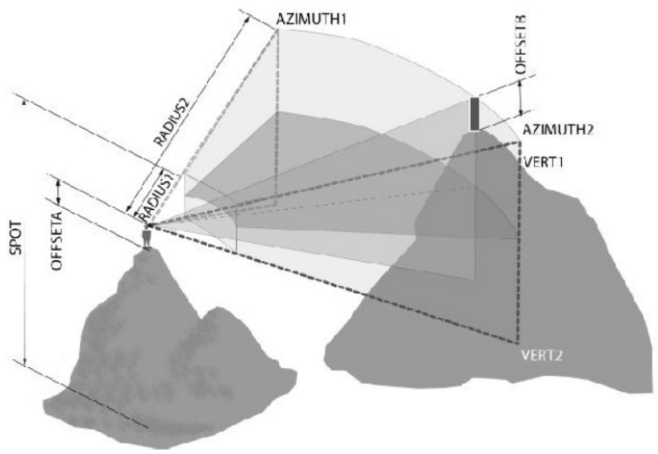

Figure 3 - Schematic illustration of the parameters used by the ESRI ArcGIS software for the viewshed analysis (Source: Voghera and La Riccia elaboration based on ESRI schemes).

Figure 4 - Landscape sensitivity (cumulative viewshed) in Mappano. Source: Voghera and La Riccia.

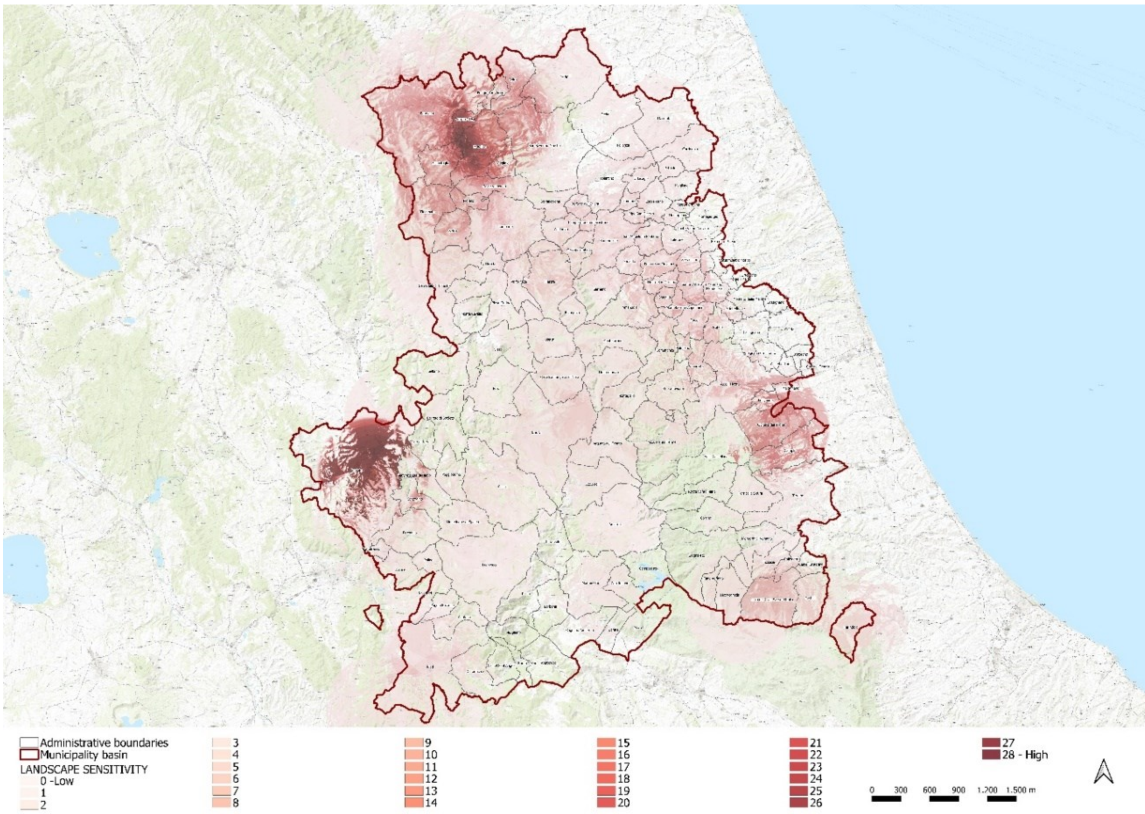

Figure 5 - Landscape sensitivity map (cumulative viewshed) in Central Italy. Source: Voghera and La Riccia.

When different visual analyses are obtained from several points, it can be possible to overlap them and create a map of “absolute visibility” of the landscape. The result can be a Boolean image (raster), or even be characterized by a more complex subdivision by incorporating the different viewshed analyses in a unique map, generated by superposition of different raster images through the “combine” function in GIS, and assumed as a result of “landscape sensitivity” index.

The Figures 4 and 5 show 6 classes of landscape sensitivity and derives from the weighted sum of the individual viewshed analyzes, calculated from several selected viewpoints. The methodology therefore makes it possible to contribute to the drafting of landscape protection indications that can be applied differently, protecting the views on the basis of three distinct levels (foreground, medium-ground, background) or defining specific management plans that include detailed indications, for example the modalities of coherence between views, development of the local ecological network and urban transformations, requests for environmental mitigation and compensation suitable for limiting urban development in the most critical territorial situations.

5 Conclusion

The presented case studies are an effective means of testing new approaches. They can encourage similar methodologies and convince decision-makers that an idea is worth pursuing. Learning from these examples can also help adjust and refine a local planning strategy, also in the view of facing NaTech events. NaTech events have in fact another dimension to be considered, that is the territorial one, again in terms of prevention, management, and resilience.

Local priorities need to be defined before developing a planning strategy based on local ecological network implementation and landscape quality. Such priorities are often driven by widely recognised challenges that may present many opportunities for urban development and decision-making. The underlying principles of ecological network planning need to be understood as part of a holistic approach based on landscape and must be adapted to the local planning system and social, economic and environmental conditions, as well as the available stakeholders.

Ecological Functionality and Landscape Sensitivity require a complex set of interventions useful for the optimal provision of services and the quality of living conditions, aimed at producing public and private wealth distribution, characterised by an ecosystemic approach, with which the city is negotiable as a dynamic organism. Bringing natural components into the different urban forms means to allow for recovering relations between open and built spaces, buildings, soils, and morphologies.

Producing urban agriculture, new solutions for public lighting linked to sustainable mobility and energy production, the reconfiguration of urban fabrics to improve microclimatic conditions and for perceptive well-being, aesthetic quality and the functionality of the pedestrian and cycle paths, the connection among parks, city gardens, cultural assets are components of a positive environmental balance, that, at the same time, favour inclusion, propensity to care and sociality, restore degraded values, recover residual and abandoned spaces, produce common goods.

In this sense, the crisis we are going through could take the form of a “window of opportunity” (Birkmann et al.; 2010) and invite us to outline paths and scenarios through which to transform extreme events and disasters, with the related ecological and economic crises , as an opportunity to rebuild better, in a different way, through the path of innovation and sustainability. We have some important flagship projects available:

- energy transition and increased exploitation of renewable sources;
- reconversion of production in a green key, to set the circular economy in motion and create new jobs;
- regeneration and redevelopment of cities and securing territories;
- enhancement of biodiversity, allowing its appropriate use.

Grounding these great strategies in the system of internal areas, extremely fragile and, at the same time, extraordinarily rich in natural and cultural resources, means, once again, grasping the profound and virtuous interactions between the actions of conservation and those of innovation. In this perspective, the strategy cannot be understood as an ordered collection of many small project actions but, first of all, the emergence of a coordinated, transversal, complex and shared, articulated and systemic thought, which touches and binds the many strings of the territory, leading them together towards the primary objective which is not that of survival, but of planning a better future based on the sustainable development of local resources.

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ECOLOGICAL FUNCTIONALITY AND LANDSCAPE SENSITIVITY ASSESSMENT FOR TERRITORIAL RESILIENCE AND SUSTAINABILITY

61st ESReDA Seminar on Technological disruptions triggered by natural events: identification, characterization, and management

September 22nd-23rd 2022

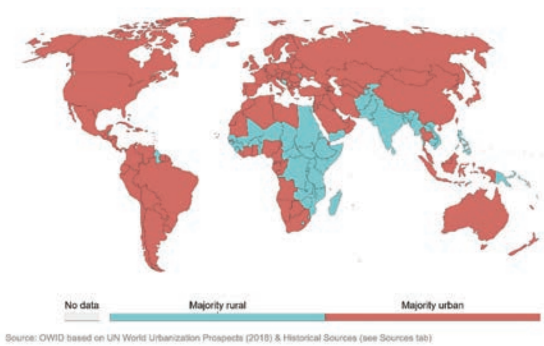
Politecnico di Torino, Lingotto Building, Torino - Italy

Luigi La Riccia & Angioletta Voghera

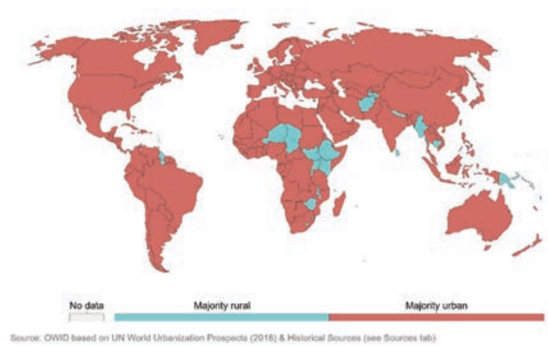
Politecnico di Torino, DIST Department

DO MORE PEOPLE LIVE IN URBAN OR RURAL AREAS?

Worldwide, **more than half of us live in cities**, and the number is increasing, making urban sprawl a specific fact of our common future.



2019



2050

CATASTROPHIC FLOOD IN THE MARCHE REGION (15/09/2022)

BIODIVERSITY LOSS

In cities, peri-urban landscapes and beyond, **concerns have grown regarding loss of biodiversity and degradation of natural resources**, giving rise to **recognition of the central role that ecological networks** have to play in these territories.

In recent years we have seen an **exponential growth of urban land use towards more natural spaces**: external urban areas (uncultivated land, cultivated land abandoned, the burnt areas, degraded forests) are **often been confined to a "inessential" position** and sometimes simply considered as "waiting for a new urbanization".

6
CONSEQUENT
PHENOMENA

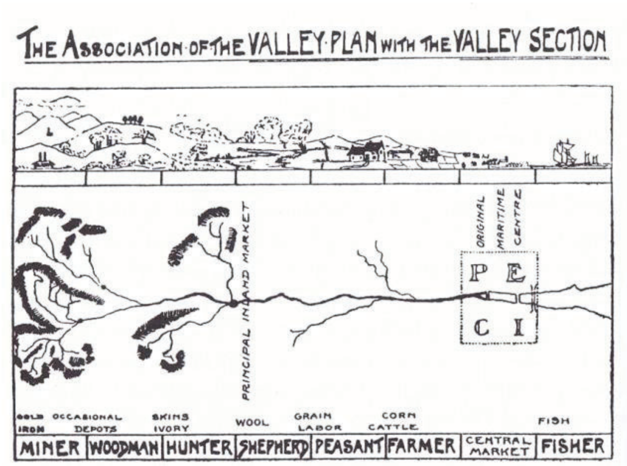
1. Substantial loss of natural areas
2. Fragmentation of natural areas
3. Degradation of wetlands
4. Inability of ecosystem to respond to change and find new ecological balance
5. Loss of ecosystem services
6. Increased costs for public services

THE REVOLUTION OF GREEN CITY

Almost since the beginning of urban planning, **planners have sought means of incorporating nature into the city and preserving the surrounding landscape**.

"*The case for the* ***conservation of nature*** *and for the increase of our accesses to her must be stated more seriously and strongly than is customary.* ***Not merely begged for on all grounds of amenity, of recreation, and repose, sound though they are, but insisted upon****. On what grounds? In terms of the maintenance and development of life*".

(Patrick Geddes, *Cities in Evolution*, 1915)



RESILIENCE APPROACH VS. SUSTAINABILITY APPROACH

	RESILIENCE	**SUSTAINABILITY**
PECULIARITIES	Capacity to change, adapt and transform over time with or without disturbances	Overarching goal for justice, environmental protection and economic efficiency
	Overcome social-ecological limits	Radical reorganization of the social-ecological system
COMMON ELEMENTS	Integrate environmental and planning management Need of a reflective capacity Need of flexibility of the process Inclusion of stakeholders Robustness Biological diversity	

Voghera and Giudice 2019

PLANNING STRATEGIES TOWARDS TERRITORIAL RESILIENCE

MULTI-OBJECTIVE AND CROSS-SECTORAL

Planning strategies must have positive effects on several components of the system (example: if the thematic focus is represented by environmental criticalities, the solutions activated must involve the social and economic dimension) through "multi-objective" strategies

MULTI-SCALE

Planning strategies must deal with different time scales and with different solutions with respect to the different "time" horizons of recovery, transition, adaptation, evolution.

INFLUENCE ON PROCESSES

"New tools" (whether they are interpretative, evaluative, technological or design, to build process innovation, leveraging the construction of possible synergies, methods and even new themes and objectives in tools already developed, offering a renewed look at the overall process

PLANNING STRATEGIES TOWARDS TERRITORIAL RESILIENCE

Research on resilience assessment, in identifying the major thematic clusters, has revealed how issues such as Green Infrastructure and Ecological resilience are less "popular" in the literature and need more in-depth analysis (Sharifi, 2020). In this case, the cluster is also fragmented.

Issues which require more attention, and which should be better linked through more integrated planning approaches.

LAUDATO SÌ (2015). THE ETHICAL VALUES UNDERLYING SUSTAINABLE DEVELOPMENT

ENVIRONMENTAL JUSTICE

It refers to the right of communities to live in a clean and healthy environment, in harmony with their culture, without the risk of being harmed by economic or industrial activities of any kind. It is based on two interconnected assumptions: that of a fair relationship between man and nature, and that of the right of access for all people to the common natural heritage.

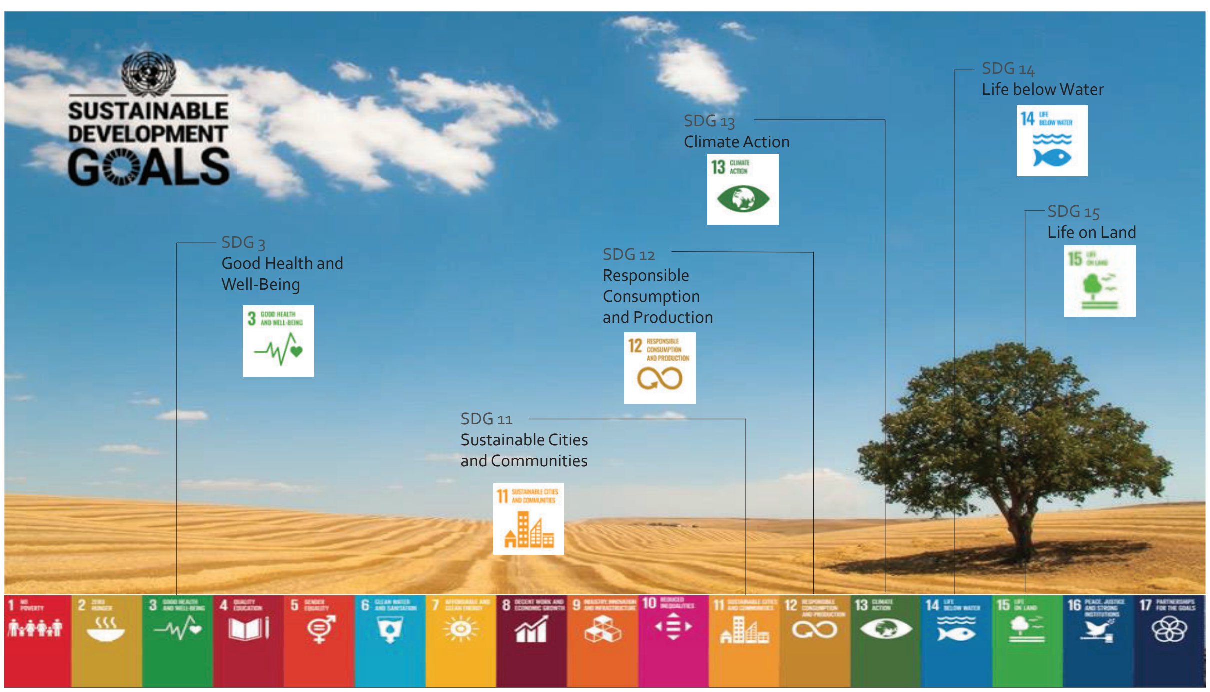
SOCIAL JUSTICE

It aims to guarantee equal rights, opportunities and well-being to all human beings (without differences due to gender, ethnicity, place of birth, status, religion, sexuality, etc.)

INTER-GENERATIONAL JUSTICE

is based on the assumption that belonging to one generation rather than another should not lead to any kind of disadvantage, but rather to continuous improvement and transformation over time. It means that young people and future generations must have the same opportunities to meet their needs as other generations do.

17 UN SUSTAINABLE DEVELOPMENT GOALS



TERRITORIAL SUSTAINABILITY

- **Paradigm** that has guided and directs reasoning, approaches and tools of spatial planning.
- It sets **ecological perspectives** and redefines the relationship between space and society **in the long term**.
- It finds reference in **territorial policies, plans and projects** as a technical response (Pasqui, 2016) to the **needs** of contemporary society (Gabellini, 2018)

NEXTGENERATIONEU. MAKE IT GREEN

Europe is on track to become the **first climate-neutral continent by 2050** – we will produce no more greenhouse gases than our ecosystems can naturally absorb. With NextGenerationEU, we will **invest in environmentally-friendly technologies**, roll out greener vehicles and public transport, and make our buildings and public spaces more energy efficient.

But we also need to protect our natural environment. We will:

IMPROVE WATER QUALITY

in our rivers and seas, reduce waste and plastic litter, plant billions of trees and bring back the bees

CREATE GREEN SPACES

in our cities and increase the use of renewable energy

MAKE FARMING MORE ENVIRONMENTALLY-FRIENDLY

so our food is healthier.

TWO CASE STUDIES

In this contribution two very different territorial scales are considered:

the local scale of the new **Municipality of Mappano** (Turin) and the supra-regional scale of **138 Municipalities in Central Italy**, part of 4 Regions and 10 Provinces, affected by the seismic events of the 2009, 2016 and 2017.

In both cases, the methodology presented below and the application of the two indicators (**Ecological Functionality** and **Landscape Sensitivity**) on these two experiences show the importance of multi-level territorial resilience for defining future planning strategies.

MAPPANO MUNICIPALITY

- recognized as **new** Municipality by the Piedmont Regional Law no. 1/2013
- unplanned sedimentation of **fragmented and contradictory settlement choices**, documented not only from the effects of the urban planning tools of the neighbouring municipalities (known as transferring municipalities) of Caselle Torinese, Borgaro Torinese, Leinì, Settimo Torinese, but also from the will of the population to **search for a community identity**
- at the time of Covid-19, Mappano therefore found itself carrying out its first town plan in this period of profound health crisis: this certainly involved **careful reflection on the interpretation of the territory** as a synthesis of the relationship between person, community and environment.
- The contradiction highlighted by this case raises discussion amid some crucial issues as to the **role of local urban planning and the protection of soil**, which cannot be fragmented or subject to local short-term interests.

CENTRAL ITALY MUNICIPALITIES

- **138 Municipalities** in total, part of 4 Regions and 10 Provinces, affected by the **seismic events of the 2009, 2016 and 2017**.
- very vast territory that still shows the scars of a series of catastrophic events.
- the territory is characterized by an **urban framework of main cities and a set of medium and small villages** that present, on the one hand, a significant wealth in terms of **historical heritage**. architectural and, on the other hand, **negative socio-economic trends** and great difficulties in rethinking and enhancing buildings and settlements, reducing consumption, favouring virtual and physical connections, in favour of a green transition.
- These territories face a series of **increasingly frequent and violent extreme event**s **that are the effect, on the one hand, of the specific conditions of natural ecosystems and the landscape** and, on the other, of the **progressive loss of social and economic capital**. The prevention and response capacity of these territories in the face of these risks is found to be weak or almost nil and requires a strong transfer of knowledge, to promote a phase of innovation and radical change in response to crises, disturbances, pressures (Folke et al. 2021).

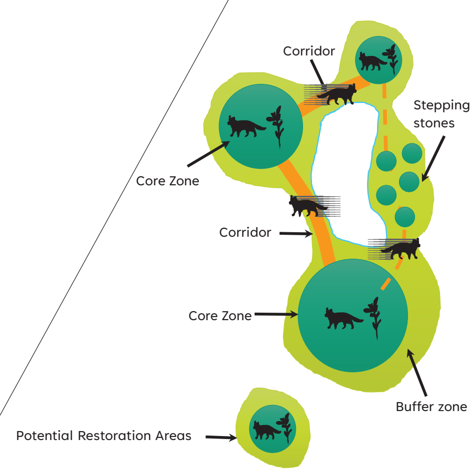
ECOLOGICAL FUNCTIONALITY

STRUCTURE OF THE NETWORK

- **Core Areas** biodiversity is important to conserve; they can be parks or reserves or even less protected
- **Corridors** (ecological corridors) fundamental bands of ecological connections between the core areas they integrate
- **Stepping stones** (punctate or scattered areas) small strategic areas
- **Buffer Zones** protection from external negative effects
- **Potential Restoration Areas** that can be integrated through environmental redevelopment actions

Local ecological network planning is a strategic planning approach that aims to **develop networks of green and blue spaces in urban and periurban areas**, designed and managed to deliver a wide range of ecosystem services and other **benefits at all spatial scales**.

Local ecological network planning **is capable of addressing a broad range of urban challenges**, such as **conserving biodiversity**, **adapting to climate change**, **supporting the green economy** and **improving social cohesion**.



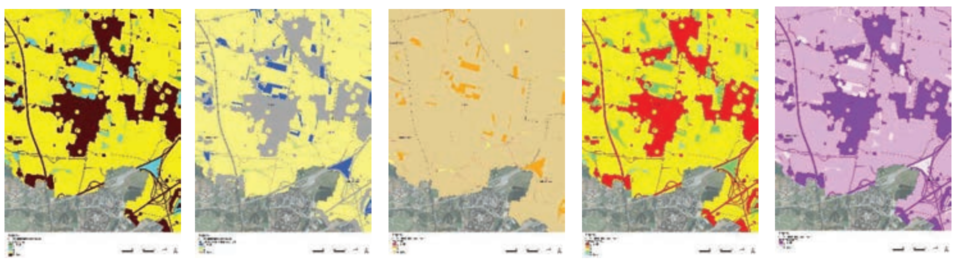
ECOLOGICAL FUNCTIONALITY

The proposed methodology identifies the ecological character of the territory and **defines the criteria for the evaluation of different types of land use**.

Subsequently, we applied **five key indicators for assessing the ecological status**: Naturalness, Relevance for conservation, Fragility, Extroversion, Irreversibility (Voghera and La Riccia, 2016 and 2019).

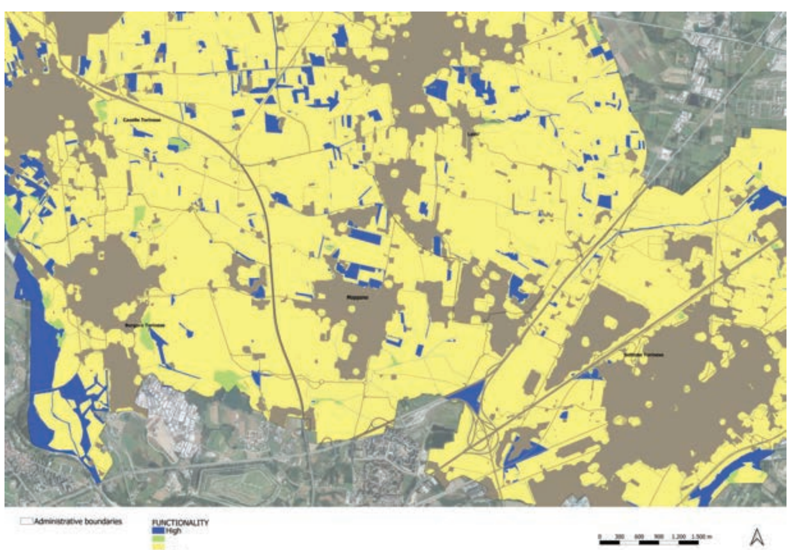
Each element, structure, subsystem that works in a partially autonomous manner, overall allows to carry out movements that ar e the integration between the functions of the ecosystem elements (emergent properties).

The **combination of patches characterized by different levels of naturalness and relevance for conservation** leads to being able define a zoning of the territory in terms of reticular value and **ecological functionality**. The fundamental attributes which can lead to the reading of the actual ecological network are Naturalness and Relevance for the conservation.

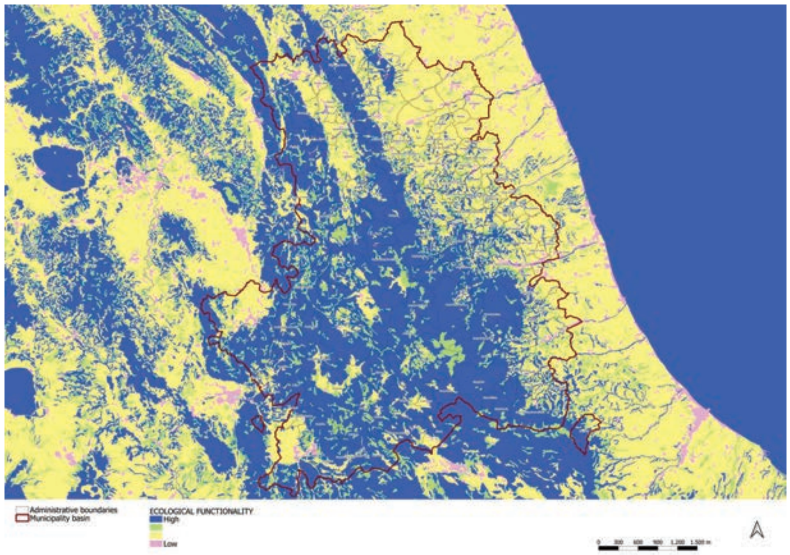


Naturalness | Relevance for conservation | Fragility | Extroversion | Irreversibility

ECOLOGICAL FUNCTIONALITY



ECOLOGICAL FUNCTIONALITY



ECOLOGICAL FUNCTIONALITY

Planning for biodiversity must take the spatial requirements of species into consideration by providing sufficient habitat for them in a connected arrangement.

Ecological networks and green infrastructures **can be viewed at different spatial scales ranging from the wider landscape-scale to the regional-scale and smaller local scale**. Planning for biodiversity needs to be considered at all spatial scales:

1. **A spatial overview of ecological networks at the landscape-scale is required** to overcome existing fragmentation and prevent further depletion of connected features.
2. **The ecological network planning at local scale is required to optimize the conditions for species survival** in order that their basic requirements are fulfilled. The quantity of urban space for plants and animals is an important factor determining biodiversity value of new developments.

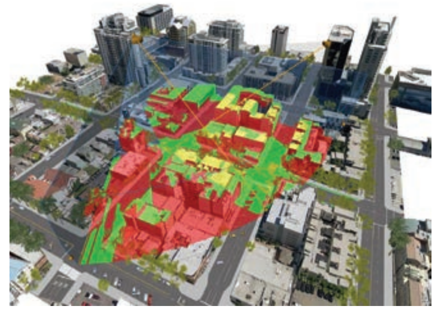
LANDSCAPE SENSITIVITY

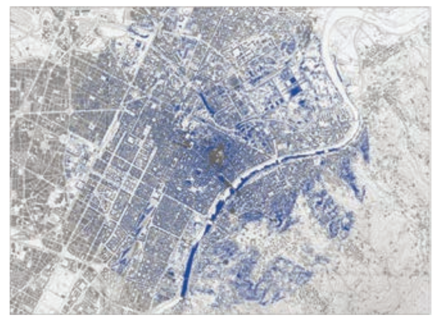
The **complexity of the landscape** brings into play a **very wide range of components**: physical, ecological, cultural, semiological, perceptive.

Landscape **constitutes the context in which the ecological network project is set and many of the processes and interactions that take place in it significantly influence biodiversity** and therefore are an essential basis for the creation and management of the network itself. Conversely, the **landscape benefits from the construction of the ecological network as it is oriented towards safeguarding the ecological relationship processes**, which are a fundamental component of landscape functionality and diversification.

With the advent of ICT, the large use of geospatial data and the creation of DEMs (Digital Elevation Models) and DSM (Digital Surface Models), the **development and implementation of new GIS methodologies help to determine visible areas in a more precise and automatic way** (Travis 1975; Yoeli 1985; La Riccia 2015b, 2017; Chiesa and La Riccia 2016).

The aim is to **contribute to the field of town planning, taking into account the objective conditions and geometries of several points of analysis** (formal features of the landscape scene, observation points, range and depth of vision, perceptual landmarks), assuming that they could be predictive of a subjective landscape experience.





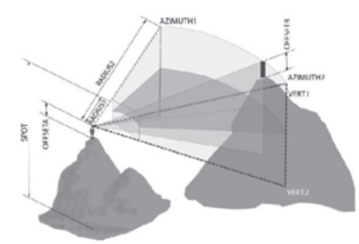
LANDSCAPE SENSITIVITY

Several conditions can influence the readability of a landscape, such as the position of the observer, the observation time, the movement and the speed (with consequences on the alternation of different sequences and the definition of the rhythm of the vision).

In general, **the physical forms of landscapes are those that primarily affect the syntax of this reading, although they may involve other cultural elements** (social values of places, symbolic meanings, place names, etc.). In addition, the depth of the visual field also seriously affects perception together with the texture and the appearance of materials, the effects of light/shade and color, and the presence or absence of a foreground.

The **set of parameters** that can be implemented by the GIS software (Fig. 3) is reported below:

- **Spatial coordinates** of the viewpoint;
- **SPOT**: altitude of the viewpoint;
- **OFFSET A**: height of the observer with respect to the ground;
- **OFFSET B**: height of a different landmark or another point of interest;
- **AZIMUTH 1 and 2**: width of the horizontal angle;
- **VERT 1 and 2**: with of the vertical angle;
- **RADIUS 1 and 2**: minimum and maximum distances (radius) of the view.

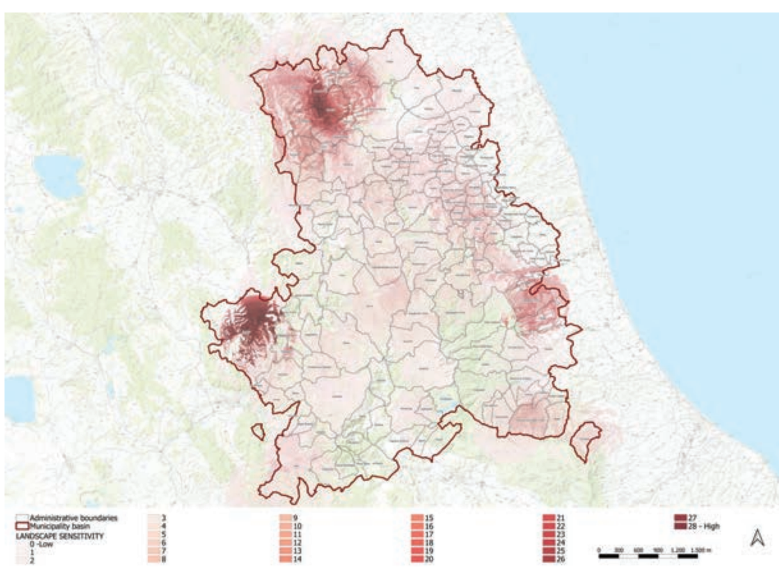


Schematic illustration of the parameters used by the ESRI ArcGIS software for the viewshed analysis (elaboration based on ESRI schemes, 2020).

Punto di ripresa	SPOT	OFFSET A	OFFSET B	AZIMUTH 1	AZIMUTH 2	VERT 1	VERT 2	RADIUS 1	RADIUS 2
1	307 m	2 m	0 m	270°	90°	60°	*- 60°	0 m	5.000 m
2	307 m	2 m	0 m	170°	300°	60°	*- 60°	0 m	5.000 m
3	284 m	2 m	0 m	180°	300°	60°	*- 60°	0 m	5.000 m
4	273 m	2 m	0 m	225°	315°	60°	*- 60°	0 m	5.000 m
5	260 m	2 m	0 m	300°	10°	60°	*- 60°	0 m	5.000 m
6	269 m	2 m	0 m	280°	20°	60°	*- 60°	0 m	5.000 m
7	272 m	2 m	0 m	315°	45°	60°	*- 60°	0 m	5.000 m

LANDSCAPE SENSITIVITY

LANDSCAPE SENSITIVITY



CONCLUSION

TESTING NEW APPROACHES

Learning from these examples can help adjust and refine a planning strategy, also in the view of facing NaTech events. NaTech events have in fact another dimension to be considered, that is the territorial one, again **in terms of prevention, management, and resilience**.

DEFINING LOCAL PRIORITIES

before developing a planning strategy based on local ecological network implementation and landscape quality. Such priorities are often driven by widely recognized challenges that may present many opportunities for urban development and decision-making.

GRASP THE WINDOW OF OPPORTUNITY

The crisis we are going through could take the form of a "window of opportunity" (Birkmann et al.; 2010) and invite us to outline paths and scenarios through which to transform extreme events and disasters, with the related ecological and economic crises , as an opportunity to rebuild better, in a different way, **through the path of innovation of resilience and sustainability**, in terms of:

- **energy transition** and increased exploitation of renewable sources;
- reconversion of **production in a green key**, to set the circular economy in motion and create new jobs;
- **regeneration and redevelopment of cities** and securing territories;
- enhancement of **biodiversity and landscape**

THANK YOU / GRAZIE

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Exploring Compound Event Impacts on Critical Infrastructures, Cascading Failures and Basic Service Disruptions

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Abstract

Critical infrastructures such as powerlines, roads, telecommunication and healthcare systems are essential for a society's daily functioning. Yet they are also more exposed than ever to the risks of extreme weather events in a changing climate [1]. Damages to interdependent infrastructure systems often lead to failure cascades, and result in catastrophic, yet poorly studied impacts when people are cut off from basic service access. The large spatial extents of infrastructure systems make them a natural target of compound events [2], and may further even connect seemingly unconnected hazard events [3], potentially amplifying impacts [4]. We present a consistent and transferrable way to study the effects of (spatio-)temporally compounding hazard events on such infrastructure systems and their impacts on disruptions of basic services. Building on an open-source modelling framework [5] which embeds a network-based infrastructure model into the globally consistent and spatially explicit natural hazard risk modelling platform CLIMADA [6, 14], we simulate failure cascades across power, mobile communications, roads, healthcare and educational infrastructures and the respective service disruptions in Bangladesh from two historic compound flood and tropical cyclone events (Typhoon Sidr 2007 with concurrent storm surges and pluvial floods, and Typhon Giri 2010 followed by a flood). We show that cascading failures are substantial with respect to final impacts, and that the consideration of sub-hazards such as flooding and wind are of utmost importance regarding impact magnitudes. Yet, we find that compound events may not necessarily escalate the level of impact further than if they had occurred in temporally well separated instances, especially if the events are spatially disjoint. The hypothesis remains, however, that such escalations may well happen for more spatially close events and/or high-impact events capable of 'tipping' system performance thresholds. We discuss implications for future connected event research and propose ways forward.

1 Introduction

Critical infrastructures (CIs) such as powerlines, roads, telecommunication and healthcare systems across the globe are more exposed than ever to the risks of extreme weather events in a changing climate [1]. Natural hazard-induced damages to CIs often lead to failure cascades with catastrophic impacts for the population which faces access disruptions for basic services such as energy, mobility and healthcare [8]. Being able to represent the spatial exposure of real-world CI systems to relevant hazards in a realistic manner, to model direct structural impacts of such events, and to capture the dependencies within and between the systems [9], is hence crucial for understanding the risk associated with failure cascades and basic service disruptions at large scales.

Research on CI interdependences has made much progress throughout the last years [10], and especially network (flow) modelling approaches have been demonstrated to lend themselves as illustrative means for hotspot analyses at large system scales (such as entire countries) [7] at which many natural hazards may typically occur.

Within the natural hazard research community, much energy has recently been dedicated to the inquiry of 'compound weather and climate events', which are an "*integral part of almost all climate-related risks and pose significant challenges to many risk-reduction measures*" [2]. Within their seminal paper, Zscheischler *et al*. [2] proposed a typology that identifies four distinct categories of compound events - preconditioned, multivariate, temporally compounding and spatially compounding - which when occurring, may aggravate the impacts of a hazard compared to its isolated treatment, and potentially drive maladaptation.

Developing this predominantly hazard-focused concept of compound events further, Raymond *et al*. [3] coined the term of "*connected events*", incorporating *"'interacting', 'cascading' or 'multi-risk' natural hazards; and* *systemic risks and complexity science*". Applied to the lens of critical infrastructures, it is suggested that *"[c]onnected extremes can exert forces on these [infrastructure] systems beyond their design specifications, making it imperative to understand and incorporate such effects into infrastructure planning and risk assessments. The relevant interactions are typically poorly constrained, despite the large investments involved, due to the great complexities of the systems and the numerous and widely disparate actors with jurisdiction over them*."

Our goal is to showcase a practical platform and means to quantitatively study such - often conceptually remaining - compound event phenomena under the aspect of interdependent critical infrastructure systems, and their connections within the (human-centric) impact space. Drawing on an end-to-end risk modelling and infrastructure failure framework, we start out on two case studies in Bangladesh, one of the most vulnerable countries to multiple hazards, involving tropical cyclones and flooding. We explore how temporally, yet not necessarily spatially compounding events may induce failure cascades and disrupt basic services. Using a generalized framework, we aim to draw preliminary conclusions on the adequacy of the approach as such to advance connected event research, and highlight insights, limitations and extension methods for the future.

2 Methods

2.1 Modelling framework - Overview

Critical infrastructure (CI) failure models often operate at local scales, with high data requirements and low transferability. The focus frequently lies on a technical performance side, and (natural) hazards are often not explicitly modelled as a physically consistent disruptive scenario. To handle the scales at which natural hazards occur, and to enable a coherent, transferrable assessment of CI risks and their social impacts, we developed an end-to-end framework [5] that employs a network modelling approach for interdependent CI systems, embedded into the natural hazard risk assessment platform CLIMADA [6], a state-of-the-art tool for impact calculations and adaptation options appraisal. CI component damages are computed from hazard footprints within the natural hazard risk module of the framework, which then initiate CI failure cascades within the CI systems module of the framework, which propagate along dependencies between the different CI systems. Result layers are computed both on a technical (functional) CI systems level and translated into human-centric impacts (basic service disruptions) for the dependent population. The framework is spatially explicit, fully open-source and open-access, allowing for the analysis of geographical regions, CI systems and hazards of interest.

2.1.1 Natural Hazard Risk Modelling with CLIMADA

While several platforms for natural hazard modelling exist, the open-source and -access software CLIMADA (CLImate ADAptation) is the only globally consistent and spatially explicit tool which is freely available to assess the risks of natural hazards and to support the appraisal of adaptation options [6, 14]. The event-based modelling approach of CLIMADA allows for a fully probabilistic risk assessment based on the IPCC risk definition as a function of hazard, exposure and vulnerability. 'Hazard' is a spatial representation of an intensity measure for the respective physical event, such as a wind field computed from the track records of a tropical cyclone, or the flood depth at certain locations within a region. 'Exposure' represents the geo-located critical infrastructures at component level which are potentially at risk (e.g. power plants and power lines, cell towers, etc.), and their associated value (such as Dollars, length or area). 'Vulnerability' is a hazard and infrastructure component-specific function, relating hazard intensity to the degree of expectable structural damage. Risk is computed efficiently in CLIMADA by overlaying these three layers, and obtaining structural damage fractions for each infrastructure component. While data curation is automated for many layers (such as downloading infrastructure shapes from OpenStreetMap, or hazard footprints for several types of natural hazards from a dedicated data API), user-specific data of many geospatial formats can readily be ingested into the platform. More details on the approach can be found in [5] and [6].

2.1.2 Infrastructure Systems Modelling within a System-of-Systems Formulation

CI graphs with directed edges and nodes are generated from the same geo-located component data as used in the risk calculations for each CI system. The individual graphs are combined into one interdependent CI graph through dependencies. Dependencies between components of different CI systems are inferred through a dependency-search algorithm described further in [5]. Population data equally forms part of the interdependent CI graph, where dependencies (representing demand for basic services such as access to power, mobile communication, healthcare, education and mobility) are similarly inferred via the search algorithm, yet additionally involve checking for availability of road access to schools and healthcare facilities. CI failure cascades are triggered through the computed component damages as described above and propagated along CI dependencies in the graph representation of the interdependent CI system until reaching a steady state. Basic service disruptions for the dependent population are calculated accordingly. More details on the approach can be found in [5].

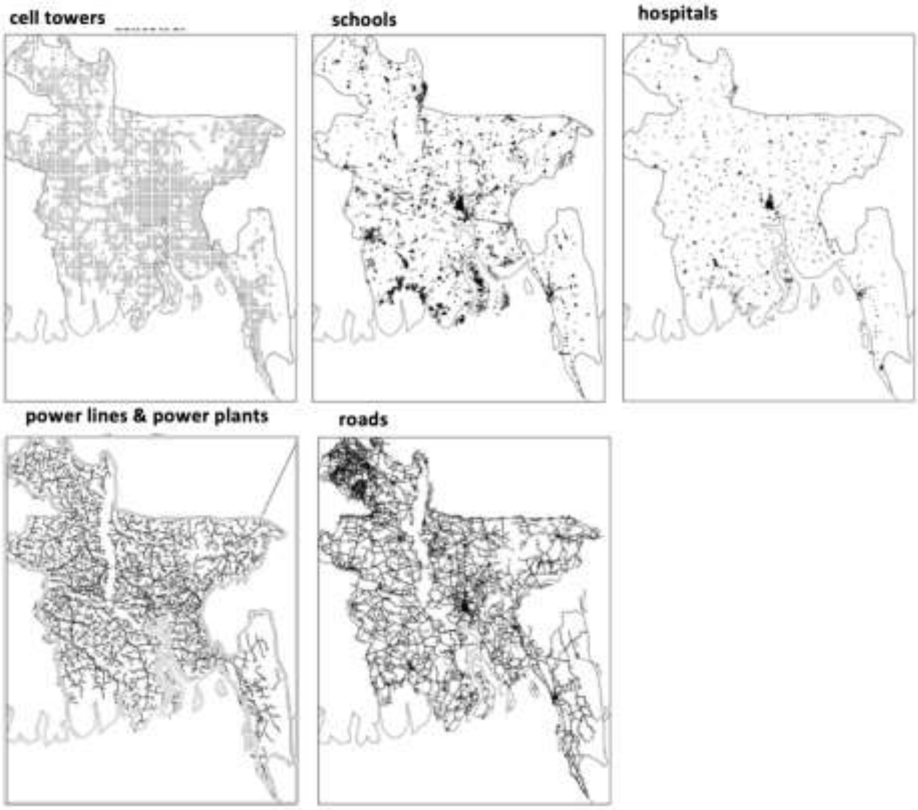
2.2 Case Selection - Two Compound Tropical Cyclone and Flood Events in Bangladesh

Bangladesh was selected due to its frequent exposure to a multitude of hazards, particularly floods and tropical cyclones (TCs). Desk research and data availability revealed two explorative case study combinations: Typhoon Giri in 2010, which brought about strong winds, and was followed by a major flood two weeks later (also termed *case A* henceforth), and typhoon Sidr in 2007, which brought about strong winds, storm surge and flooding due to torrential rainfalls (also termed *case B* henceforth). Impacts were explored for the interdependent power, mobile communications, road, healthcare and educational infrastructure systems, both on a functional basis and in terms of service disruptions to the dependent population. To study the possible increased effects of temporally compounding events, two types of simulations were performed: Once, impact and cascading failure calculations were run separately per hazard (i.e. once per TC wind and once per flooding), following a single-event logic, and once, structural damages on components were first combined from both winds and floods, and then propagated through the failure cascade module.

2.2.1 Data

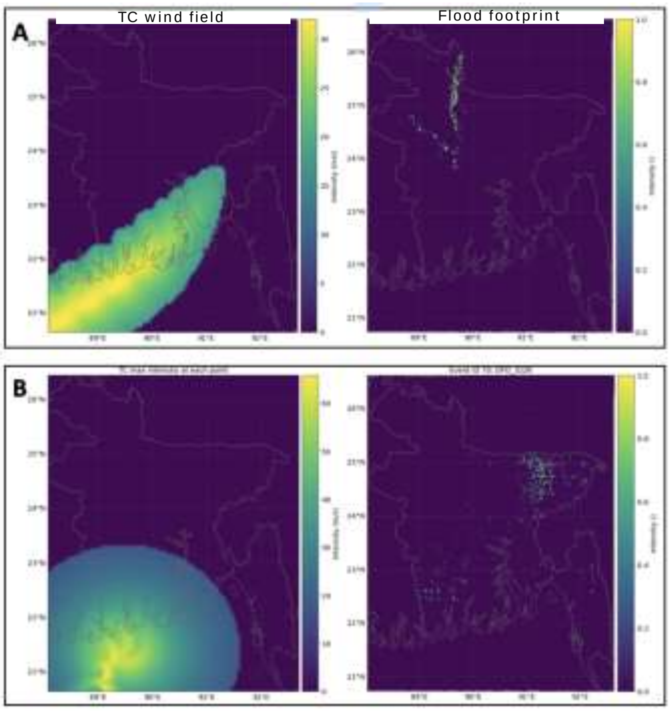
- Infrastructure component data within Bangladesh is collected for power plants, high-and medium voltage power lines, cell towers, main roads, hospitals and schools (see Figure 1). Data is taken from gridfinder [11], World Bank Open Data and OpenStreetMap. Gridded population count data is extracted from WorldPop [12] at a 1km^2 resolution.
- Supply and demand data were obtained for the power sector (electricity generation and per capita electricity consumption) from the International Energy Agency IEA.
- Hazard source data is taken from IBTrACS, the International Best Track Archive for Climate Stewardship project [13], providing time and location of TC tracks for typhoons Giri (storm-ID 2010280N17085) and Sidr (storm-ID 2007314N10093). Flood footprints are obtained from the Cloud To Street database, for the two events with identifiers DFO 3713 and DFO 3226. See figure 2.
- Impact functions (also termed vulnerability curves or fragility functions), relating hazard intensity to structural damage extent are taken from FEMA's Hazus MH manuals and literature, as detailed in [5].

Figure 1. Critical infrastructure systems within Bangladesh considered in case studies A and B.



Source: OpenStreetMap, 2022; gridfinder, 2018; World Bank OpenData, 2019.

Figure 2. Hazard pairs considered in compound event computations: A - consecutive TC wind (Giri 2010) and flood event (DFO 3713), B - concurrent TC wind (Sidr 2007) and flood sub-hazards from storm surge and torrential rainfalls (DFO 3226).



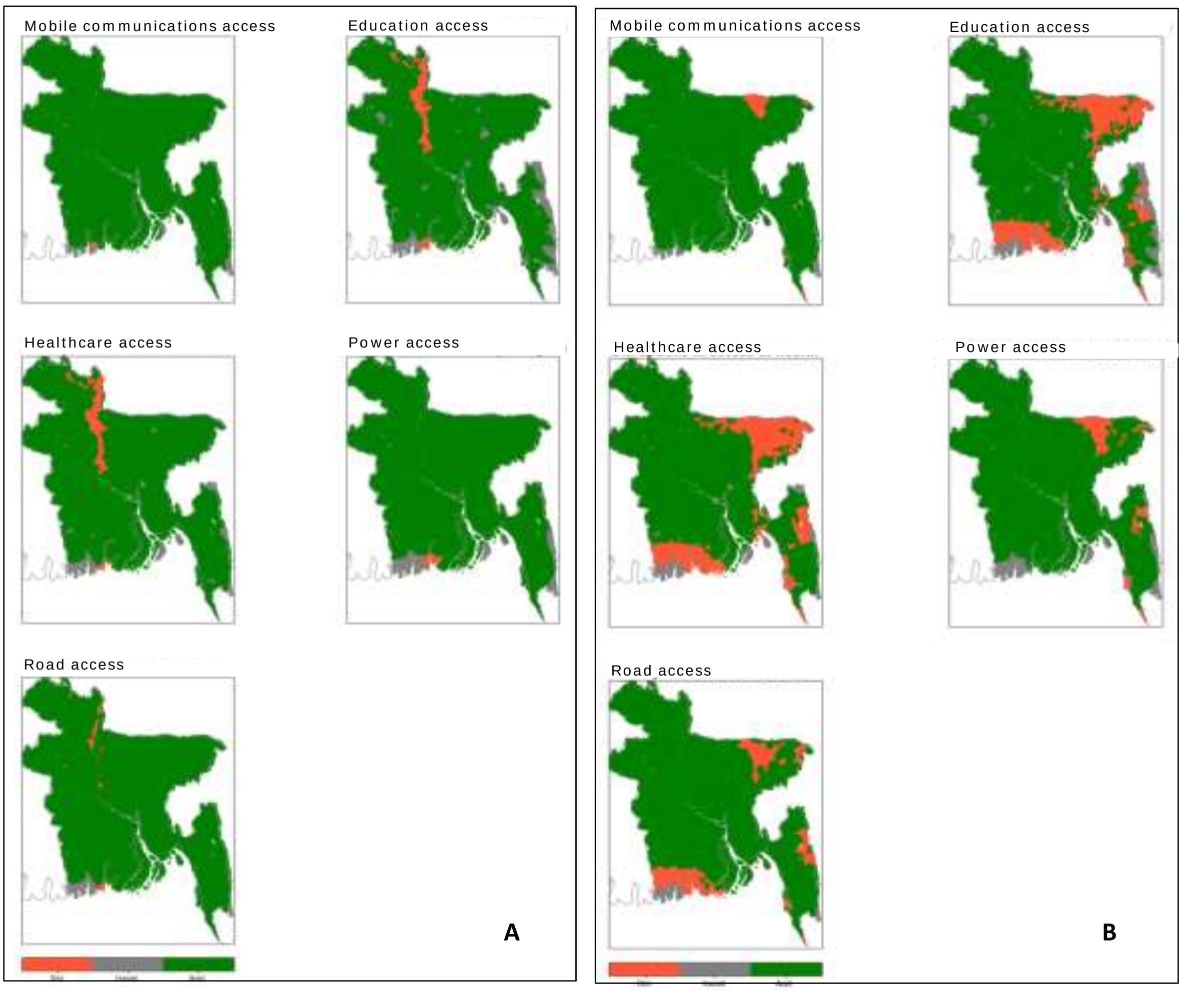
Source: authors, with source data from Cloud to Street flood database and IBTrACS [13].

3 Results

Figure 3 summarizes the spatial results in terms of people being affected by basic service disruptions due to infrastructure failure cascades induced by temporally compounding hazard events. As visible in the hazard figures in Section 2, the flooding and wind footprints were spatially disjoint, without any geographic overlap in case A. Particularly in this case (Figure 2, left), impacts are clearly attributable to either of the two hazard events - the flooding for disruptions in the northern part of the country, and some minor disruptions due to winds in the southern part of the country. Similar, yet not as pronounced, is case B (Figure 3, right), with flood-induced impacts in the north-east and east part, and wind-induced impacts in the south of the country.

Result tables 1 and 2 confirm the visual impression quantitatively by detailing the number of people affected by service disruptions due to either the wind hazard or the flood hazard individually, following a single-event logic, and for the compound-event logic in comparison: The sums of people experiencing disruptions per individual hazard type (columns 'min-sum'), result in the same impact figures as for the compound event computations (columns 'compound'), without bigger, escalating effects in the latter.

Figure 3. Maps of population estimated to experience service disruptions in access to telecommunications, education, healthcare, power and roads, due to (cascading) infrastructure failures induced by compound hazard events as presented above: panel A (consecutive TC Giri and flood events) and panel B (compound TC Sidr and surge/pluvial flooding event). Green - population cluster has access to respective service, red - population cluster lost access to respective service, grey - population cluster never had access to respective service.



Source: authors' calculations, 2022

Table 1. Total population estimated to experience disruption in access to the respective services from event pair A (TC Giri and a consecutive flood event). *Wind Only* - disruption scenario computed only from the tropical cyclone wind field; *Flooding Only* - disruption scenario computed only from the flood footprint; *Compound* - disruption scenario computed from wind and flood being treated as a single, co-occurring hazard event; Min-Sum - Sum of separately computed disruption scenarios *Wind Only* and *Flooding Only,* avoiding double-counting of potential population clusters which are affected by both scenarios.

	Wind Only	**Flooding Only**	**Compound** ([1])	**Min-Sum** ([2])
mobile comm's.	5'368	-	5'368	5'368
education	50'953	4'569'298	4'620'251	4'620'251
healthcare	30'878	4'799'014	4'829'892	4'829'892
power	243'593	-	243'593	243'593
road	16'129	653'864	669'993	669'993

Source: Authors' calculations.

Table 2. Total population estimated to experience disruption in access to the respective services from event pair B (concurrent TC wind and flood sub-hazards of Typhoon Sidr, 2007). Columns are as explained in caption of Table 1.

	Wind Only	**Flooding Only**	**Compound** ([1])	**Min-Sum** ([2])
mobile comm's.	-	1'981'026	1'981'026	1'981'026
education	2'475'998	14'265'789	16'741'787	16'741'787
healthcare	2'579'788	15'398'783	17'978'571	17'978'571
power	-	4'672'555	4'672'555	4'672'555
road	1'717'565	4'536'270	6'253'836	6'253'836

Source: Authors' calculations.

It is important to point out that failure cascades were still triggered due to the networked character of the infrastructure systems under study and their dependencies between each other, and that they are a dominant factor in healthcare and education access disruptions. Cascades did, however, not spread beyond their single-event extent.

The non-occurrence of any detectable 'connections' magnifying impacts beyond their initial scopes for the cases studied here may be attributable to two factors: Firstly, due to the different spatial patterns of the wind and flooding occurrence, those hazards were not acting on the same infrastructure components, and hence would not contribute to a joint failure (such as winds weakening a structure, which is rendered fully dysfunctional through the onset of a flood). Secondly, no 'system thresholds' were surpassed that would have led to a system-wide failure (such as the power network falling below a certain capacity, which then results in a full blackout). However, the occurrence of such scenarios would in general lie within the ranges of possibility, for instance through the occurrence of more intense or more spatially compounding hazard events.

Lastly, looking particularly at case B, where a tropical cyclone event entailed several compounding sub-hazards (wind, and storm surge and torrential rainfalls producing flooding), the importance of explicitly capturing those becomes obvious despite any secondary escalating effects: While strong winds did cause some basic service disruptions, the resulting floods were the main drivers of impacts. This would have been neglected when proxying the event through the wind field only, as is frequently done.

4 Conclusions and Outlook

In this contribution, we demonstrated a flexible approach to study the systemic impacts of compound events interacting with interdependent critical infrastructure systems. The approach was demonstrated on two tropical cyclone wind and flooding compound events in Bangladesh, for five infrastructure systems and basic services. It demonstrated that an event connection, i.e. the modification of impacts through the multiple interplay of system interdependencies and compounding hazards, may not necessarily occur: If events, though temporally compounding, are spatially disjoint enough, and if the sum of individual impacts are not grave enough to tip the system towards a larger failure scenario (such as a wide-spread blackout), compound events may be considered as multiple single events. Vice-versa, this leaves many possibilities for such magnifying impact scenarios to occur Further to that, the present approach lends itself to explore more extreme counterfactual events in future studies, either be magnifying the intensity of the constituent (sub-)hazards and/or the connections between the systems studied – not least with respect to the appraisal of potentially robust measures to strengthen system resilience [14].

The flexibility of the framework to readily study other regions and hazard pairs allows to explore more such events and their impact characteristics. Further, historic case studies which are known for their escalating behaviour due to compound event impacts (such as Hurricane Harvey 2017 in Texas and Louisiana) could serve as a model calibration and validation source.

Acknowledgements

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 821010 and under grant agreement No 820712.

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List of abbreviations and definitions

CI	Critical Infrastructure
NH	Natural Hazard
TC	Tropical Cyclone

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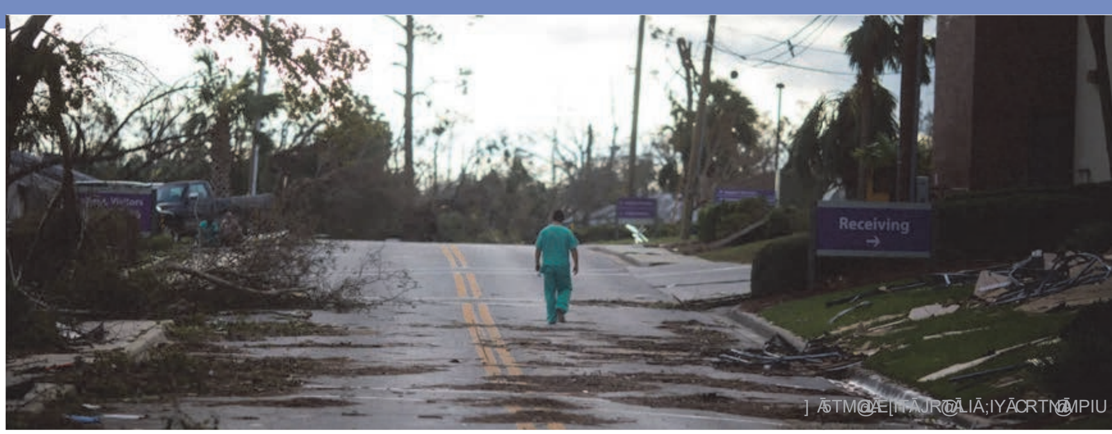

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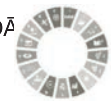

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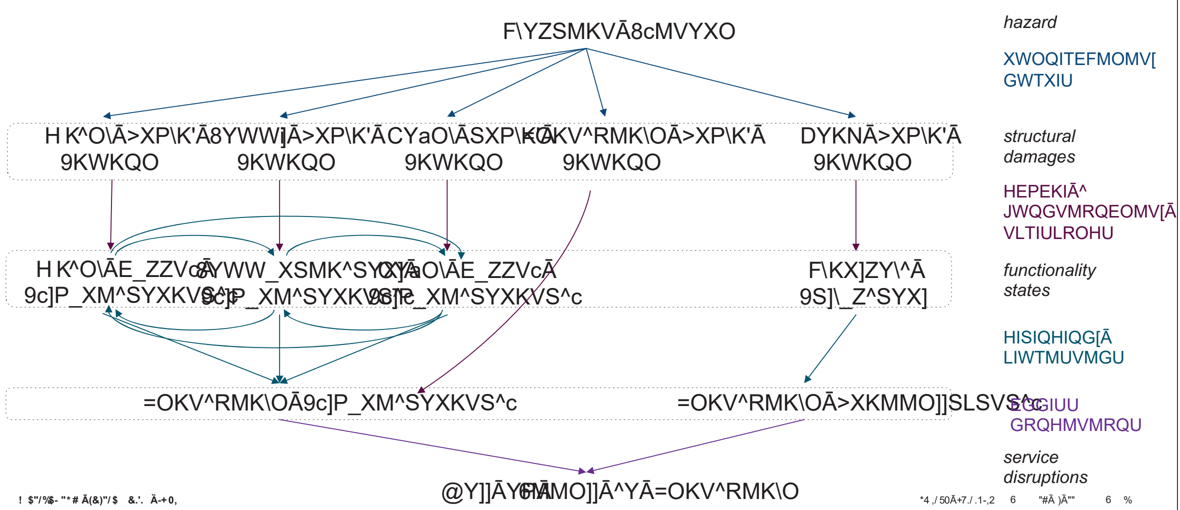

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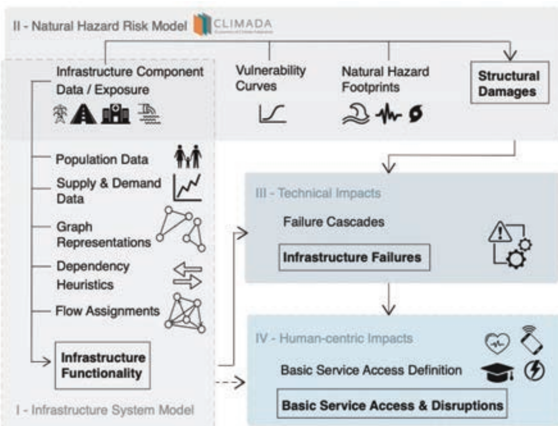

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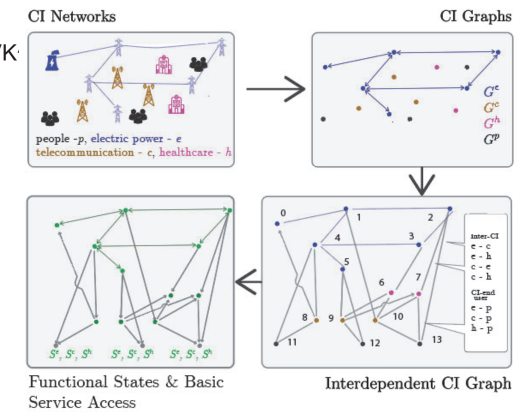

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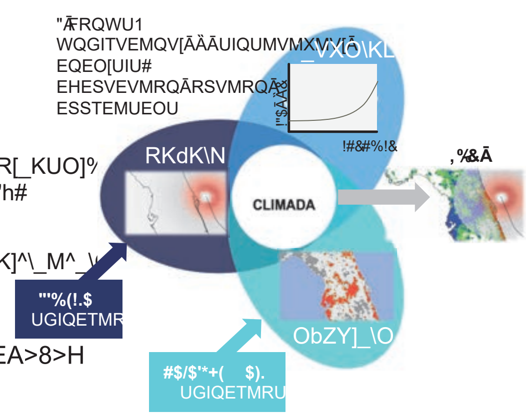

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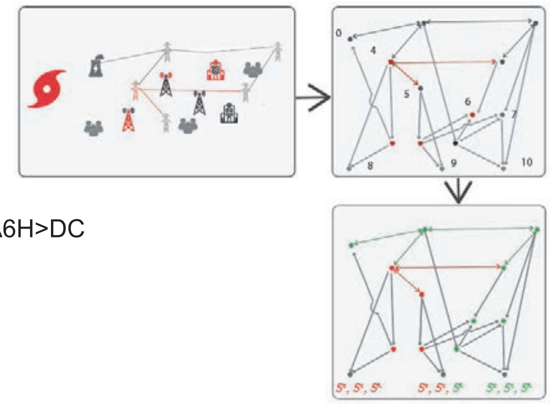

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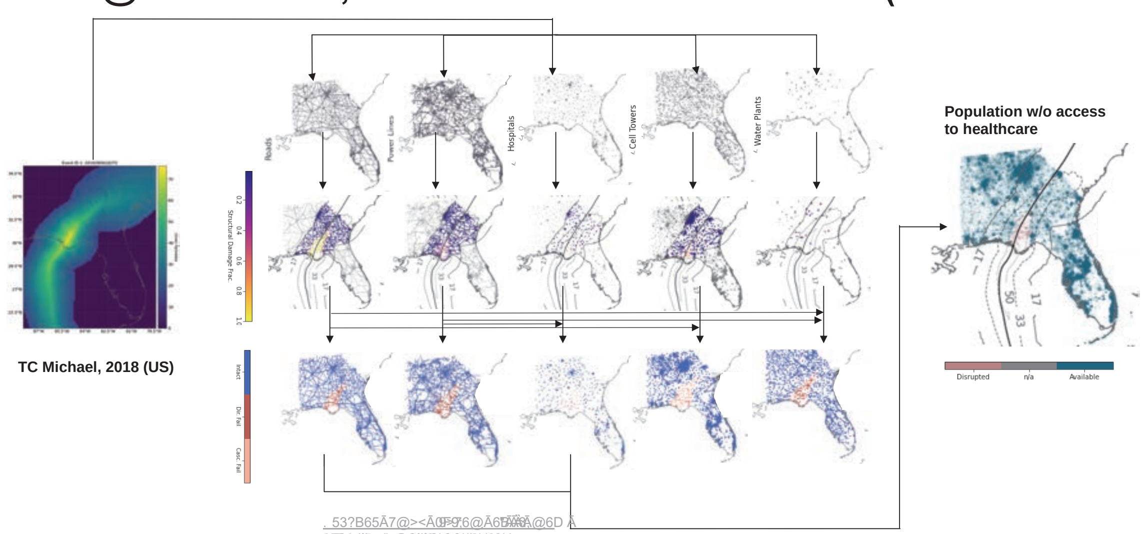

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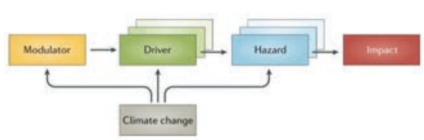
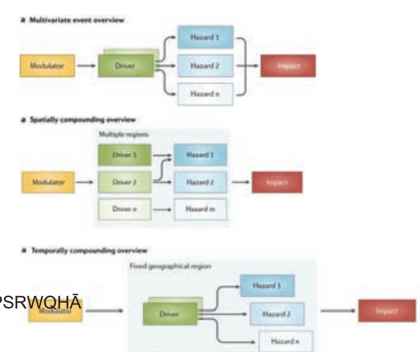
- ?*The combination of multiple drivers and/or hazards that contributes to societal or environmental risk.*@





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- *" The concept of connected extreme weather and climate events further recognizes that compound event impacts are often substantially and nonlinearly influenced by non-physical factors such as exposure and vulnerability, cutting across sectors and scales (from personal to society wide)."*

- *"Connected extremes can exert forces on [infrastructure] systems beyond their design specifications, making it imperative to understand and incorporate such effects into infrastructure planning and risk assessments."*

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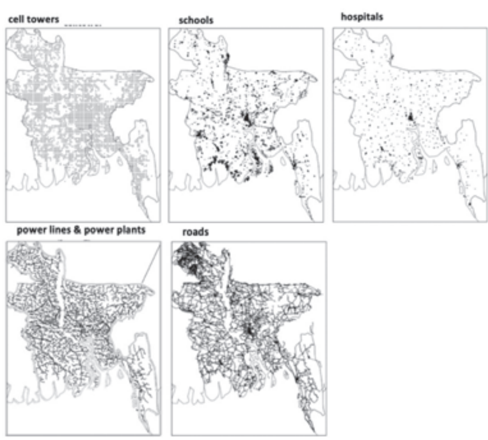

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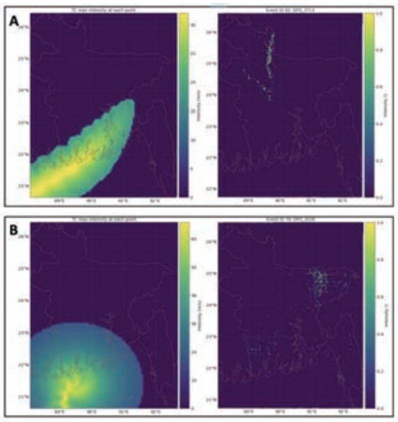

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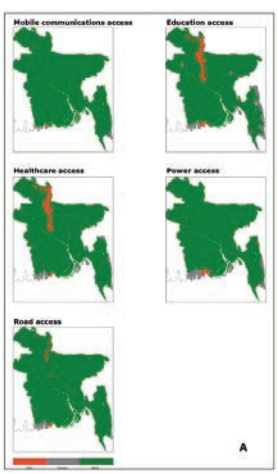

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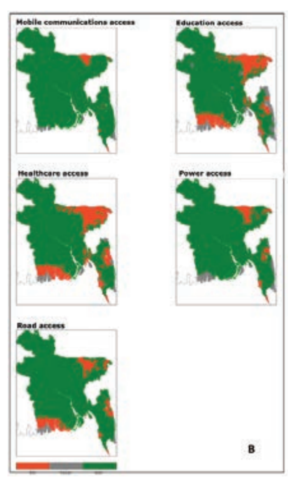

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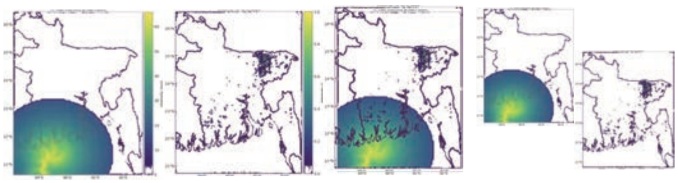

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education	2'475'998	14'265'789	16'741'787	16'741'787
healthcare	2'579'788	15'398'783	17'978'571	17'978'571
power	-	4'672'555	4'672'555	4'672'555
road	1'717'565	4'536'270	6'253'836	6'253'836

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Hydric erosion in touristic beaches influenced by extreme rainfall events: case contribution of the pluvial drainage of the Ancon Hotel, Cuba.

Omar Gutiérrez Benítez, Department of Chemical Engineering, University of Cienfuegos Carlos Rafael Rodríguez. Cienfuegos, Cuba, ogutierrez@ucf.edu.cu

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Abstract

In some areas of the world, due to climate change, some natural hazards have expected return periods shorter than those considered to build single infrastructures long decades ago. The delays in adopting corrective actions join this issue, increasing the number of disrupting events triggered by natural hazards. Specifically, the tourism and entertainment industry disruptions induced by natural events may cause severe environmental, economic, and service functionality losses. In Cuba, 89 % of the beaches show signs of erosion; therefore, this problem represents a national priority established in the Cuban State Plan to Confront Climate Change. This plan sets the identification of existing vulnerability and the undertaking of actions to reduce it, as well as the recovery of beaches, prioritizing those for tourist use. The goal was to evaluate the contribution of one hotel's storm drainage system to the hydric erosion in the hotel's beach sector and its mitigation. The Ancon Hotel, located in Trinidad, Cuba, was used as a study case. The hydrologic calculations of the design rainstorm used the isoyetic map of maximum daily rainfall for 1 % probability and the calculation nomogram for different probabilities and time duration in the Republic of Cuba. Two scenarios were performed: Scenario 1: A 20 % probability of rainfall with a duration time of 10 minutes, a rain intensity of 1.83 mm/min was taken. Scenario 2: A 5 % probability of rainfall with a duration time of 5 minutes, established according to the degree of protection to be provided to the installation, considering the category of the work and the ecological damage it may cause, a rain intensity of 3.1 mm/min was taken. It was shown that erosion is predominantly of hydric origin, with gully-type erosion manifestations evaluated as critical and intense, limiting the tourist use of the beach. The rainfall erosivity, enhanced by technical and organizational deficiencies in the hotel's storm drainage system, the erodability of soil, and the presence of built elements, lead to increased flows towards the beach berm and influence changes in flow velocities. A corrective measures plan was designed to mitigate erosion based on minimizing the stormwater runoff to the beach and good beach management practices. The radical solutions contemplated eliminating the built environment and evacuating rainwater from the roofs for reuse to irrigate green areas. Implementing the proposed measures by beach operators enabled the Ancon Hotel's requalification, reducing the risk caused by natural events, building resilience against natural events, and contributing to the sustainability of tourism in Cuba.

Keywords: *beach, drainage, hydric erosion, runoff, vulnerability.*

1 Introduction

In 2015 United Nations Agenda presented an expansive vision of sustainability focused on the three pillars of sustainable development, which were settled in Sustainable Development Goals (SDGs). Precisely, SDG 11 focus on the necessity of making cities and human settlements inclusive, safe, resilient, and sustainable, including substantially increasing resource efficiency, mitigation and adaptation to climate change, resilience to disasters, and development and implementation of holistic disaster risk management at all levels. Likewise, one goal target of SDG 13 states the strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries [1].

Moreover, the Sendai Framework for Disaster Risk Reduction 2015-2030 outlines seven clear targets and four priorities for action to prevent new and reduce existing disaster risks: (i) Understanding disaster risk; (ii) Strengthening disaster risk governance to manage disaster risk; (iii) Investing in disaster reduction for resilience; and (iv) Enhancing disaster preparedness for effective response, and to "Build Back Better" in recovery, rehabilitation, and reconstruction. It aims to substantially reduce disaster risk and losses in lives, livelihoods and health and the economic, physical, social, cultural, and environmental assets of persons, businesses, communities, and countries [2].

Natural events triggering technological scenarios (Natech events) are generated considerable recent research interest for regulatory authorities and industry, particularly in areas prone to natural disasters. Meteorological events, such as storms, extreme temperatures, and lightning, were the main trigger of Natech scenarios [3]. Among all the typologies of natural disasters, in recent years, the number of hydro-meteorological events is featuring a significant increase and their frequency and severity are expected to grow further due to climate change [4]. Significantly, the number of studies on the topic of hydrological/weather triggered Natech events has been continually growing, a trend that might be attributed, according to experts, to the increasing number of extreme weather phenomena due to climate change [5].

On the other hand, the World Tourism Organization (UNWTO) [6] recognize the necessity of be aware of the current and future economic, social, and environmental impacts, addressing the needs of visitors, the industry, the environment, and the hosting communities, to achieve sustainable tourism. Thus, it should make optimal use of environmental resources that constitute a crucial element in its development, maintaining essential ecological processes and helping to conserve natural heritage and biodiversity. From this, UNWTO recalls the Sendai Framework for Disaster Risk Reduction 2015–2030 to set up the need to promote and integrate disaster risk management approaches throughout the tourism industry, given the often-heavy reliance on tourism as a critical economic driver. Likewise, it underlines the need to foster resilient tourism development, considering the sector's vulnerabilities the emergencies, and to develop strategies for rehabilitation [7].

Due to their location, a large proportion of the global tourism installations are highly exposed and vulnerable to environmental hazards. Tourism involves the interactions of organizations, infrastructure, people, and events in various subsystems. The complexity of this interconnected system and the relatively early stage of tourism disaster studies suggests that a dialogue between tourism and the disaster risk research community could be beneficial to share knowledge and define gaps regarding disruptions affecting the tourism industry [8]. State of the art regarding disasters, tourism, and infrastructure (hotels), has increased over the last 20 years. However, the hotels and sector's disaster preparedness improvements still appear to not be on the same line [9].

The small Island Developing States represent unique destinations where the visitors can enjoy their natural and cultural heritage richness. Nevertheless, many of these islands confront several challenges and vulnerabilities which have increased due to the impacts of climate change - from devastating storms to the threat of sea level rise [10-11]. Expressly, in the Caribbean Island States, beaches represent the primary natural resource the tourism industry uses. Unfortunately, climate change inducing beach erosion is one of the coastal systems' most severe impacts. In addition to marine dynamics, precipitation, and river flow can significantly alter beach erosion/accretion patterns [12].

In Cuba, over 89 % of the beaches show signs of erosion [13-15]. Numerous research in recent years has found the beaches in Cuba needed to counteract erosion processes and past human responses to prevent/slow down erosion processes. Moreover, beach erosion causes degradation and the emplacement of rigid, disorganized protection structures. In this sense, coastal structure dismantlement and beach nourishment represent proactive responses and have been carried out with good results in several areas devoted to local and national visitors [16-19]. Since this problem represents a national priority established in the Cuban State Plan to Confront Climate Change [20], the identification of existing vulnerability and the undertaking of actions to reduce it, represent an explicit national necessity, as well as the recovery of beaches.

Given all above, this paper focused on the hydric erosion in touristic beaches influenced by extreme rainfall events. Specifically, in this report is presented the contribution of one hotel's storm drainage system to the hydric erosion in the hotel's beach sector and its mitigation. The study case corresponds to the Ancon Hotel located in the Ancon Peninsula, which is one of Cuba's main poles of sun and beach tourism. It is a narrow projection of land on the south marine platform of the city of Trinidad and is formed by deposits of biogenic sands that make up about 3 900 linear meters of the beach with the same name. Owing to its geographical location and geological and hydrometeorological characteristics, it is a region prone and vulnerable to natural adverse events.

2 Material and Method

The procedure for the eight-step in solving a problem [21] was partially used. It consists of a methodology, inspired by the PDCA (plan-do-check-act) cycle, adapted to the hydric erosion in the hotel's beach sector as described below:

Step 1: Selecting and characterizing a problem (Planning Stage)

— Hydrographic characterization

A preliminary study of the hydrography of the study area was carried out through desk and fieldwork. The criteria established by González and Suárez [22] will be used, which include physical-geographical and anthropic characteristics: location and shape; geological formations, soil types and vegetation cover; buildings and hydraulic works; and morphometric parameters.

— Background studies of engineering research

A documentary review of the engineering studies carried out on the Ancon Peninsula was carried out.

— Study and survey of relief, soil, and vegetation information.

Six strata were defined according to the homogeneity of relief, soils, vegetation, and cover. The topographic map scale 1:25000 was used to study the relief and geomorphological characteristics of the area of interest. A topographic survey was also carried out on a scale of 1:500. The soils of the green areas were studied by visual examination and the execution of simple manual tests according to the Cuban technical standard NC 61:2000 [23]. The soil infiltration rate was determined according to RC-9005:2001 [24]. Likewise, the criteria established by González and Suárez [22] and the Cuban technical standard NC 700:2010 [25] were used to estimate soil erodability according to the relief, the kind of vegetation, and the soil type and permeability. The vegetation was surveyed according to González and Suárez [22], including trees, herbaceous species, and the level of soil cover.

— Assessment of erosion evidence in the emerged beach area.

The erosive evidence was identified during the rainy season using the qualitative method, recommended for preliminary and diagnosis studies [26-27]. During the identification processes, some characteristics as geographic coordinates, photographs, and dimensions (length, depths, and maximum widths) were taken. In cases of hydric clues, the classification was done according to established criteria [28-29], that implemented an ordinal scale with four categories: mild, medium, intense, and critical.

— Identification and description of the existing storm water collection, evacuation, and disposal system (SWCEDS).

Topographic maps with contour lines were interpreted to identify the drainage network, landforms, and relief designations. Due to the limited technical information on projects and plans of the hotel, the identification and description of the SWCEDS were made during the fieldwork, defining four subsystems: A, B, C and D.

— Review of SWCEDS status, functionality, operating conditions, and maintenance.

The requirements established in regulations and technical manuals were analyzed. Likewise, Cuban technical standards related to the design of storm drainage systems were used: NC 600:2008 [30], NC 683:2009 [31], NC 770:2010 [25], NC 775-13:2020 [32]. Moreover, the infiltration rate of wells was determined according to RC-9005:2001 [24] and diagnosed according to the criteria proposed in MINVU [33]. Finally, the existing maintenance conditions of the system were inspected.

— Definition of drainage sectors and hydrological calculations

The erodability of rainfall depends on the magnitude or sheet of water, intensity, and frequency [22].

The natural drainage network was divided by exhaustive sections of runoff, given by the topography characteristics, and confirmed from direct observation in the presence of rainfall events. Furthermore, the runoff contribution areas were measured in fieldwork.

The Rational Method was implemented for the hydrological calculation as described by the Cuban technical standard NC 770:2010 [25] and González and Suárez [22].

Subsequently, the rainfall intensity was estimated using the isoyetic map of maximum daily rainfall for 1 % probability and the calculation nomogram for different probabilities and duration times of the Cuban Republic. The following scenarios were studied in accordance with recomendations in the established regulations:

- Scenario 1: A 20 % probability of rainfall (5-year return period), and duration time of 10 minutes, according to the Cuban technical standard NC 775-13: 2020 [32]. A rainfall intensity of 1.83 mm/min was estimated.

- Scenario 2: A 5 % probability of rainfall (20-year return period), and duration time of 5 minutes, established according to the degree of protection to be provided to the facility, considering the category of the work and the ecological damage to which it may give rise, according to NC 600:2008 [30]. A rainfall intensity of 3.1 mm/min was estimated.

The runoff coefficient (C) is a dimensionless value that establishes the fixed relationship between the rainfall rate for the drainage inter basin and the surface and subsurface runoff. It was estimated according to the criteria established by the Cuban technical standards NC 600:2008 [30], NC 770:2010 [25], NC 775-13:2020 [32], and González and Suárez [22].

Some of the techniques and tools used were: direct observation, interviews, and a checklist. Global Mapper 11.02, Autodesk AutoCAD 2016, Google Earth Pro 7.1, and MapInfo Pro 16.0 software were used, ArcGIS Pro.

2.1 Step 2: Search for all possible causes (Plan Stage)

For the determination of water erosion causes in the emerged area of the beach sector, qualitative and quantitative criteria from the background of engineering research mentioned in Step 1 were considered.

The cause-effect diagram was used as a graphic method that relates the problem with the factors which possibly generate it [21].

2.2 Step 3: Investigate which causes are most important (Plan Stage)

The selection was based on qualitative and quantitative criteria according with the above-mentioned background of engineering research. The Failure Mode and Effect Analysis (FMEA) described by Gutiérrez and De La Vara [21] was used.

2.3 Step 4: Elaborate a plan of measures focused on remedying the most important causes (Plan Stage)

Then, a corrective action plan was developed, with a scope of conceptual ideas to mitigate the hydric erosion caused by extreme rainy events, detailed according to the proposal of Gutiérrez and De La Vara [21]. The validity of the measures was corroborated from the simulations of the rainfall scenarios defined in Step 1, where the mitigation of rainwater load was considered.

2.4 Steps 5, 6, 7 y 8: Implementation of the countermeasures (Do Stage), Check the obtained results (Check Stage), Prevent recurrence, and conclude (Act Stage).

Steps 5, 6, 7 and 8 (Execute remedial measures; Review results obtained; Prevent recurrence; and Conclude) were proposed to the decision makers of the hotel owner and operator.

3 Results and discussion

3.1 Step 1: Selecting and characterizing a problem

— Hydrographic characterization

The study confirmed that the natural hydrography of the study area was considerably modified by the construction of the hotel and access roads.

— Background studies of engineering research

As far as it concerns, the lithological characterization of the natural soils before the intervention on the plot for the hotel's construction showed an upper stratum of medium-grained calcareous sand, varying from 2.20 to 3.60 meters. Likewise, the studies confirmed the anthropic modifications to which the field was subjected, with the gravelly-sandy fill material, compact and of variable thickness used in the terrace.

— Study and survey of relief, soil, and vegetation information

The satellite image of the study area (Figure 1) shows the proximity of the hotel buildings to the emerged area of the beach (berm), separated only by a longitudinal strip of green areas with small squares and stairs for access to the beach. The six strata into which the study area was divided can also be appreciated.

Figure 1. Ancon Hotel and beach sector. Representation of the defined strata.

Source: Own source.

First, the relief of strata 1, 2 and 3 were classified as hilly and undulating. Moreover, the average slopes were between 5 % and 15 %, reaching 25 % in stratum 1. The rest of the strata were classified as flat, with less than 5 % slopes.

Second, high variability of grass cover for each stratum was constated. For instance, the stratum 2 constituted less than 10 % of the surface, while the rest of the strata have covered between 50 % and 90 %. In general, the type of existing turf is inadequate and lacks an artificial irrigation system, which is aggravated by poor maintenance practices.

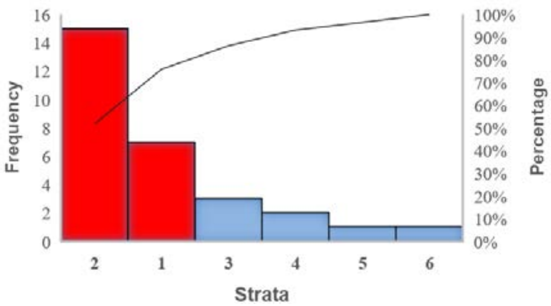
On the other hand, the soil characteristics are according with the characteristics of the borrowed materials used in the hotel's infill terrace. Therefore, it was not very permeable, its softness, compactness and slightly plasticity, restricting the infiltration capacity.

Finally, the results of the infiltration tests show that the soil has a relative absorption average (infiltration index of 12.08 min), comparable with soils of the fine-grained sand, silt, sand, silt and clay mixture and stratified clay types.

— Assessment of erosion evidence in the emerged beach area.

In the Ancon Hotel beach emerged area (berm) considerable predominates the hydric erosion, in correspondence with the characteristics and factors reported in the literature [26-29]. The Pareto diagram in Figure 2 illustrates the absolute frequency of the erosive evidence recorded in each stratum (left vertical axis) and the accumulated percentage concerning the factual evidence that appeared in all the strata (line above the bars). As could be appreciated, over the 75 % erosion evidence was concentrated in strata 1 and 2 (southwest sector of the main building). In these strata, the presence of several rigid build elements was observed, such as the extra hotel point of sale, hotel platforms, terraces, stairs, concrete walkways in the green area of the hotel, concrete slabs, hoses, and surface pipes in the emerged area of the beach, as well as the longitudinal retaining wall contiguous to the green area of the hotel and the emerged area of the beach.

Figure 2. Pareto diagram for erosional evidence. Analysis by strata.



Source: Own source.

As far as it concerns with what has been discussed, strata 1 and 2 coincide with a rugged relief, a woodland with a superficial root system and poor vegetation. Figure 3 shows some of the evidence detected.

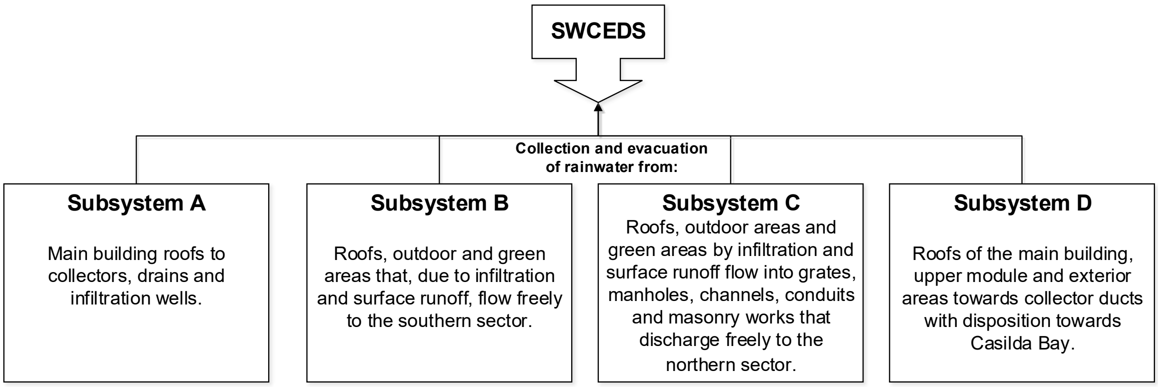
Figure 3. Sample of hydric erosion evidence in the berm, and green areas adjacent to strata 1 and 2.

Source: Own source.

— Identification and description of the storm water collection, evacuation, and disposal system (SWCEDS).

The rainwater collection, evacuation, and final disposal system at Ancon Hotel is of the conventional separate type, with four basic subsystems consisting of natural drainage elements and collection, evacuation, and infiltration works. There is no segregation and reuse of this water. Figure 4 shows its main subsystems.

Figure 4. Schematic representation of the storm drainage system of Ancon Hotel.



Source: Own source.

— Review of SWCEDS status, functionality, operating conditions, and maintenance

Numerous shortcomings were detected in the design, operation, and maintenance of the SWCEDS. In addition, inadequate practices were observed that affect the poor functioning and operation of the system, which have repercussions on the intensification of erosive processes. A crucial issue detected was that the effective infiltration areas of the four wells in subsystem A, were significantly lower than those required for the operating conditions evaluated and do not meet the recommended design requirements [33].

With a glace to the Figure 5, could be appreciated that filter beds were silted and filled with trash, soil, and sediment carried away by runoff from outside or covered areas. Regarding these issues, joint to the fact of plant rooting inside the filter beds the infiltration capacity of the wells was sensibly decreased with slow relative absorption (infiltration rate of 3.21 min).

Figure 5. Evidence of technical and maintenance deficiencies in the infiltration works.

Source: Own source

— Definition of drainage sectors and hydrological calculations

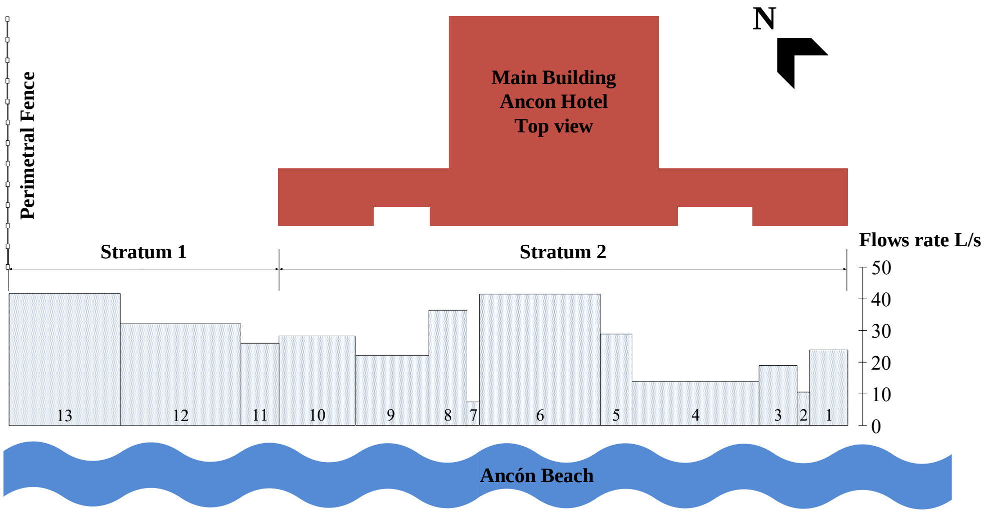
Thirteen runoff sections were identified in the natural drainage network for strata 1 and 2. Figure 6 shows a sketch of these strata, including the main building Ancon Hotel top view, as well as the surface runoff flows rate that reach the berm in each runoff section. This flow rates, were estimated for the rainfall scenario 2 (defined as the most critical) and were plotted proportionally to the length of each runoff section on the ground.

From the analysis of the figure can be realized the high flows that reach the emerged area of the beach in the strata 1 and 2, which are also the most damaged. In this sense, the Table 1 offered the association of the erosive evidence to the runoff sections, the gullies in each section and their categories. As c

It is important to highlight that critical gullies were identified in all sections except sections 11 and 13. The sections that showed larger numbers of gullies was corresponding to the ones with the highest flows rates (approximately the 54 % of the total reaching the emerged beach area). On the other hand, the section 7 offered results due to having the lowest flow, it was associated with two critical gullies. In this case were found the flow changed the natural patron increasing the velocity because of the effect of constructed elements.

Moreover, resulted evident the association among the number and categories of gullies, the runoff flow rates and other factors such as relief, grass cover, soil infiltration and build elements. The combination of the above factors and the high flow rates modify the laminar flow patterns, creating interceptions and turbulence effects that favor the increase in runoff velocity and the appearance of the phenomenon of water erosion.

Figure 6. Sketch of the southwest sector of the Ancon Hotel (strata 1 and 2). Estimated flows reaching the beach berm in the 13 runoff sections for rainfall scenario 2.



Source: Own source.

The figure shows the high flows that reach the emerged area of the beach (berm) in strata 1 and 2, which are also the most eroded. In this sense, it was convenient to associate their erosive evidence to the runoff sections represented in the previous figure. Table 1 shows the existing gullies in each section and the categories into which they were classified.

Table 1. Classification of erosional evidence associated with runoff sections.

Sections / Categories	13	12	11	10	9	8	7	6	5	4	3	2	1	Total
Slight	1	1	1											3
Medium	1	1												2
Intense	1													1
Critic		1		1	1	2	2	3	2	1	1	1	1	16
Total	3	3	1	1	1	2	2	3	2	1	1	1	1	22

Source: Own elaboration.

In summary, the relief of sections 13 to 11 is rugged, with slopes of up to 26 %. There is little grass cover in sections 10 to 1 (less than 10 % of the surface), and the trees present have superficial rooting. As previously discussed, the soil had a medium infiltration capacity, with the presence of constructed elements such as small squares, stairs, sidewalks, walls, and surface pipes.

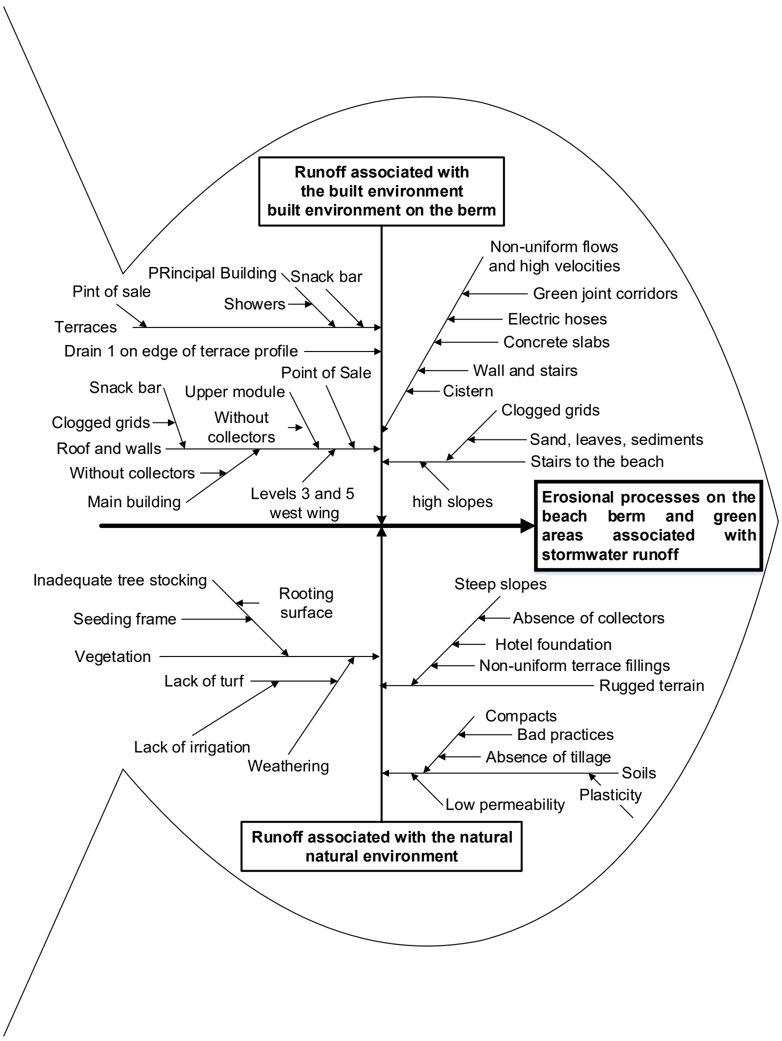
Regarding the estimated flows that reach the berm, it can be added that the hotel does not reuse rainwater and there is potential for rainwater harvesting in the order of 13 523.10 m^3/year. It is important to remark that the previous value resulted higher than the estimated water demand for irrigation of the hotel's green areas (11 679.00 m^3/year). Therefore, the reuse alternative represents an equivalent saving of potable water currently used to irrigate the gardens.

Furthermore, the water reusing represented that the hotel would no longer incur an economic expense of USD$18 102.45/year for water supply and services. This is a viable alternative, considering the presence of a water storage tank for reuse, distribution networks, and irrigation system accessories, although they are no longer in use.

3.2 Step 2: Search for all possible causes

This analysis contributed to characterize causes up to the sixth order in the SWCEDS subsystems, responsible for the erosive processes characterized in all strata. Figure 7 illustrated the causes identified for subsystem B, which was one of the most critical and representative.

Figure 7. Identification of the causes that aggravate erosive processes of water origin, Subsystem B.



Source: Own source.

3.3 Step 3: Investigate which causes are most important

The risk priority level obtained from the FMEA allowed to prioritize the list of possible causes detected in the previous point. In consequence, deficiencies in the design, operation, and maintenance of the Ancon Hotel SWCEDS; together with the state of the relief, soil, vegetation, and the presence of constructed elements were the main causes.

3.4 Step 4: Elaborate a plan of measures focused on remedying the most important causes

A corrective measures plan was proposed with 69 solutions, classified as palliative or radical (33 and 36 measures respectively). They were based on prevent or mitigate the stormwater runoff to the berm; and on applying good management practices and exploiting the hotel's stormwater drainage system and the emergent area of the beach [34].

The radical solutions firstly included the elimination of the elements built in the southwest sector of the Ancon Hotel. Secondly, involved the use hanging collectors to evacuate the rainwater from the roofs to a cistern for the reuse in the irrigation system of green areas. Finally, considered the beach profile rehabilitation and the protection zone in the hotel southwest sector.

Palliative solutions consist of relief leveling, soil tillage, turf improvement, technological improvements in the infiltration wells and the construction of infiltration ditches, and collectors. The infiltration trenches were also considered as a palliative solution according with its application in similar study case [35].

The validity of the measures was corroborated from the simulation of the rainfall scenarios defined in Step 1, where the prevention or mitigation of rainwater input was considered. Then, it was corroborated that runoff can be reduced to only the rainfall inputs on the beach profile if the remedial action plan were implemented. Therefore, the comprehensive package implementation contributes to enhance the preparedness and resilience, even facing an extreme event as intense rains and hurricanes, which are undergoing an increase due to climate change effects [36].

4 Conclusions

First, the procedure constitutes a valuable methodological instrument which can be generalized for diagnosing storm drainage systems and, especially, to evaluate how they contribute to erosive processes on beaches, coastal areas, and soils.

Second, it was confirmed that the Ancon Hotel and its beach sector, due to its geographic location and geological and hydrometeorological characteristics, are in a fragile ecosystem, highly vulnerable to natural phenomena such as heavy rains and hurricanes. The previous situation, combined with the deficiencies in the design and operation of the hotel's storm drainage system, increases the vulnerabilities in the berm of the beach caused by hydric phenomena, with negative impacts on the ecosystem, the hotel's image, and the tourism enjoyment, typifying disruption caused by natural events.

Third, it was demonstrated that the erosivity of the rain, intensified by the lack of water segregation, together with technical and organizational deficiencies in the rain drainage system, originate high runoff flows on the ground and the emerged area of the beach. Likewise, the erodibility of the terrain and the built elements increased flow velocities and favors the appearance of the phenomenon of hydric erosion.

Moreover, the solutions proposed were based on minimizing stormwater runoff to the berm; and on applying good management and operation practices for the hotel's stormwater drainage system and the emergent area of the beach. The simulation after implementing the package of solutions, showed a considerable runoff reduction. Consequently, the vulnerability of the Ancon Hotel beach facing extreme storm events was mitigated.

Finally, the implementation of the proposed measures by beach operators enabled the Ancon Hotel's requalification, reducing the risk caused by natural events, building resilience against natural events, and contributing to the sustainability of tourism in Cuba.

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Conclusions

The 61th ESReDA Seminar had the aim to start collecting the scientists involved in the analysis of NaTech and the related impacts on infrastructures (energy, industry and more widely territories).

The capability of managing the risks associated with NaTech events and coping with their impact is a part of the resilience of complex systems.

Linking to the 60th ESReDA Seminar on Advances in Modelling to Improve Network Resilience, final moment of the ESReDA project group titled 'Resilience Engineering and Modelling of Networked Infrastructure" we think we have added a piece of the puzzle in the resilience assessment domain, considering the risk assessment of NaTech events and the coping capacity of systems in case of accidents triggered by natural events.

The seminar highlighted the presence of a multi-faceted and multi-disciplinary group of scientists working on the subject that will be able to contribute to further works in the field, also within ESReDA activities.

Appendix

61st ESReDA Seminar On

Technological disruptions triggered by natural events: identification, characterization, and management

September 22nd – 23rd, 2022, Politecnico di Torino, Lingotto building, Torino, Italy

PROGRAM

1st DAY: SEPTEMBER 22nd

8.45- 9.45	Registration
9.45-10.00	Welcome and opening
10.00-11.00	KEYNOTE LECTURE **Resilience as capacity: a proposed approach** Marcelo Masera, former Head of Unit "Energy Security, Distribution and Markets" at the JRC, Politecnico di Torino, Italy
11.00-11.30	Coffee Break
11.30-12.10	**Resilience indicators for a power grid with focus on natural hazards** Georgios Karagiannis, Bogdan Vamanu, Elisabeth Krausmann and Vytis Kopustinskas
12.10-12.50	**A monitoring-based management approach for Natech-related risks: reflection from a case study** Emmanuel Plot, Yann Balouin, Sophie Ferreira, Marine Boutillon, Vass-ishtasaï Ramany, Eric David, Maria Chiara Leva, Micaela Demichela and Thomas Marcon
12.50-13.30	**Including natural events in dynamic risk assessments. A case study on landslides.** Tomaso Vairo, Stefania Magri and Bruno Fabiano
13.30-14.30	Lunch
14.30-15.10	**Na-Tech Risk: a New Challenge for Local Planners.** Eleonora Pilone, Micaela Demichela and Gianfranco Camuncoli
15.10-15.50	**Autonomous Mobile Robot (AMR) operating in internal material handling systems – problems of obstacle detection in various operational conditions** Alicja Dabrowska, Robert Giel and Sylwia Werbińska-Wojciechowska
15.50-16.30	**A Game for Simultaneous Risk and Resilience Optimization** Sandra König, Stefan Rass and Stefan Schauer

16.30-17.00	Coffee Break
17.00-19.00	ESReDa Board of Directors
20.00	Gala Dinner

2nd DAY: SEPTEMBER 23rd

10.00-11.00	KEYNOTE LECTURE **Advances in the management of NaTech events** Valerio Cozzani, Full Professor, Università di Bologna
11.00-11.30	Coffee Break
11.30-12.10	**Development of fragility models to support security vulnerability assessment in the framework of multi-risk analyses** Giulia Marroni, Gabriele Landucci, Andrea Bartolucci, Sanneke Kuipers and Wout Broekema
12.10-12.50	**Ecological Functionality and Landscape Sensitivity Assessment for Territorial Resilience and Sustainability** Luigi La Riccia & Angioletta Voghera, Politecnico di Torino – DIST Department
12.50-13.30	**Cascading Failures and Basic Service Disruptions - a Critical Infra-structure Perspective on Compound Events** Evelyn Mühlhofer, Elco E. Koks and David N. Bresch
13.30-14.30	Lunch
14.30-15.00	KEYNOTE LECTURE **Impact of Natech's to SE Med Critical Infrastructure** (distance presentation) George Boustras, CERIDES Director, European University, Cyprus
15.00-15.40	**Hydric erosion in touristic beaches influenced by extreme rainfall events on the built infrastructure: case Hotel Ancon, Cuba.** Omar Gutiérrez Benítez and David Javier Castro Rodriguez
15.50-17.00	Closure & announcement of the 62nd ESReDA seminar & Farewell coffee break

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