Risk assessment for the future: challenges and directions for the research

LASAR[3]

Laboratory of Analysis of Systems for the Assessment of Reliability, Risk and Resilience

Prof. Francesco Di Maio

POLITECNICO MILANO 1863 | DIPARTIMENTO DI ENERGIA

Risk Assessment: A “knowledge exercise”

Accident Scenarios

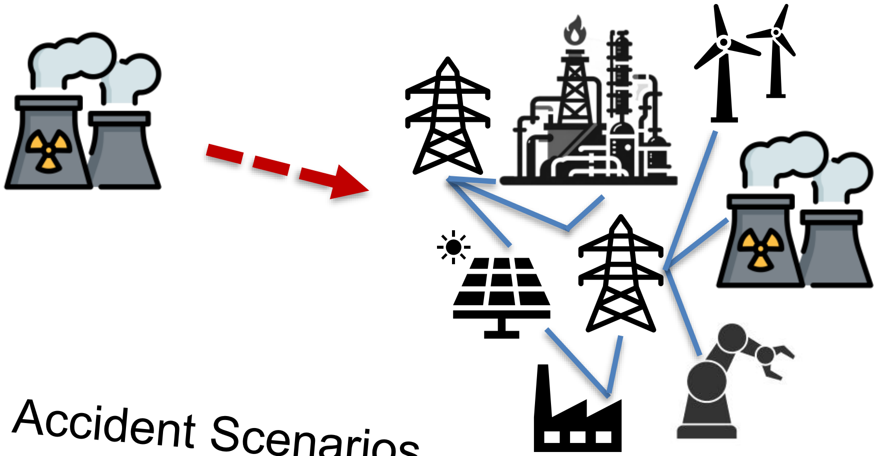
Knowledge

$$\boldsymbol{Risk} = (\mathbf{A}, \mathbf{C}, \mathbf{P} \mid \mathcal{K})$$

Consequences

Probability

Risk Assessment: A "knowledge exercise"



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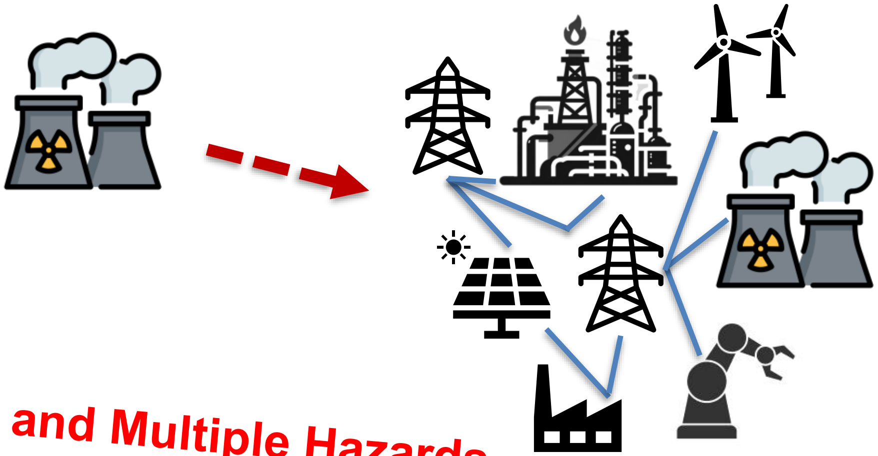


New and Multiple Hazards

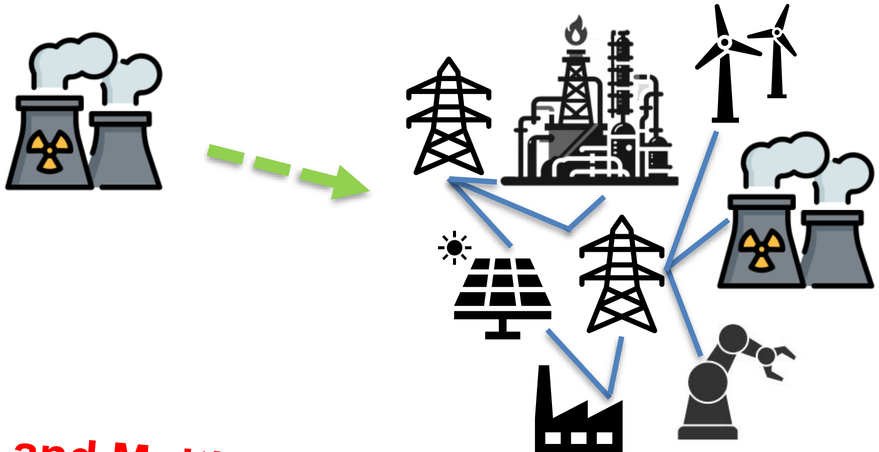
Knowledge

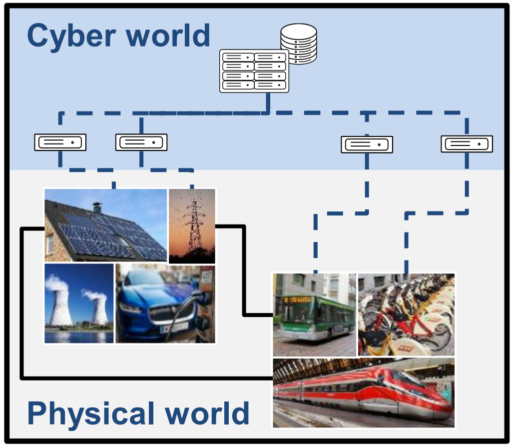
$$\boldsymbol{Risk} = (\mathbf{A}, \mathbf{C}, \mathbf{P} \,|\, \mathcal{K})$$

Consequences

Probability

Risk Assessment: directions for the research





New and Multiple Hazards

Cyber threats

$$Risk = (A, C, P \mid \mathcal{K})$$

W. Wang, F. Di Maio, E. Zio, "*Considering the human operator cognitive process for the interpretation of diagnostic outcomes related to component failures and cyber security attacks*", Reliability Engineering and System Safety, Volume 202, October 2020, 107007.

F. Di Maio, R. Mascherona, E. Zio, "*Risk analysis of cyber-physical systems by GTST-MLD*", IEEE Systems Journal, pp. 1333-1340, vol. 14, no. 1, March 2020.

W. Wang, F. Di Maio, E. Zio, "*Adversarial Risk Analysis to Allocate Optimal Defense Resources for Protecting Nuclear Power Plants from Cyber Attacks*", Risk Analysis, 39(12), pp. 2766-2785, 2019.

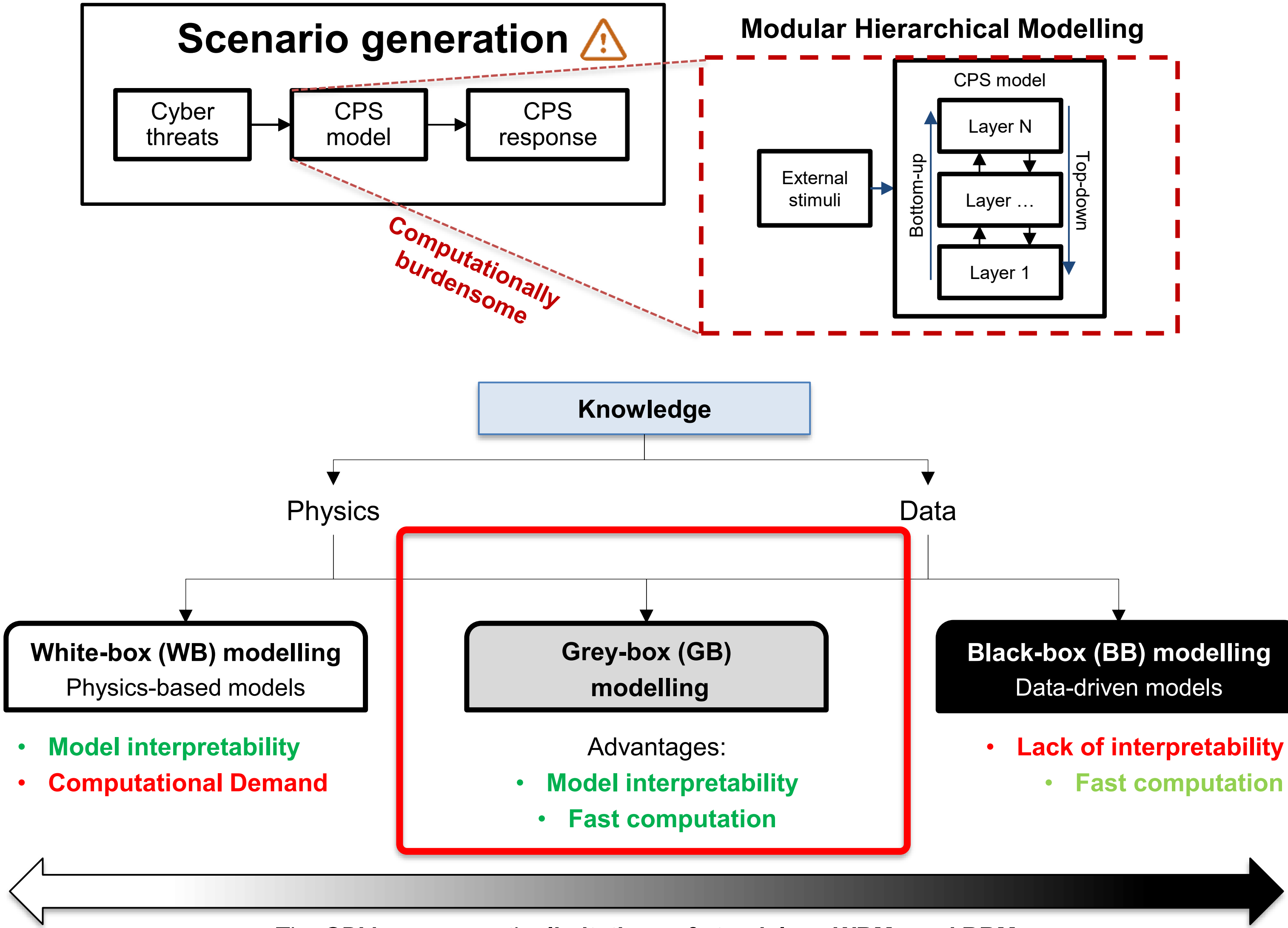
J. P. Futalef, F. Di Maio, E. Zio, "*A dynamic importance function for accidental scenarios generation by RESTART in the computational risk assessment of cyber-physical infrastructures*", Reliability Engineering and Systems Safety, 2025.

J.P. Futalef, F. Di Maio, E. Zio. *Value-of-Information-based Optimization of Grey-Box Models for Computational Risk Assessment of Cyber Physical Systems, 2025.*

J. P. Futalef, F. Di Maio, E. Zio, "*A Methodology for Developing Grey-Box Models for Cyber-Physical Systems Reliability, Safety and Resilience Assessment*", ESREL2022, Dublin, Ireland, 28th August - 1st September 2022.

A: New and Multiple Hazards

Cyber threats scenarios: Computational Risk Assessment by Grey Box Models (GBMs)

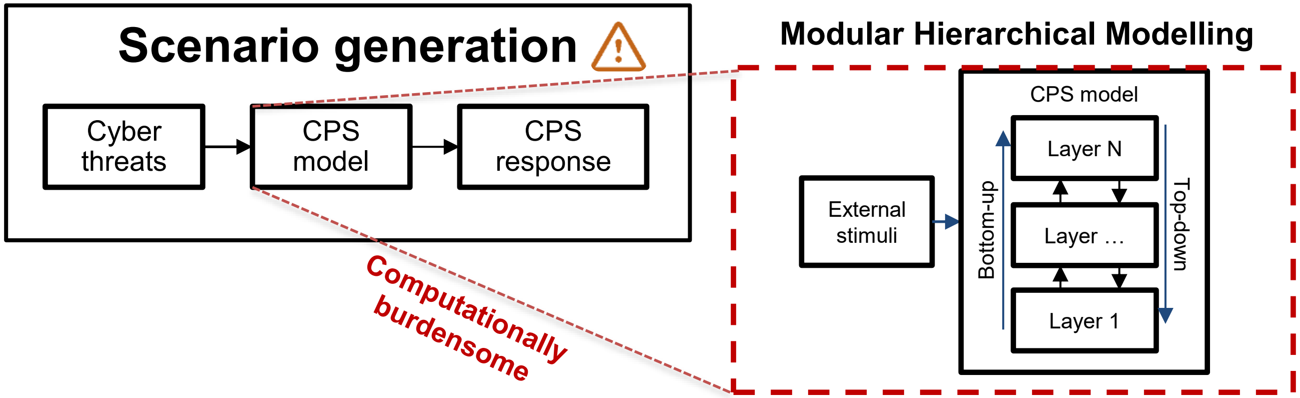


The GBM overcomes the **limitations of standalone WBMs and BBMs**

The GBM offers a tailored trade-off between **accuracy, computational burden, and model interpretability**

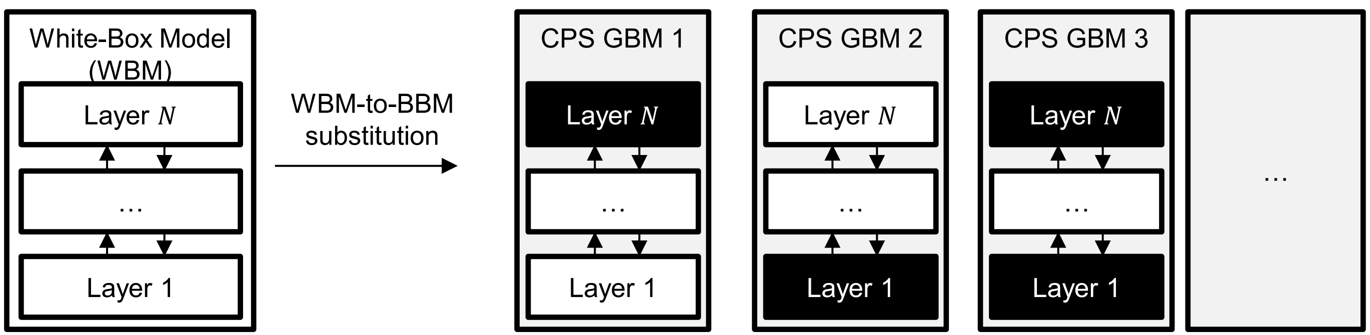
A: New and Multiple Hazards

Cyber threats scenarios: Computational Risk Assessment by Grey Box Models (GBMs)



Grey-Box Models (**GBM**) leverage first principles and monitored data for lowering computational burden

$2^N - 1$ GBM alternatives



✓ Modular
✓ Interpretable
✓ Fast

How to select the best alternative?

Optimal Substitution Plan Problem **(OSPP)**

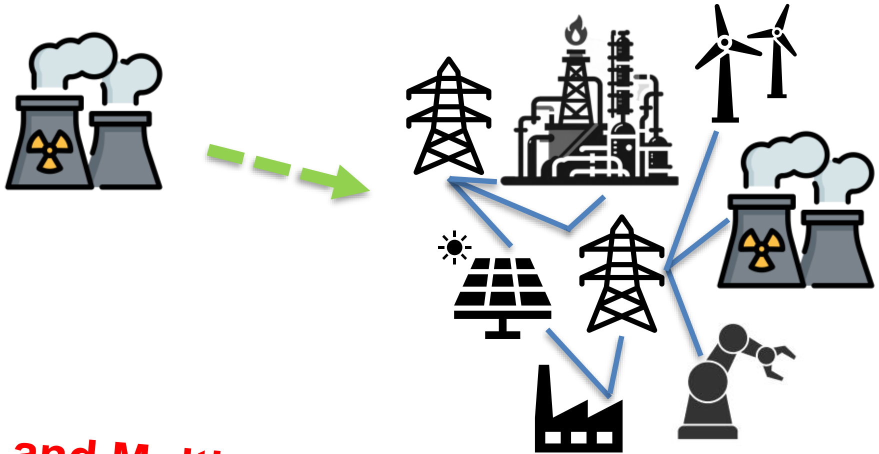
Value-of-Information (VoI) quantifies loss improvement of making decision S with respect to reference $\emptyset$:

$$\mathrm{VoI}(S) = \mathbb{E}\{L_\emptyset\} - \mathbb{E}\{L_S\}$$

Losses: L_1: Computational load, L_2: Lack of fit
Decision: GBM architecture

J.P. Futalef, F. Di Maio, E. Zio. (2025). *Value-of-Information-based Optimization of Grey-Box Models for Computational Risk Assessment of Cyber Physical Systems.*

Risk Assessment: A “knowledge exercise”



New and Multiple Hazards

Cyber threats

Climate change

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M. Vagnoli, F. Di Maio, E. Zio, “*Ensembles of climate change models for risk assessment of nuclear power plants*”, Proceedings of the Institution of Mechanical Engineers, Part O: Journal of Risk and Reliability, Vol. 232(2) 185–200, DOI: 10.1177/1748006X17734946, 2018.

F. Di Maio, S. Morelli, E. Zio, “*A Simulation-Based Framework for the Adequacy Assessment of Integrated Energy Systems Exposed to Climate Change*”, Handbook of Smart Energy Systems, Editors Mahdi Fathi, Enrico Zio and Panos M. Pardalo, Springer Nature, 2022.

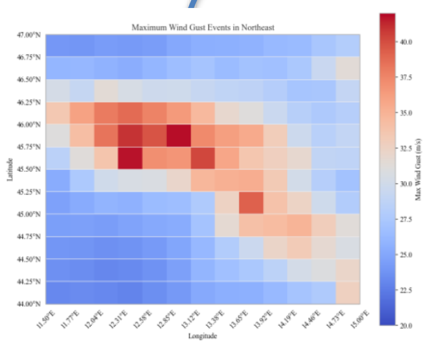
F. Di Maio, M. Belotti, Manuela Volpe, Jacopo Selva, E. Zio, ”*Parallel density scanned Adaptive Kriging to improve local Tsunami Hazard Assessment for coastal infrastructures*”, Reliability Engineering and System Safety, 2022, 222, 108441.

P. Asaridis, D. Molinari, F. Di Maio, F. Ballio, E. Zio, “*A probabilistic modelling and simulation framework for power grid flood risk assessment*”, International Journal of Disaster Risk Reduction, 2025

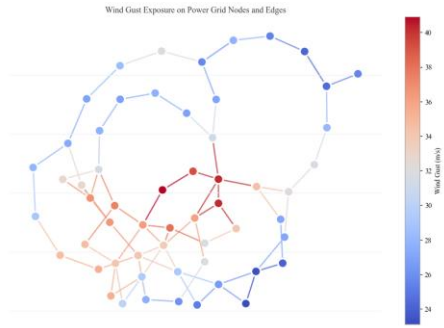
T. M. Coscia, F. Di Maio, E. Zio, “*A Modelling Framework to Analyze Climate Change Effects on Radionuclide Aquifer Contamination*”, Journal of Contaminant Hydrology, 2025.

A: New and Multiple Hazards
Natual Hazards scenarios: Computational Risk Assessment by Stochastic Fields and Input-Output Inoperability Modelling

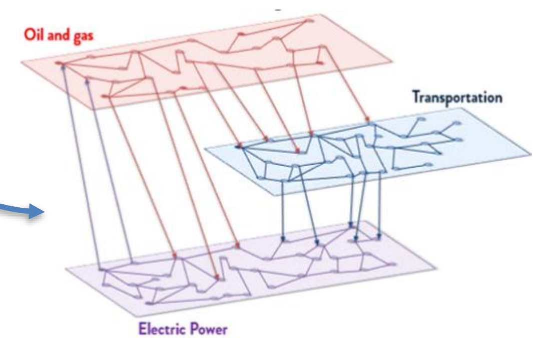
Natural hazards analysis



Spatial modeling of natural hazards



Hazard impact analysis on the critical infrastructure



Performance assessment of interdependent critical infrastructures

M.V. Clavijo Mesa, F. Di Maio, E. Zio, *“Dynamic Inoperability Input-Output Modeling of a System of Systems Made of Multi-State Interdependent Critical Infrastructures”*, 2025

A: New and Multiple Hazards

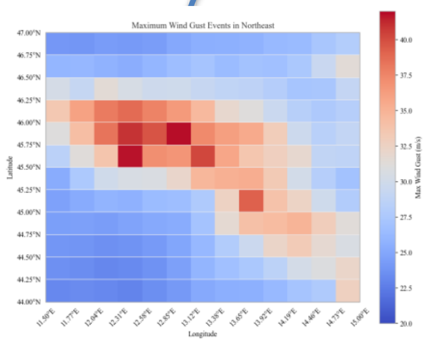
Natual Hazards scenarios: Computational Risk Assessment by Stochastic Fields and Input-Output Inoperability Modelling

Historical data

Geographical data

Natural hazard analysis

Statistical description of environmental variable



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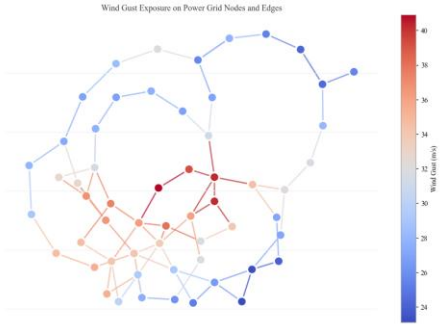

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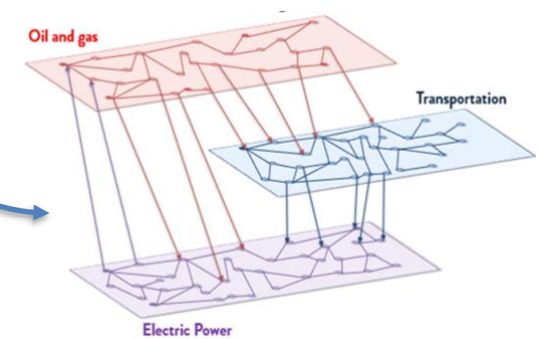

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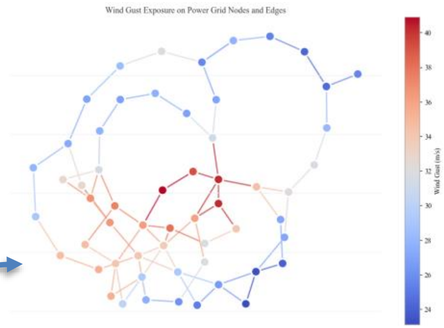
Statistical description of environmental variable

Stochastic field generation

CI topology

SF of the environmental variable across the grid



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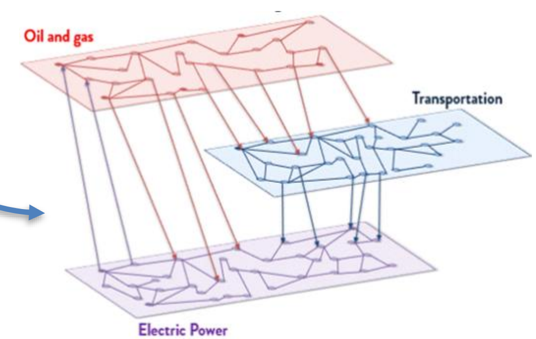

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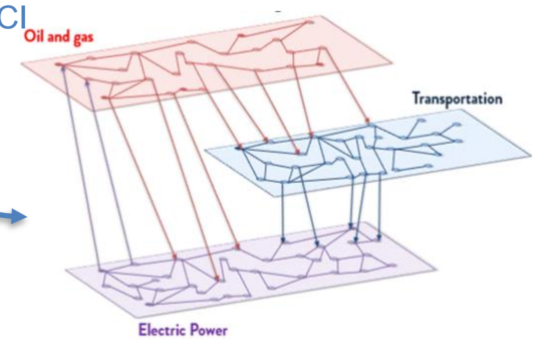
Fragility curves for elements of CI

Hazard impact analysis on the critical infrastructure

Failure probability for the elements of the CI



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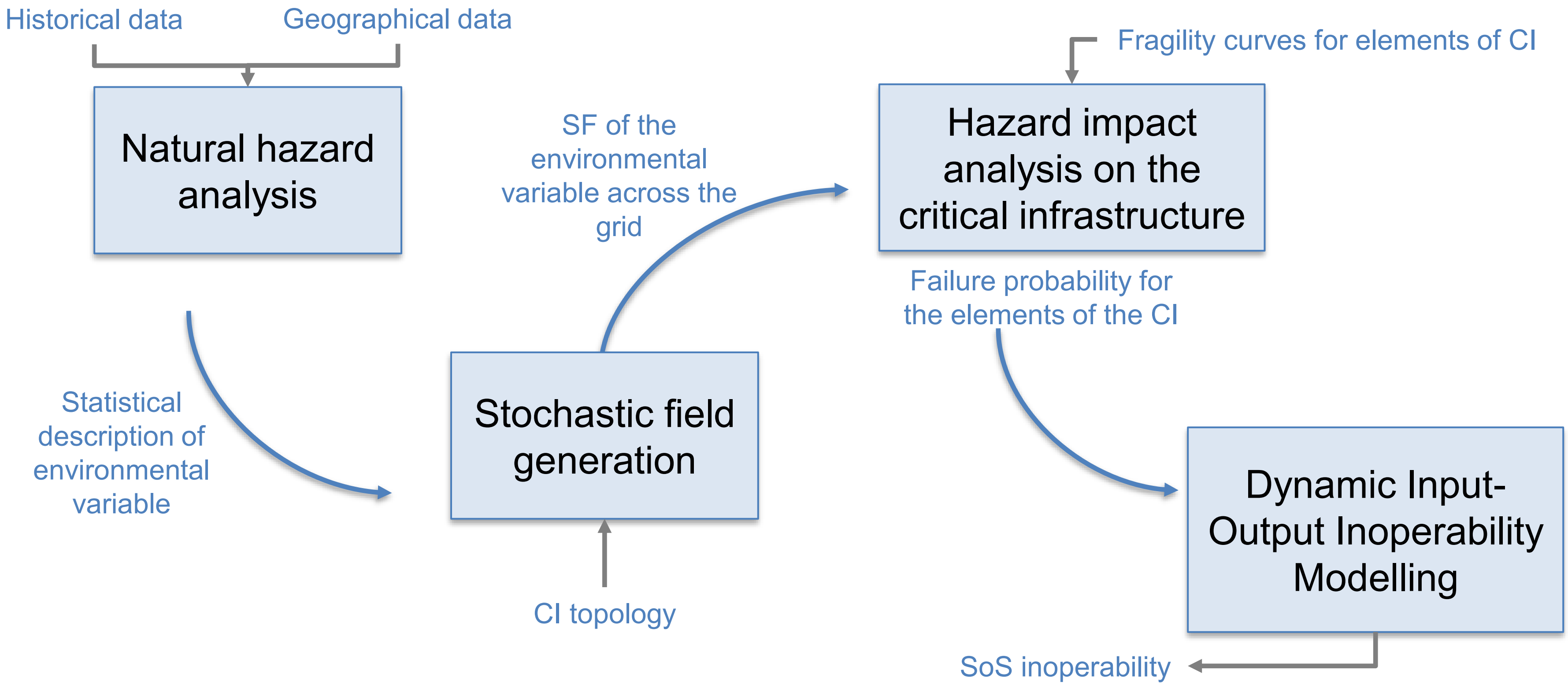

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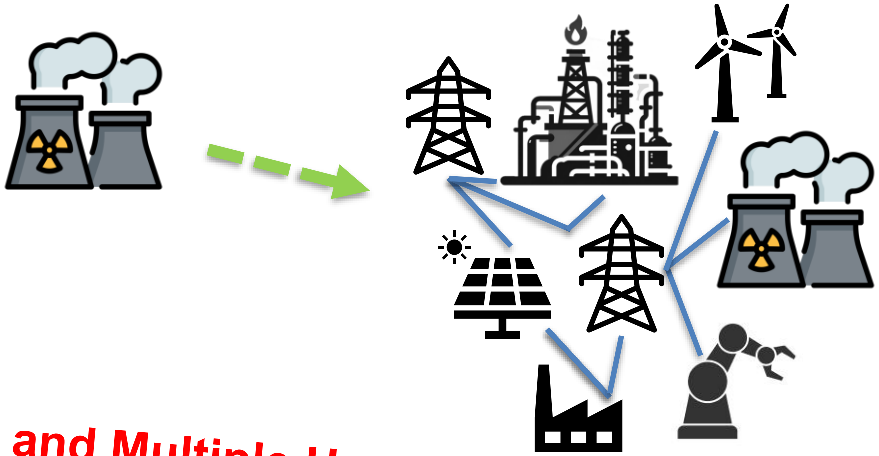
Risk Assessment: A "knowledge exercise"



New and Multiple Hazards

Cyber threats

Climate change

$$Risk = (A, C, P \mid \mathcal{K})$$

Complexity and Computation

Artificial Intelligence

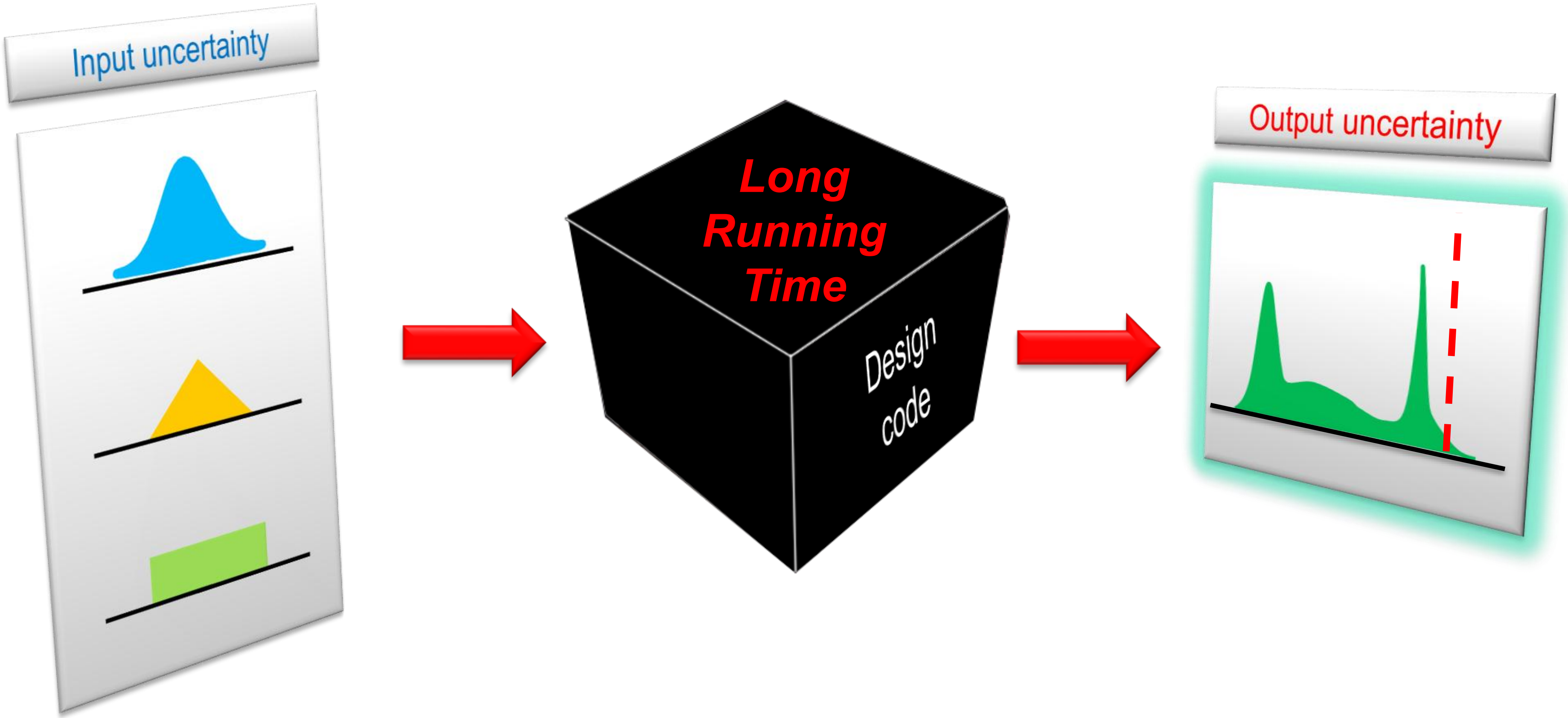
E. Zio, and F. Di Maio, "*Bootstrap and Order Statistics for Quantifying Thermal-Hydraulic Code Uncertainties in the Estimation of Safety Margins*", Science and Technology of Nuclear Installations, Volume 2008 (2008), Article ID 340164, 9 pages, doi:10.1155/2008/340164.

E. Zio, F. Di Maio, S. Martorell and Y. Nebot, "*Neural Networks and Order Statistics for Quantifying Nuclear Power Plants Safety Margins*", Safety, Reliability and Risk Analysis, Taylor & Francis Group, London, ISBN 978-0-415-48513-5, proceedings of ESREL 2008 Conference, Valencia, Spain, September 2008.

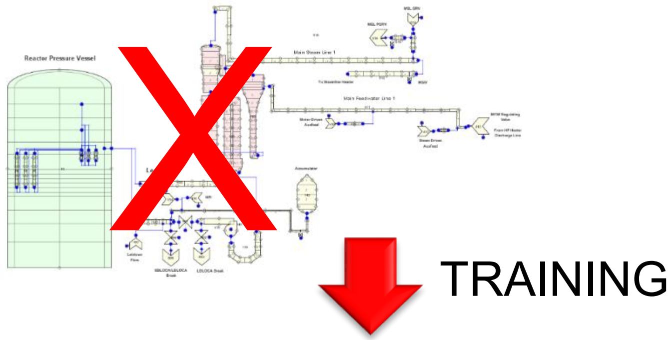
Zio, E., *A study of the bootstrap method for estimating the accuracy of artificial neural networks in predicting nuclear transient processes*. IEEE Transactions on Nuclear Science, 53(3), 1460-1478, 2006.

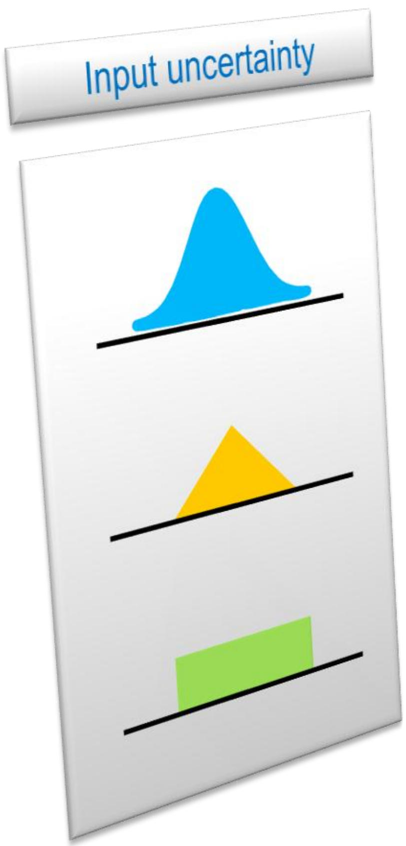
Secchi, P., Zio, E., Di Maio, F., *Quantifying Uncertainties in the Estimation of Safety Parameters by Using Bootstrapped Artificial Neural Networks*, Annals of Nuclear Energy, Volume 35, Issue 12, Pages 2338-2350, 2008

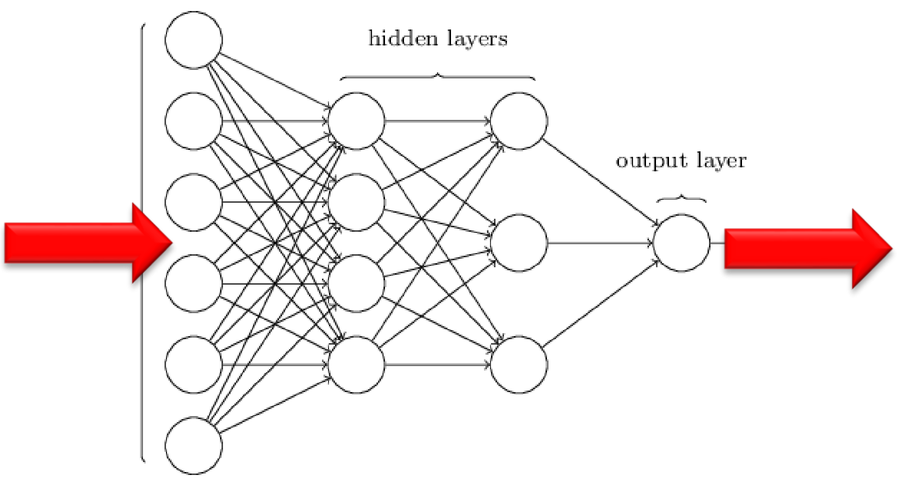
C: Complexity and computation

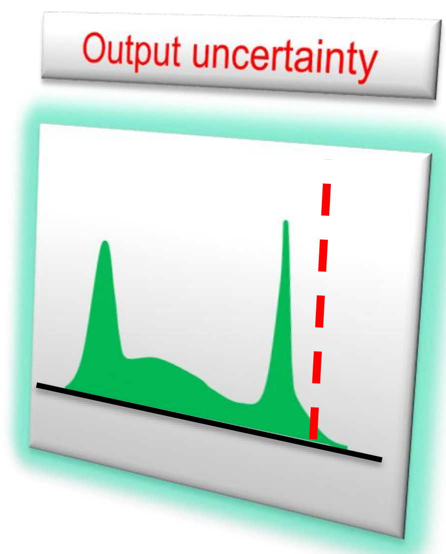


C: Complexity and computation
AI meta-modelling / Surrogate modelling / Reduced Order modelling







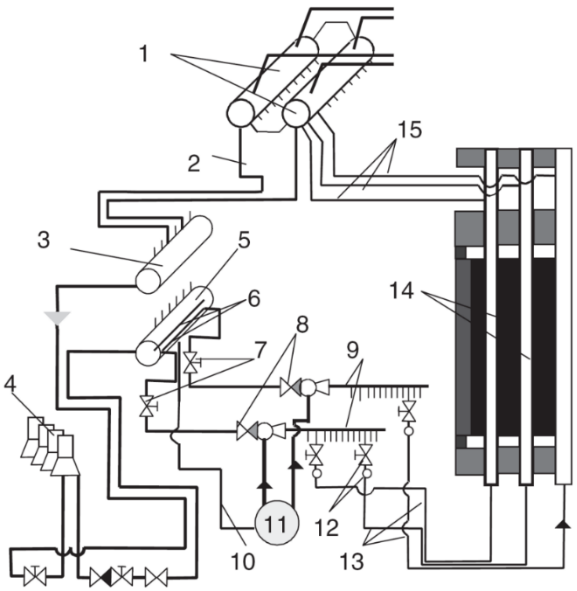


Artificial Neural Netwok (ANNs)
Deep Neural Networks (DNNs)
Physics-Informed Neural Networks (PINN)
Kriging - Gaussian Processes (GPs)
....

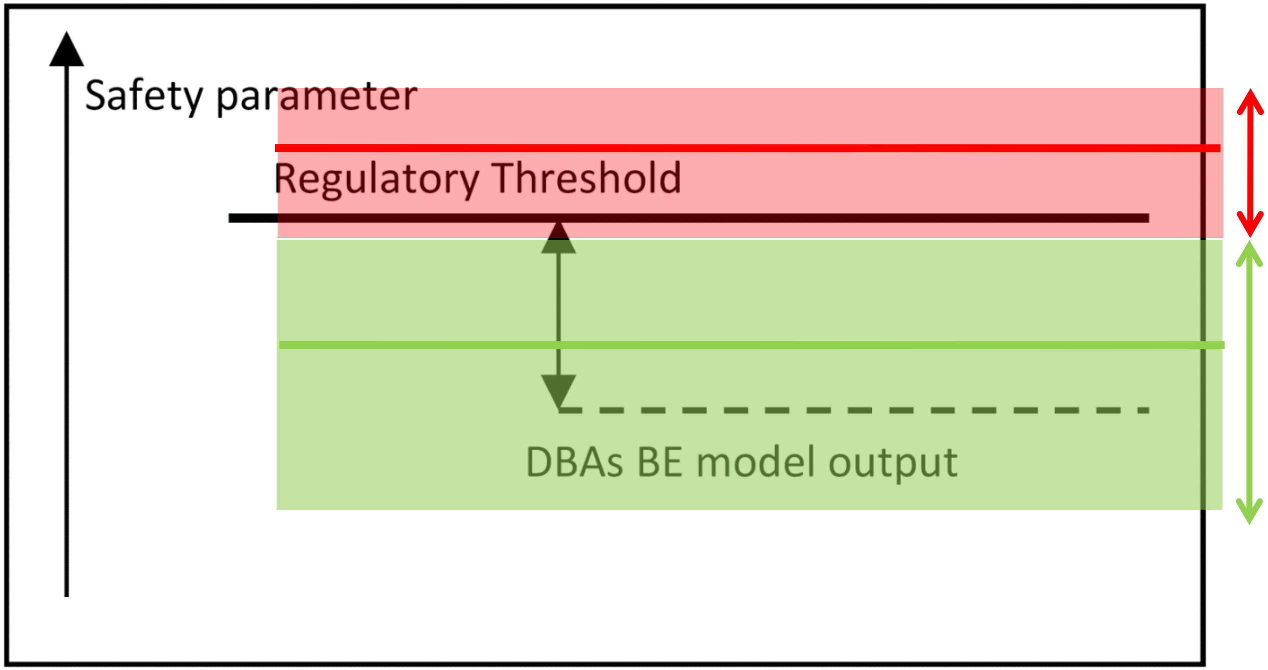
C: Complexity and computation
Bootstrapped ANN

Safety margin quantification for the PCT during the Complete Group Distribution Header (GDH) Blockage Scenario

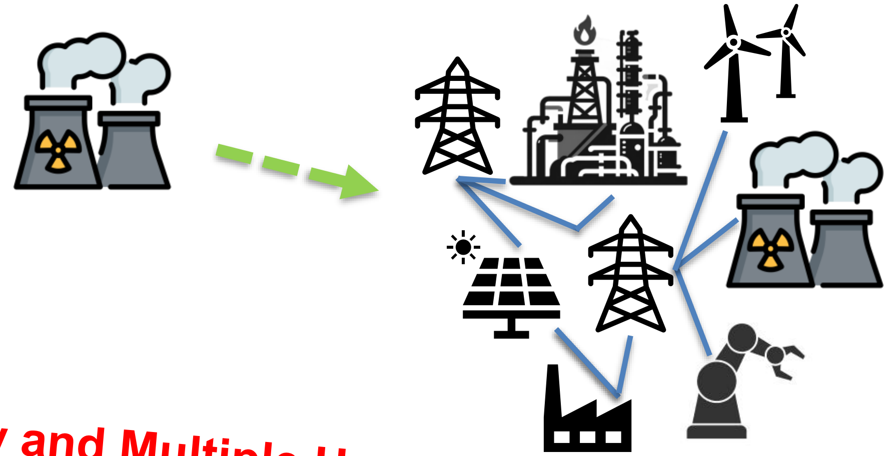
Zio, E., Di Maio, F., "*Bootstrap and Order Statistics for Quantifying Thermal-Hydraulic Code Uncertainties in the Estimation of Safety Margins*", Science and Technology of Nuclear Installations, Article ID 340164, 9 pages, 2008.



Ignalina NPP model nodalization scheme [Ušpuras et al., Accident and Transient Processes at NPPs with Channel-type Reactors, monograph, Kaunas: Lithuanian Energy Institute. Thermophysics, 28, 2006]



Risk Assessment: A "knowledge exercise"



New and Multiple Hazards

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Complexity and Computation

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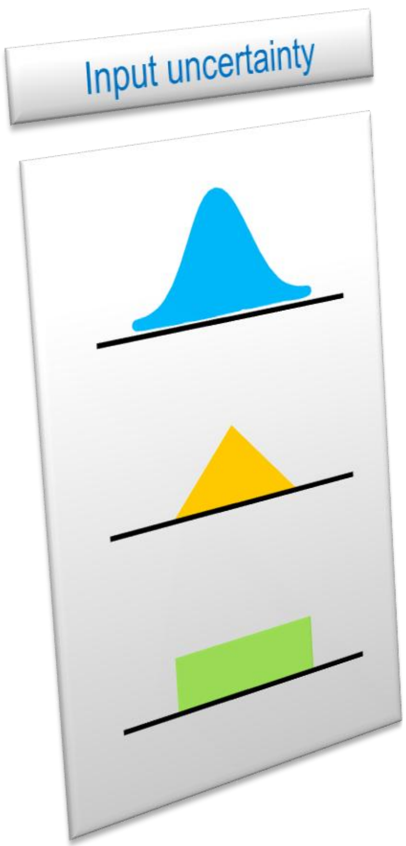
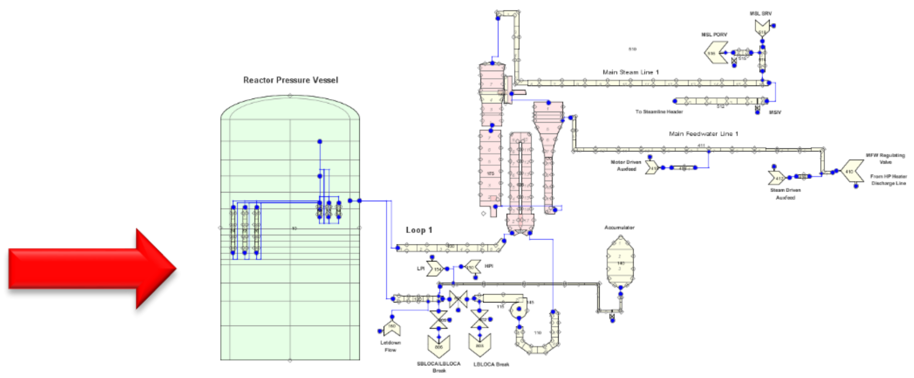
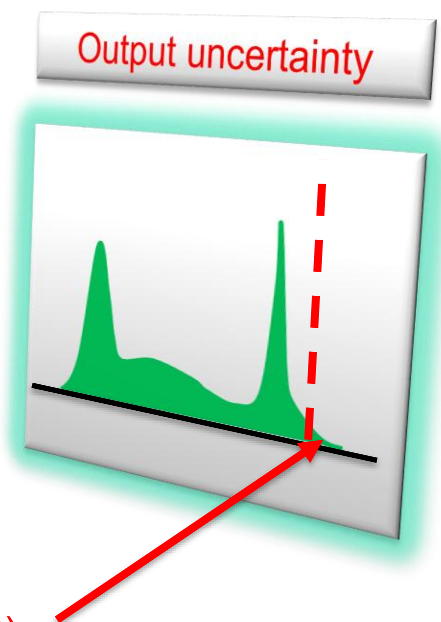
Deep Uncertainties & Rare Events

Advanced Monte Carlo Simulation

P: Deep Uncertainties & Rare Events
Advanced Monte Carlo Simulation



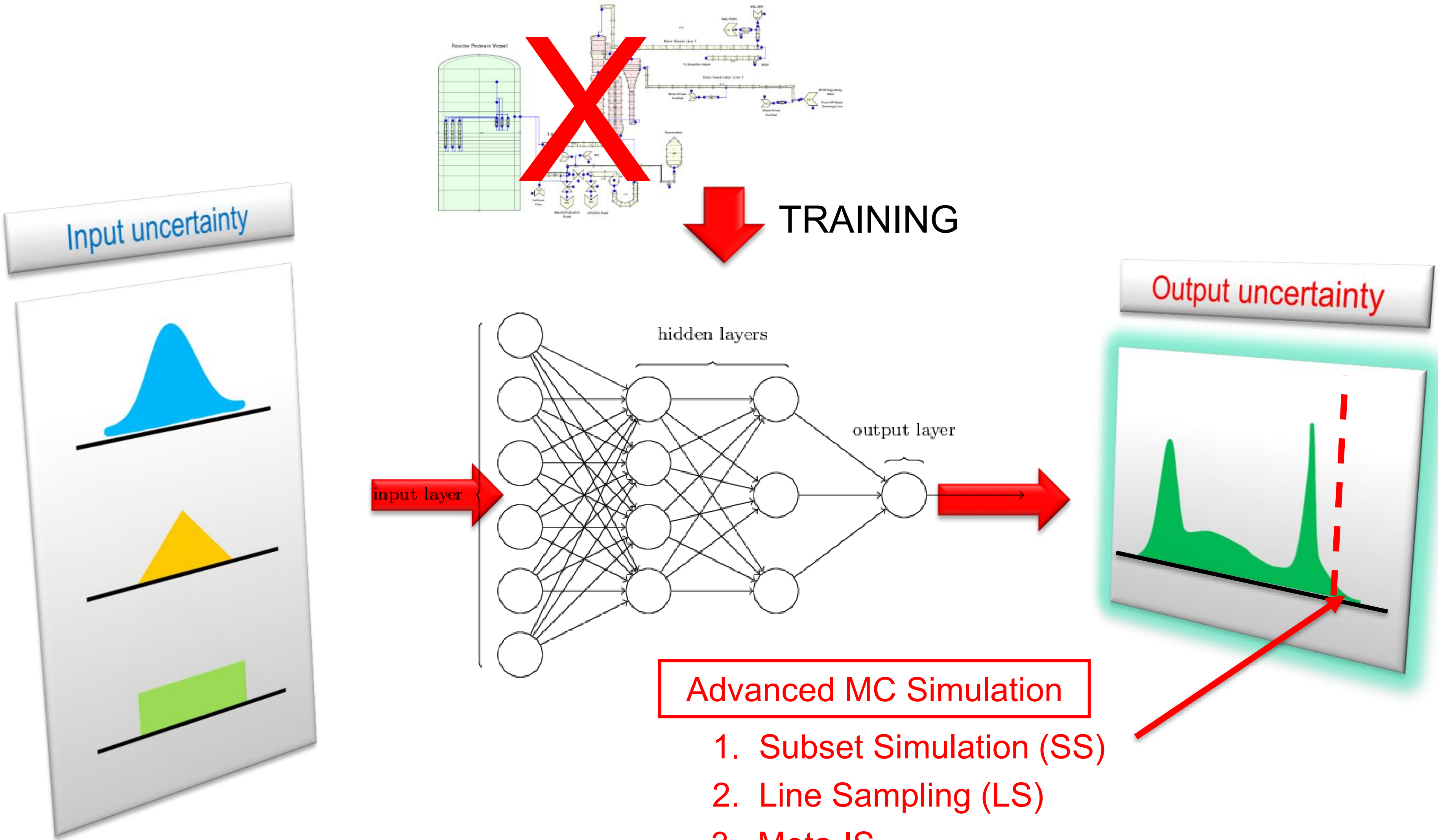




Advanced MC Simulation

1. Subset Simulation (SS)
2. Line Sampling (LS)
3. Meta-IS

P: Deep Uncertainties & Rare Events
AI & Advanced MC Simulation



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AI & Advanced MC Simulation: Adaptive Kriging Monte Carlo Sampling (AK-MCS)

L. Puppo, N. Pedroni, A. Bersano, F. Di Maio, C. Bertani, E. Zio, "*Failure Identification in a Nuclear Passive Safety System by Monte Carlo Simulation with Adaptive Kriging*", Nuclear Engineering and Design, 380, 111308, 2021.

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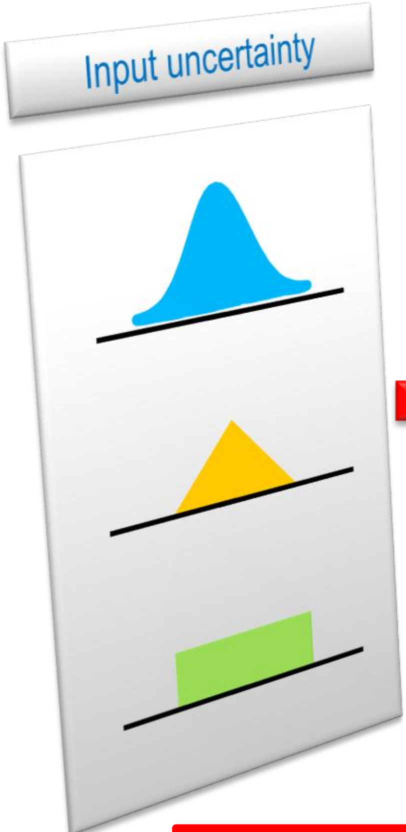

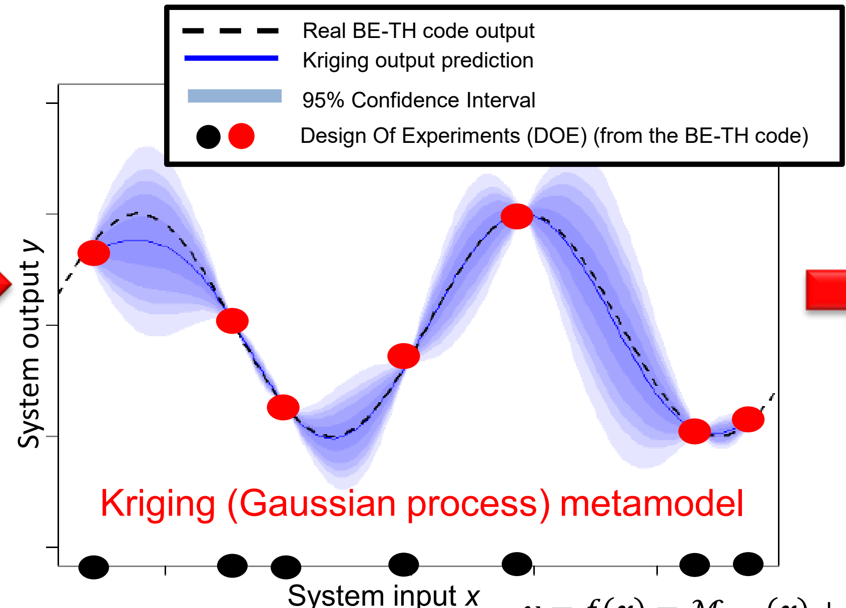

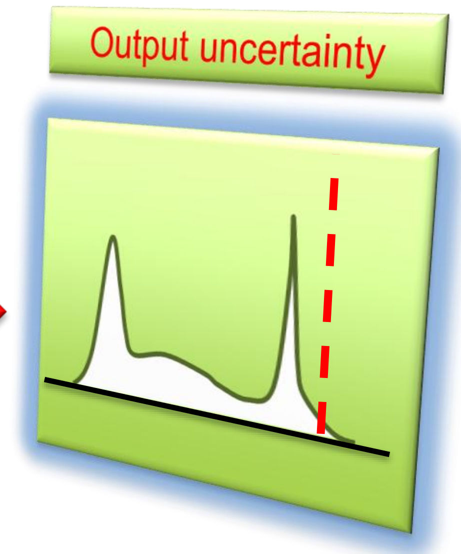

$$y = f(\boldsymbol{x}) = \mathcal{M}_{\boldsymbol{x},y}(\boldsymbol{x}) + \sigma^2(\boldsymbol{x})$$

Prediction — **Gaussian Process** → **Kriging metamodel uncertainty**

- **Kriging (Gaussian process) metamodel**
  - ✓ Fast-running surrogate of the original BE-TH code
  - ✓ Direct evaluation of the uncertainty in the metamodel predictions

AI & Advanced MC Simulation:
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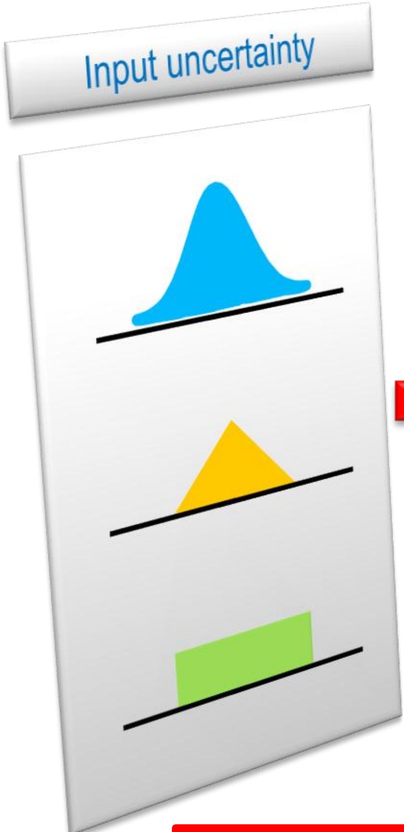

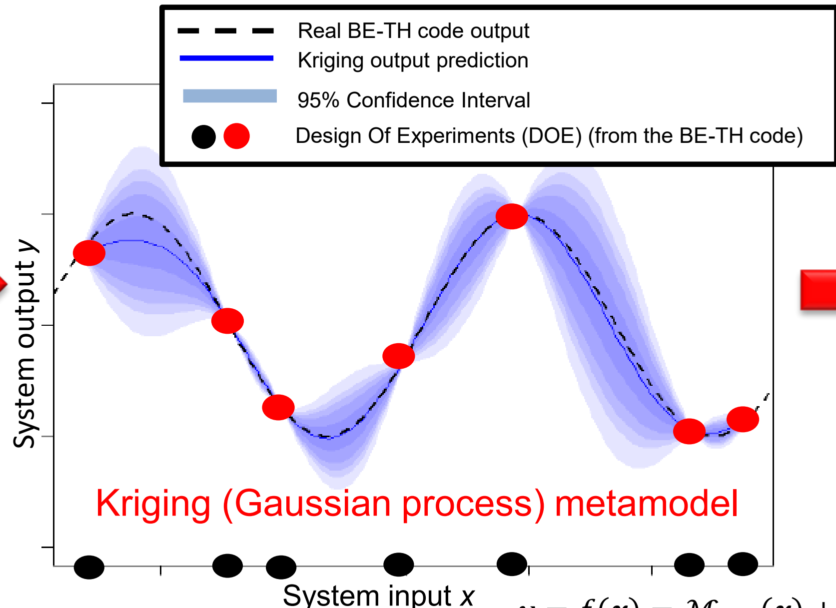

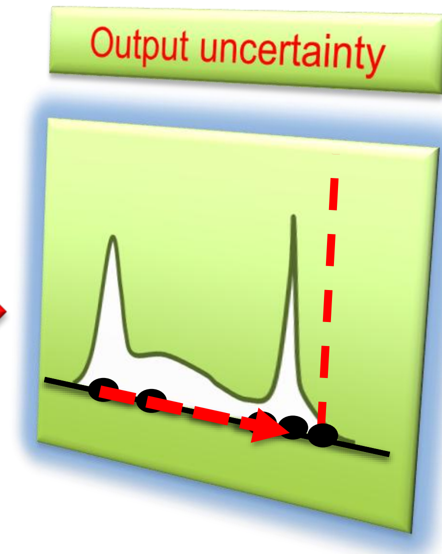

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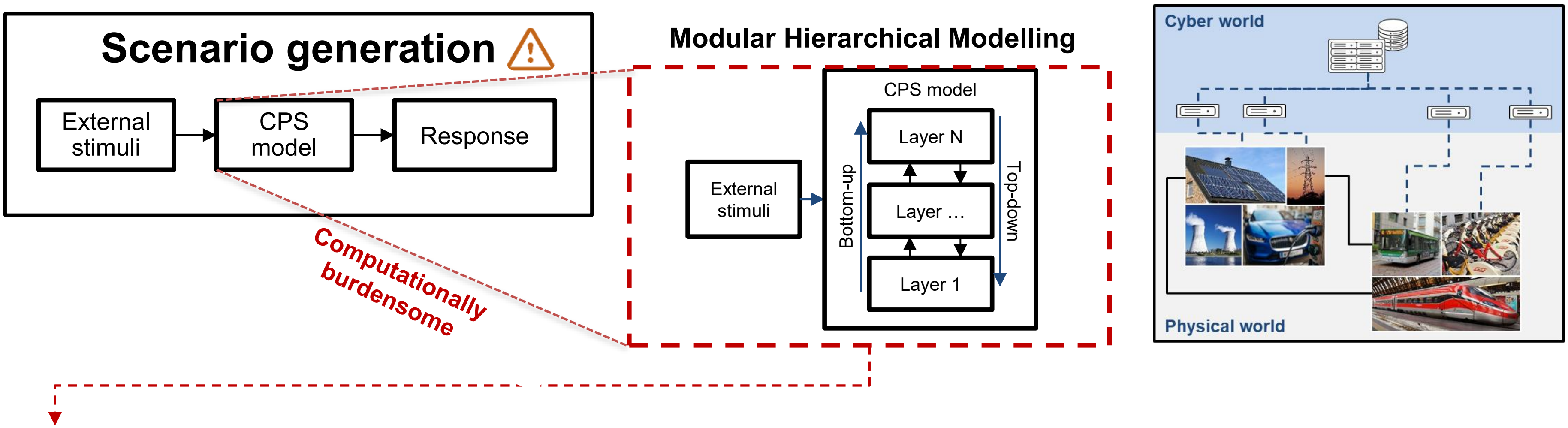
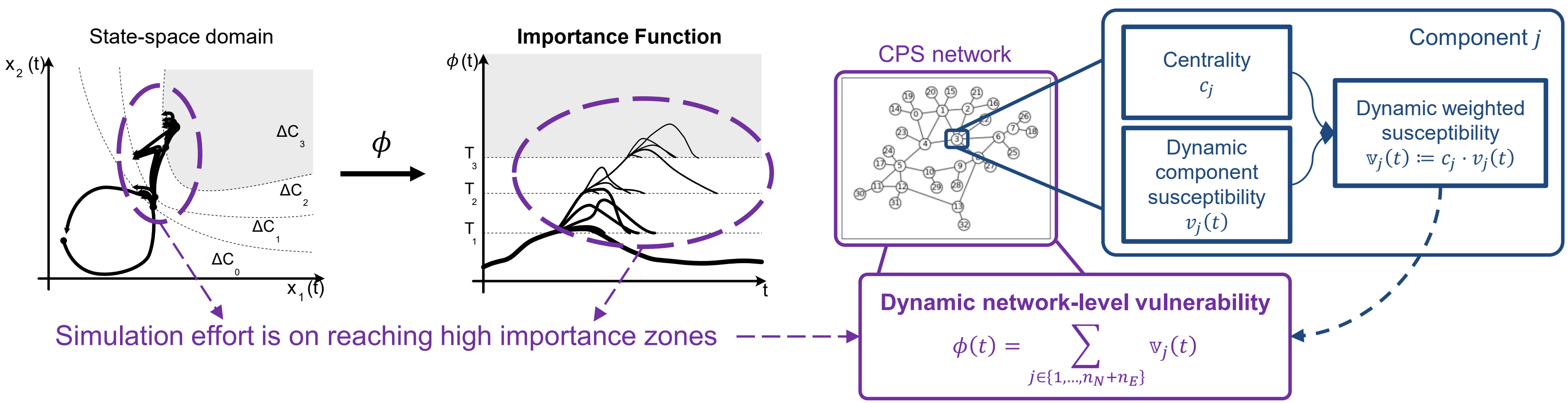
  - ✓ Direct evaluation of the uncertainty in the metamodel predictions
- **Adaptive Monte Carlo Sampling**
  - ✓ Learning function → Intelligent update of the DOE across the failure limit

GBMs & Advanced MC Simulation



Rare event simulation to drive the simulations to reach states where relevant components contribute more to the overall CPS vulnerability

- RESTART (REpetitive Simulation Trials After Reaching Thresholds)
- Splitting technique, oversampling of high-importance regions



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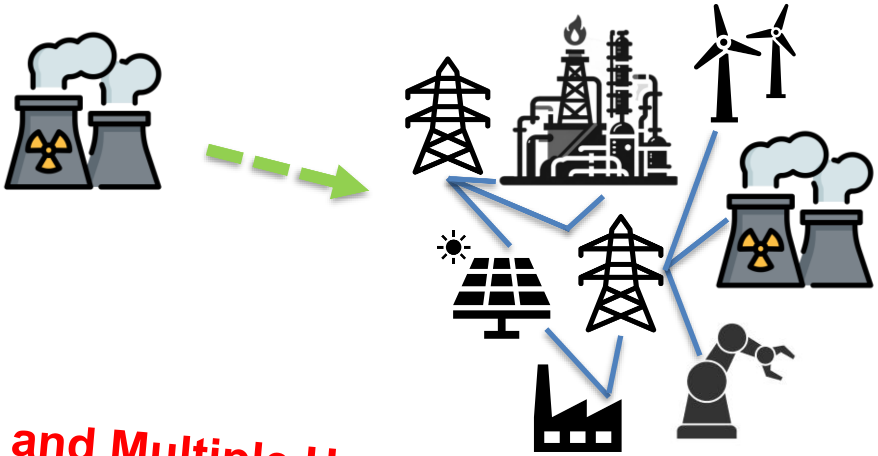

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Cyber threats
Climate change

Big & Heterogeneous Data

Condition-monitoring

$$Risk = (A, C, P \mid \mathcal{K})$$

Complexity and Computation

Artificial Intelligence

Deep Uncertainties & Rare Events

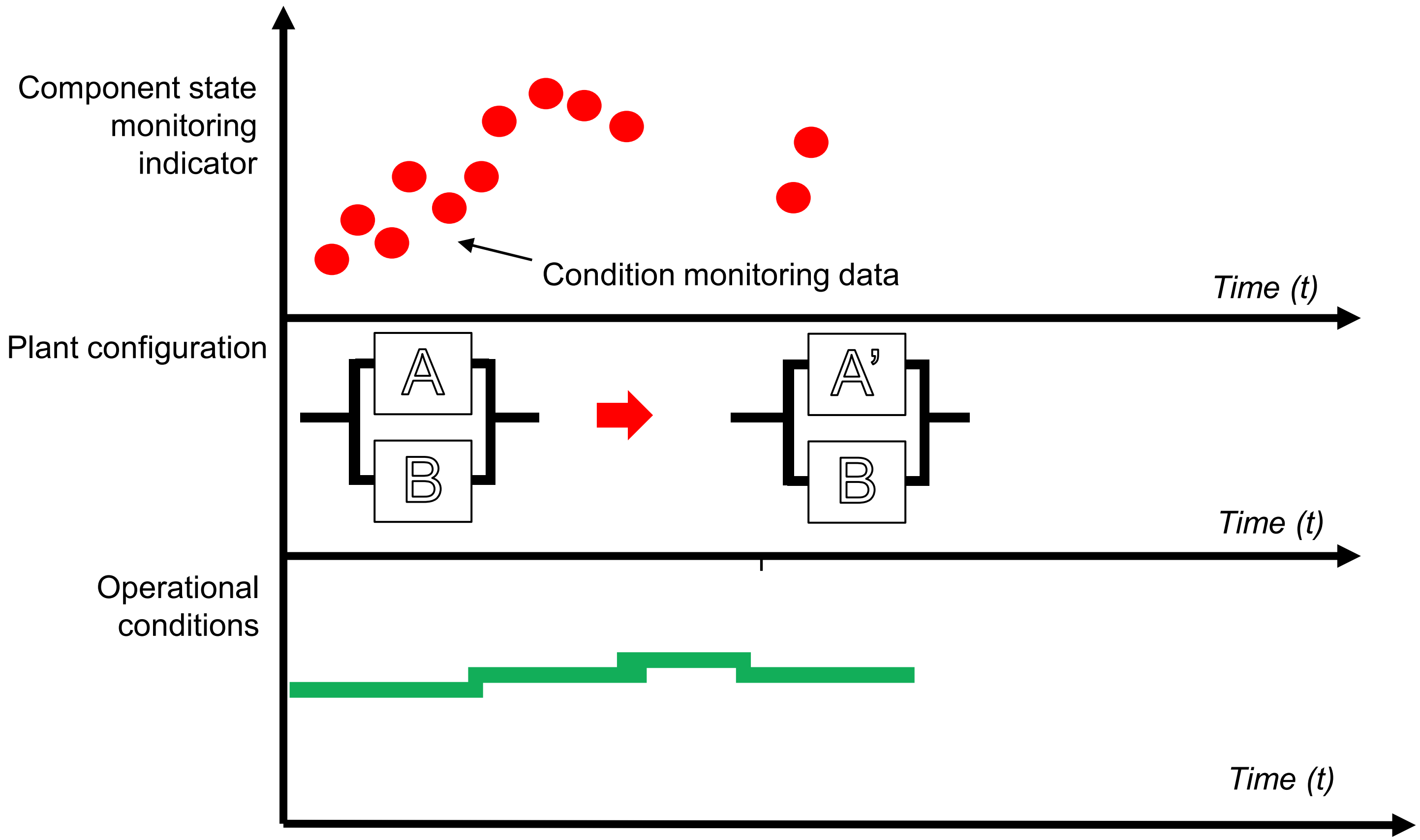
Advanced Monte Carlo Simulation

F. Di Maio, F. Antonello, E. Zio, “*Condition-Based Probabilistic Safety Assessment of a Spontaneous Steam Generator Tube Rupture Accident Scenario*”, NUCLEAR ENGINEERING AND DESIGN, 326, pp. 41–54, 2018.

S. M. Hoseyni, F. Di Maio, E. Zio, "*Condition-based probabilistic safety assessment for maintenance decision making regarding a nuclear power plant steam generator undergoing multiple degradation mechanisms*", RELIABILITY AND SYSTEMS SAFETY, 191, 106583, 2019.

S. Hoseyni, Di Maio, Zio “*Subset simulation for optimal sensors positioning based on value of information*”, Proceedings of the Institution of Mechanical Engineers, Part O: JOURNAL OF RISK AND RELIABILITY, 2022.

K: Condition monitoring
Condition-based risk assessment and management



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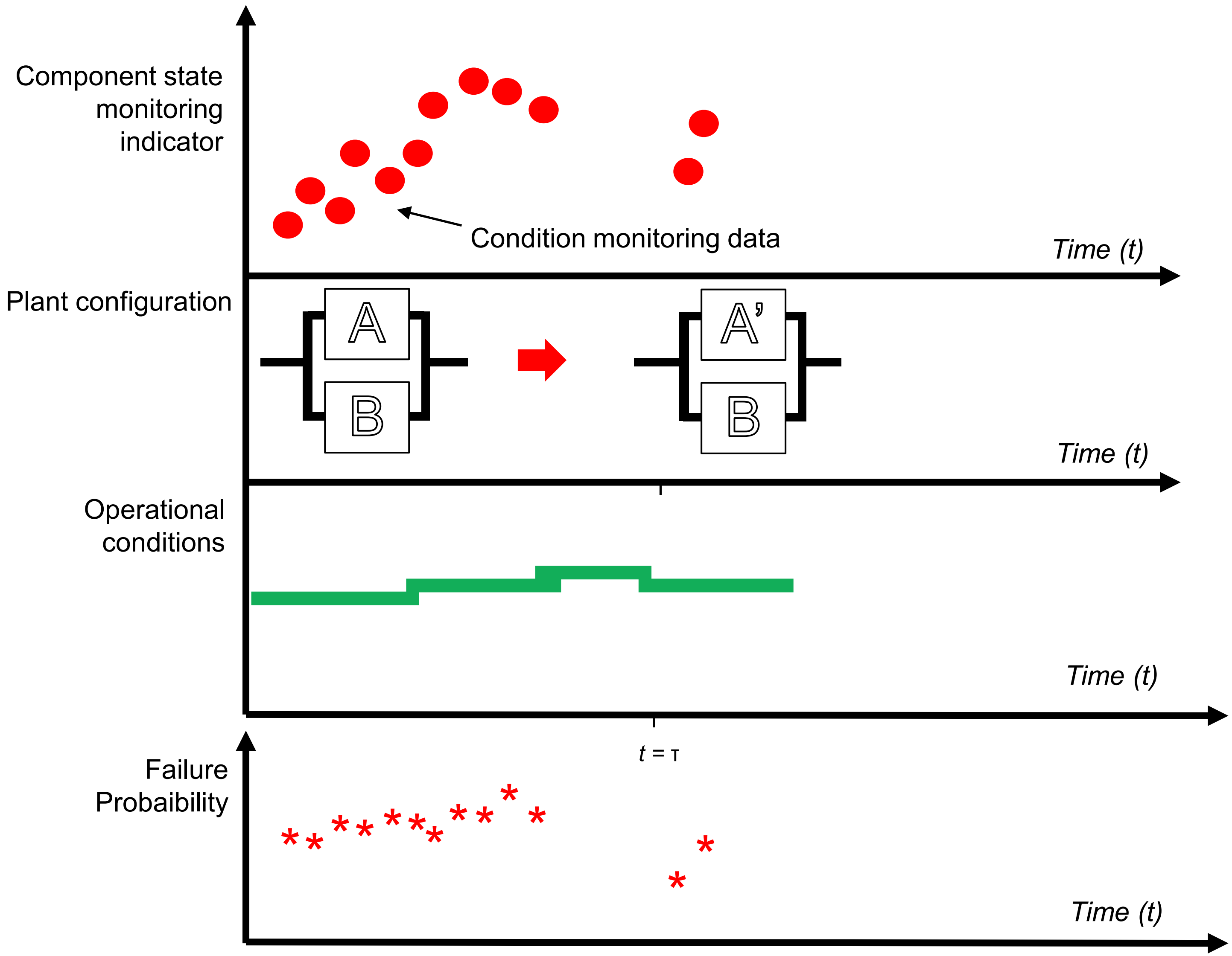
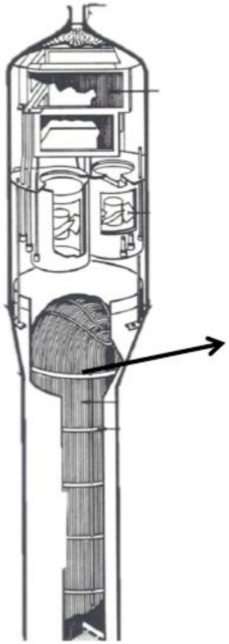
Condition-based risk assessment and management



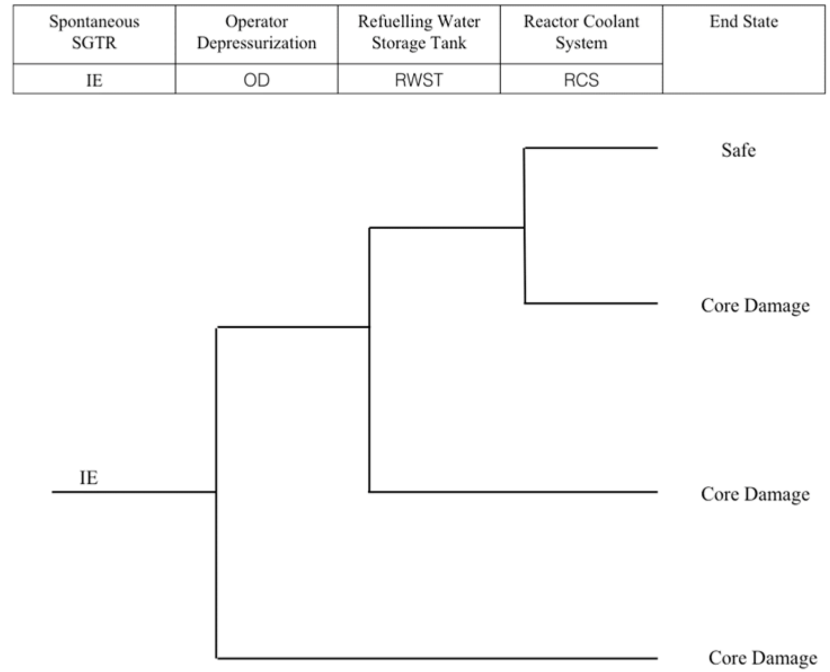
Spontaneous rupture of a SG tube due to the SCC and pitting

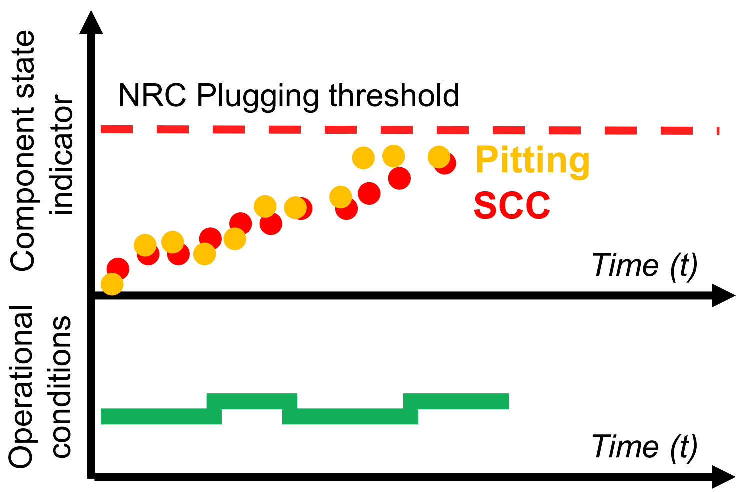
F. Di Maio, F. Antonello, E. Zio, “*Condition-Based Probabilistic Safety Assessment of a Spontaneous Steam Generator Tube Rupture Accident Scenario*”, NUCLEAR ENGINEERING AND DESIGN, 326, pp. 41–54, 2018.

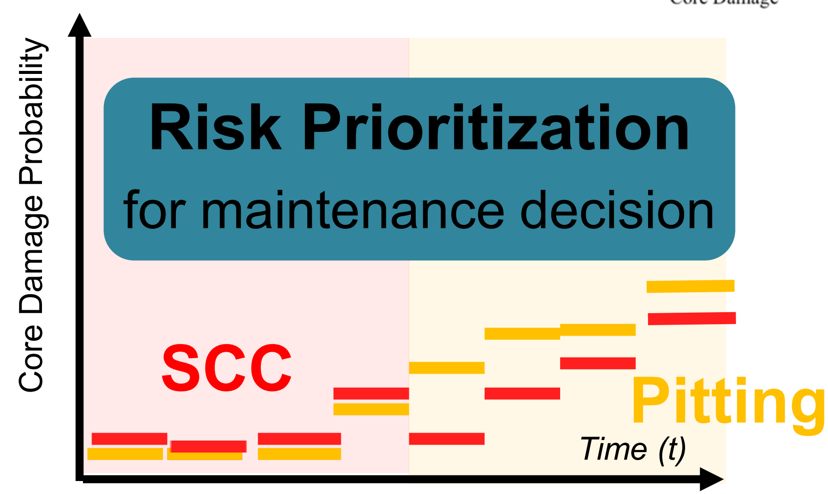
S. M. Hoseyni, F. Di Maio, E. Zio, "*Condition-based probabilistic safety assessment for maintenance decision making regarding a nuclear power plant steam generator undergoing multiple degradation mechanisms*", RELIABILITY AND SYSTEMS SAFETY, 191, 106583, 2019.



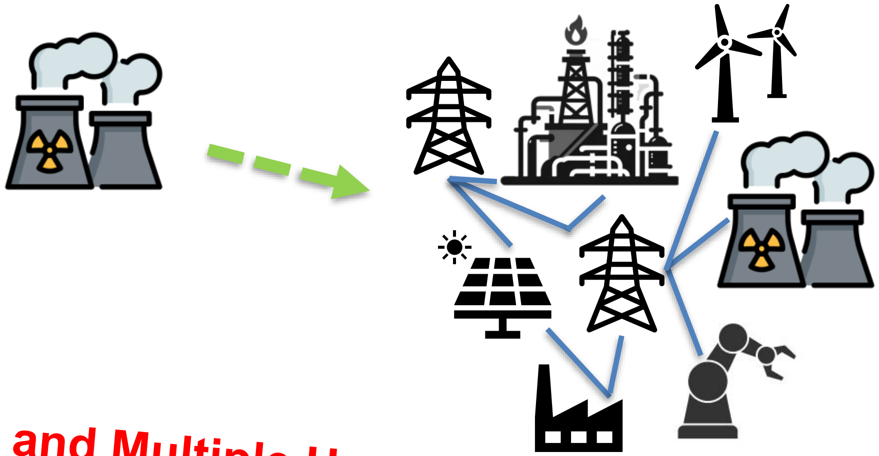
phenomena, during normal operating condition







Risk Assessment: directions for the research



New and Multiple Hazards

Cyber threats
Climate change

Big & Heterogeneous Data

Condition-monitoring
Digital Twins

$$Risk = (A, C, P \mid \mathcal{K})$$

Complexity and Computation

Artificial Intelligence

Deep Uncertainties & Rare Events

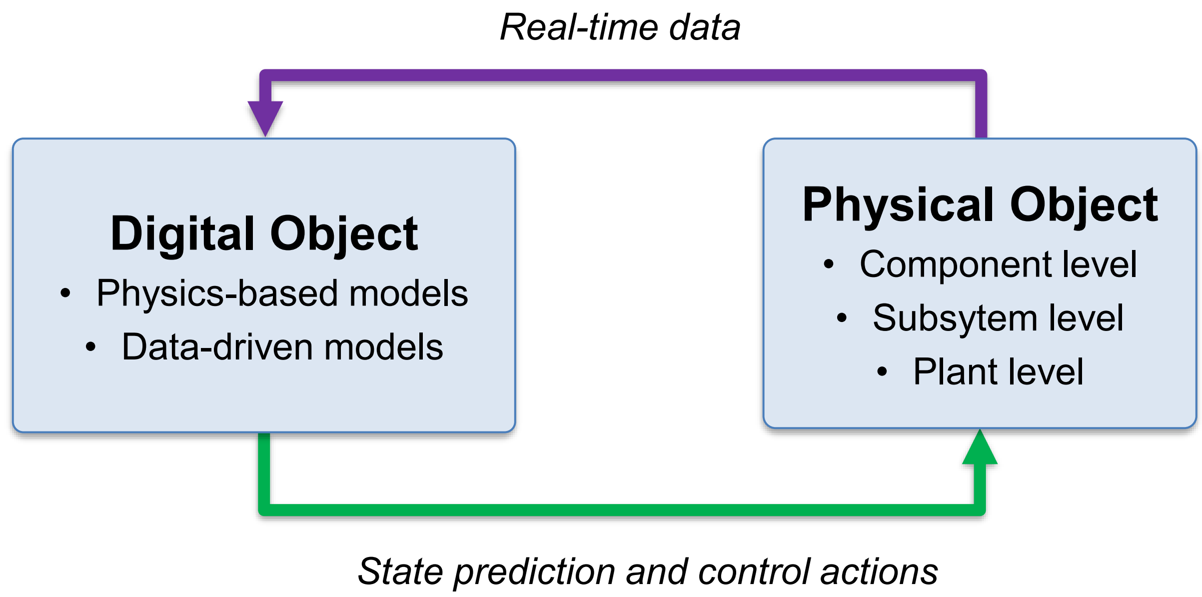
Advanced Monte Carlo Simulation

F. Di Maio, F. Antonello, E. Zio, "*Condition-Based Probabilistic Safety Assessment of a Spontaneous Steam Generator Tube Rupture Accident Scenario*", NUCLEAR ENGINEERING AND DESIGN, 326, pp. 41–54, 2018.

S. M. Hoseyni, F. Di Maio, E. Zio, "*Condition-based probabilistic safety assessment for maintenance decision making regarding a nuclear power plant steam generator undergoing multiple degradation mechanisms*", RELIABILITY AND SYSTEMS SAFETY, 191, 106583, 2019.

S. Hoseyni, Di Maio, Zio "*Subset simulation for optimal sensors positioning based on value of information*", Proceedings of the Institution of Mechanical Engineers, Part O: JOURNAL OF RISK AND RELIABILITY, 2022.

K: Big & Heterogeneous Data
Digital Twins

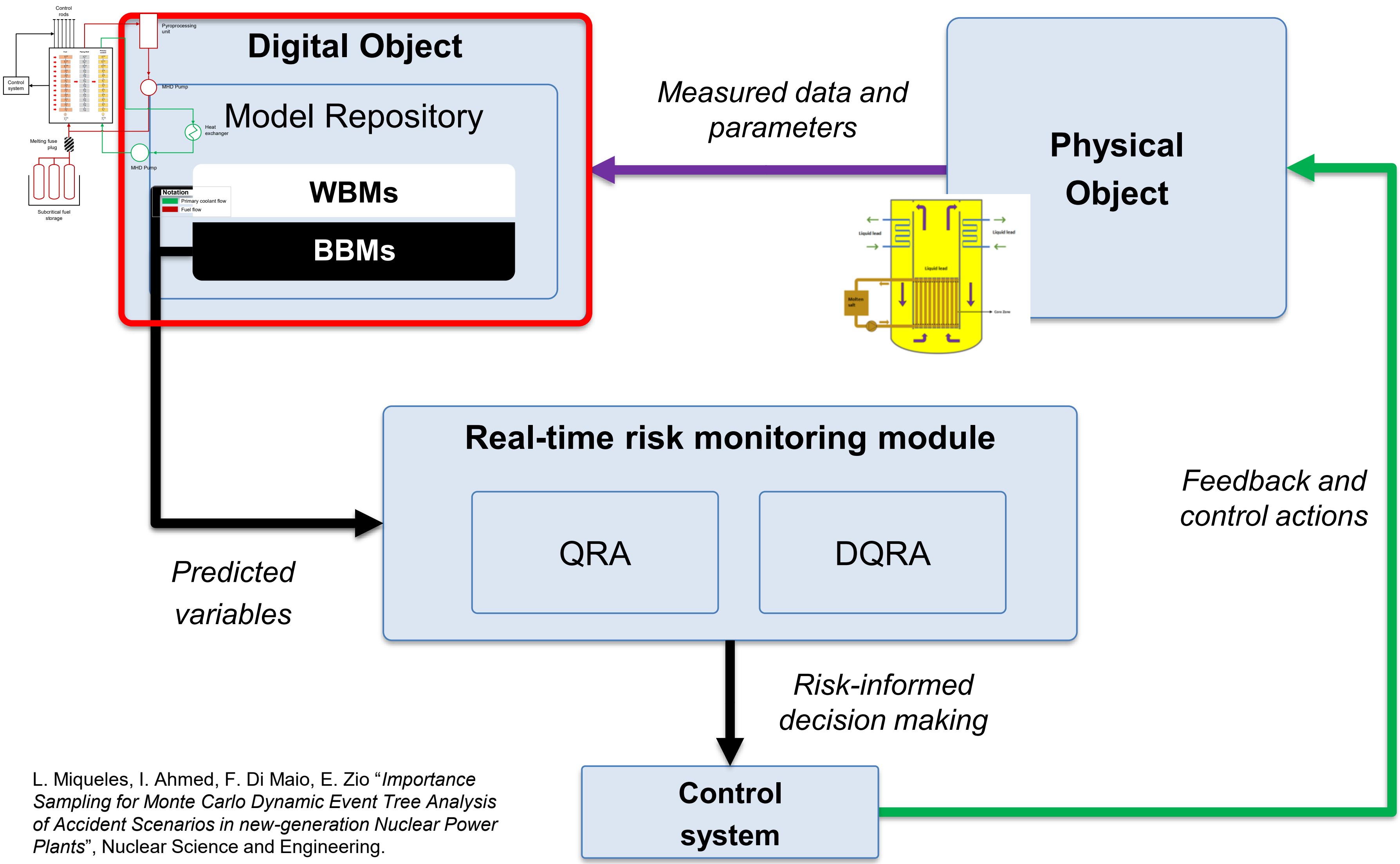


<u>Issues to be addressed</u>

- Bi-directional communication between the Physical and the Digital Object
- Real-time feedback between the two objects (state prediction and control)
- Dynamic nature: adaptation of the physical object along the whole lifetime

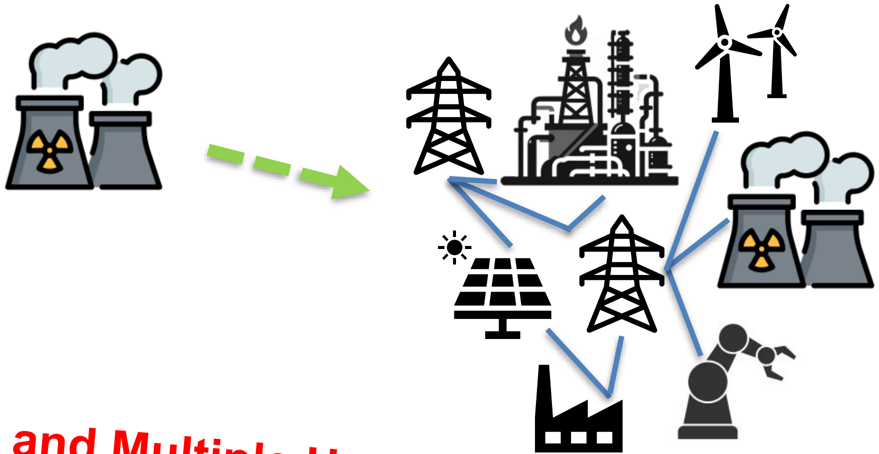
L. Miqueles, I. Ahmed, F. Di Maio, E. Zio "*Importance Sampling for Monte Carlo Dynamic Event Tree Analysis of Accident Scenarios in new-generation Nuclear Power Plants*", <u>accepted</u>, Nuclear Science and Engineering.
L. Miqueles, I. Ahmed, F. Di Maio, E. Zio, "*A Grey-Box Digital Twin-based Approach for Risk Monitoring of Nuclear Power Plants*", ESREL2022, Dublin, Ireland, 28th August - 1st September 2022.

K: Big & Heterogeneous Data
A DT for the risk monitoring of a Small Modular Reactor



L. Miqueles, I. Ahmed, F. Di Maio, E. Zio "*Importance Sampling for Monte Carlo Dynamic Event Tree Analysis of Accident Scenarios in new-generation Nuclear Power Plants*", Nuclear Science and Engineering.

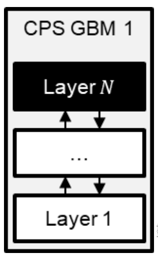
Risk Assessment: A "knowledge exercise"

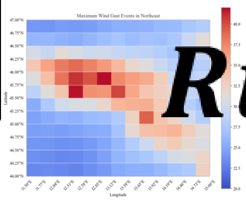


New and Multiple Hazards

Cyber threats

Climate change



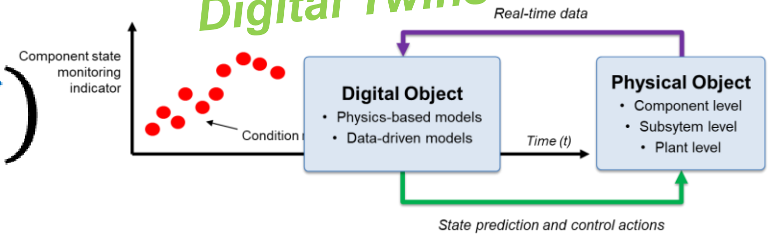


$$Risk = (A, C, P \mid \mathcal{K})$$

Big & Heterogeneous Data

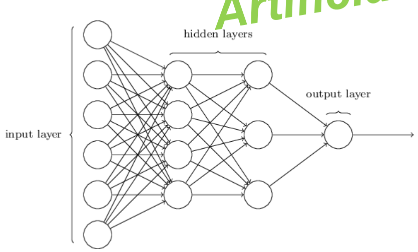
Condition-monitoring

Digital Twins



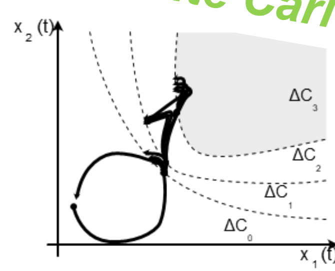
Complexity and Computation

Artificial Intelligence



Deep Uncertainties & Rare Events

Advanced Monte Carlo Simulation



University
of Stavanger

ROGER FLAGE, professor

Risk assessment for the future: Challenges and directions for the research

Interest in foundational issues

Artificial intelligence (AI) for risk assessment

Digital twins as a security risk

We need to regain the enthusiasm for foundational issues that we experienced in the 80s and 90s

Risk Analysis, Vol. 1, No. 1, 1981

On The Quantitative Definition of Risk

Stanley Kaplan[1] and B. John Garrick[2]

Received July 14, 1980

A quantitative definition of risk
definition is extended to include
is described in this connection. T
"relativity of risk," and "accept

KEY WORDS: risk; uncertainty; pr

ELSEVIER

Reliability Engineering and System Safety 54 (1996) 12
PII: S0951-8320(96)00070-1
0951-8320/96/$

Uncertainty in probabilistic risk assessment

Robert L. Winkler
Fuqua School of Business, Duke University, Durham, NC 27708-0120, USA

Dealing with uncertainty is an important and difficult aspect of analyses for complex systems. Such systems involve many uncertainties, and assessing probabilities to represent these uncertainties is itself a complex undertaking utilizing a variety of information sources. At a very basic level, uncertainty is uncertainty, and attempting to distinguish between 'types of uncertainty' is questionable. At a practical level, on the other hand, a close look at such distinctions suggests that they are driven by important modelling issues related to model structuring, probability assessment, information gathering, and sensitivity analysis. Anything that brings more attention to these issues should improve the state of the art. However, I would prefer to attack the issues directly instead of working indirectly through the notion of 'types of uncertainty.' © 1996 Elsevier Science Limited.

ELSEVIER

Reliability Engineering and System Safety 54 (1996) 95–111
PII: S0951-8320(96)00067-1
0951-8320/96/$15.00

Uncertainties in risk analysis: Six levels of treatment

M. Elisabeth Paté-Cornell
Department of Industrial Engineering and Engineering Management, Stanford University, Stanford, CA 94305, USA

This paper examines different levels of analytical sophistication in the treatment of uncertainties in risk analysis, and the possibility of transfer of experience across fields of application. First, this paper describes deterministic and probabilistic methods of treatment of risk and uncertainties, and the different viewpoints that shape these analyses. Second, six different levels of treatment of uncertainty are presented and discussed in the light of the evolution of the risk management philosophy in the US. Because an in-depth treatment of uncertainties can be complex and costly, this paper then discusses when and why a full (two-tier) uncertainty analysis is justified. In the treatment of epistemic uncertainty, an unavoidable and difficult problem is the encoding of probability distributions based on scientific evidence and expert judgments. The last sections include a description of different approaches to the aggregation of expert opinions and their use in risk analysis, and a recent example of methodology and application (in seismic hazard analysis) that can be transferred to other domains. © 1996 Elsevier Science Limited

IEEE TRANSACTIONS ON SYSTEMS, MAN, AND CYBERNETICS—PART A: SYSTEMS AND HUMANS, VOL. 26, NO. 3, MAY 1996 303

Uncertainty About Probability: A Reconciliation with the Subjectivist Viewpoint

Ali Mosleh and Vicki M. Bier

Abstract— **The use of probability distributions to represent uncertainty about probabilities (rather than events) has long been a subject of controversy among theorists. Many well-known theorists, such as de Finetti, have concluded that it is inherently meaningless to be uncertain about a probability, because this appears to violate the subjectivists' assumption that individuals can develop unique and precise probability judgments. Others have found the concept of uncertainty about probability to be both intuitively appealing and potentially useful. This paper presents a resolution of this question, indicating that at least one type of uncertainty about probabilities (that arising from uncertainty about the underlying events on which those proba-**

inherent imprecison in our cognitive processes. We argue that the first type of uncertainty does not violate the axioms of subjective probability theory, and that this type of "conditional uncertainty" will often be more important in practice. Finally, we believe that the approach proposed for addressing conditional uncertainty can also offer pragmatic (although nonaxiomatic) guidance for dealing with the other type of uncertainty (cognitive imprecision) as well.

II. THE DEBATE OVER UNCERTAINTY ABOUT PROBABILITIES

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HOME > SCIENCE > VOL. 250, NO. 4986 > THE CONCEPT OF PROBABILITY IN SAFETY ASSESSMENTS OF TECHNOLOGICAL SYSTEMS

ARTICLE

The Concept of Probability in Safety Assessments of Technological Systems

GEORGE APOSTOLAKIS

SCIENCE • 7 Dec 1990 • Vol 250, Issue 4986 • pp. 1359-1364 • DOI: 10.1126/science.2255906

Risk Analysis, Vol. 17, No. 4, 1997

Distinguished Award

The Words of Risk Analysis

Stan Kaplan[1]

Received January 28, 1997; revised June 17, 1997

This paper is a transcript of a talk given to a plenary session at the 1996 Annual Meeting of the Society for Risk Analysis. Its purpose is to contribute toward a single, uniformly understood language for the risk analysis community.

SRA Newsletter 1986, 6(1)

PRESIDENT'S COLUMN

The Problem with Risk Analysis and Management

(1) There is no discipline of risk analysis and management (RAAM); there are no academic departments, and no professional degrees given.

(2) Many professional groups and several professional journals deal with RAAM, but there is almost no communication among the groups.

(3) Few decision makers take RAAM seriously in the sense of allowing RAAM considerations to shape their fundamental design, construction, and operation decisions. Instead, they make their decisions and then seek risk assessors to convince people that their decisions were right or to get them out of bad situations.

These are three symptoms of the disorganized, chaotic nature of RAAM. Our fledgling society has begun to bring rigor, peer review, and anticipation into the field, but the job is only started. Where are the textbooks-monographs that set out the analytic tools? How can we bring together the systems safety experts, the trauma-injury experts, the disease experts, and the financial risk experts?

SRA Newsletter, 1992, 12(2)

Should there be an academic program offering a PhD in risk analysis?

A panel discussion chaired by John Graham, SRA Council member and Harvard University faculty member, addressed the above question at the Society's 1991 Annual Meeting in Baltimore without reaching a consensus. Representing the affirmative, Tony Cox of U S WEST Advanced Technologies and Cox Associates (Denver) argued that the availability of a PhD risk analysis program would protect qualified practitioners, set standards, define the field, promote research, and attract the best and brightest to the field.

In fact, he said, "there *is* a field of risk analysis" and it has largely developed outside academia, albeit with considerable input from individual academics. He believes that if universities were to offer good programs, they would be flooded with applicants and their graduates would be sought to attack "open research questions that are deep, real, hard, persistent, important, and cross-disciplinary."

Panelist Lester Lave, an economist at Carnegie-Mellon University, disagreed. The principal reason for

Elisabeth Paté-Cornell of Stanford University agreed with Lave that risk analysts should have a solid background in an already recognized discipline; however, she supported the concept of a PhD program in risk analysis. She pointed out that promoting expertise in a specific discipline is the philosophy of her own department of Industrial Engineering, where the PhD candidates who choose to specialize in risk analysis are expected to have a master's degree in one of the classical engineering disciplines.

Panelist Halina Brown of Clark University argued that risk analysts would be much stronger professionally if they had strong backgrounds in both the physical sciences and the social sciences. "We need to bring together faculty who share these interests," she said. She pointed out that Clark University emphasizes that duality in its Environment, Technology, and Society Program, which offers both MA and PhD degrees and has the following four required core courses: Risk Assessment and Hazard Management, Limits of the Earth, Technology Assessment, and Quantitative Methods in

Artificial intelligence (AI) for risk assessment

- How far *can* and *should* we go in letting AI influence risk management and decision-making?

Technical and value issue

AI for risk assessment – Current use

- **Consequence characterization**
  - Consequence specification, e.g., event specification using natural language processing or scenario specification using causal graph models
  - Consequence prediction, e.g., effect prediction using regression models

- **Uncertainty characterization**
  - Uncertainty representation, e.g., probability estimation using regression models

- **Knowledge characterization**
  - Knowledge representation, e.g., representing rules, constraints, and facts as conceptual graphs
  - Data/information/knowledge integration, e.g., extracting and combining data from different databases

AI for risk assessment – Potential use?

- Set risk acceptance criteria
- Define scope

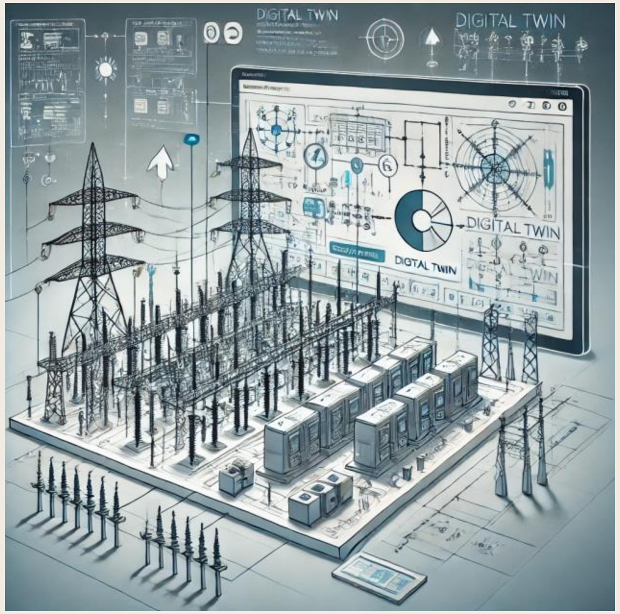
- Compare risk description with risk criteria

- Consequence characterizatior
- Uncertainty characterizatior
- Knowledge characterizatior

- Acceptable risk?
- Which measures to implement?

University of Stavanger

Digital twins as a security risk



DALL·E (generated through ChatGPT)

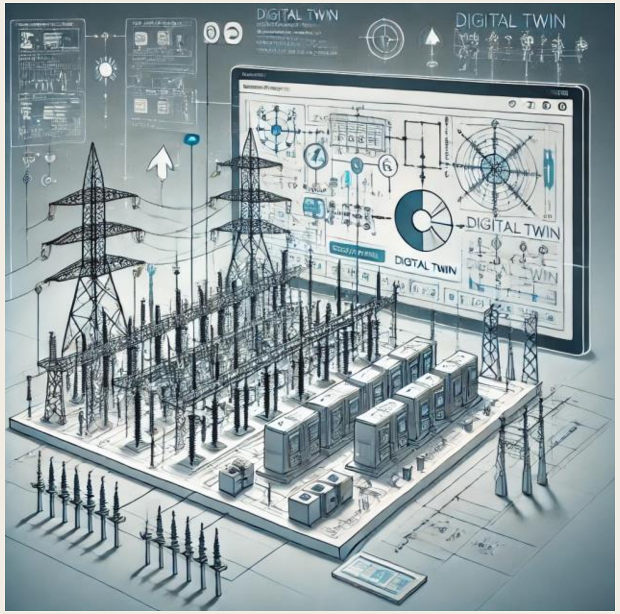
Digital twin:
"… a computer-based representation of a physical system that is used for research, planning, or management (often in real-time) purposes" (Zio & Miqueles, 2024)

=> A model of a system
(Typically, with the connotation of being a high-fidelity, accurate model)

Digital twin examples

- Autonomous vehicles (Almeaibed et al., 2021)
- Sewer systems (Bartos & Kerkez, 2021)
- Buildings (Hosamo et al., 2022)
- Hospitals (Peng et al., 2020)

What is the problem?



DALL·E (generated through ChatGPT)

Reverse engineering / Inverse modeling

Research needs

I. How can we continue the development of digital twin methodology while managing the security risk?

II. How should the security risk impact how we as researchers disseminate our results?

Risk assessment for the future: Challenges and research directions

Plenary Session

Dr. Floris Goerlandt

Associate Professor, Canada Research Chair

DALHOUSIE UNIVERSITY

ESREL & SRA-E 2025

Stavanger, Norway, 06.2025

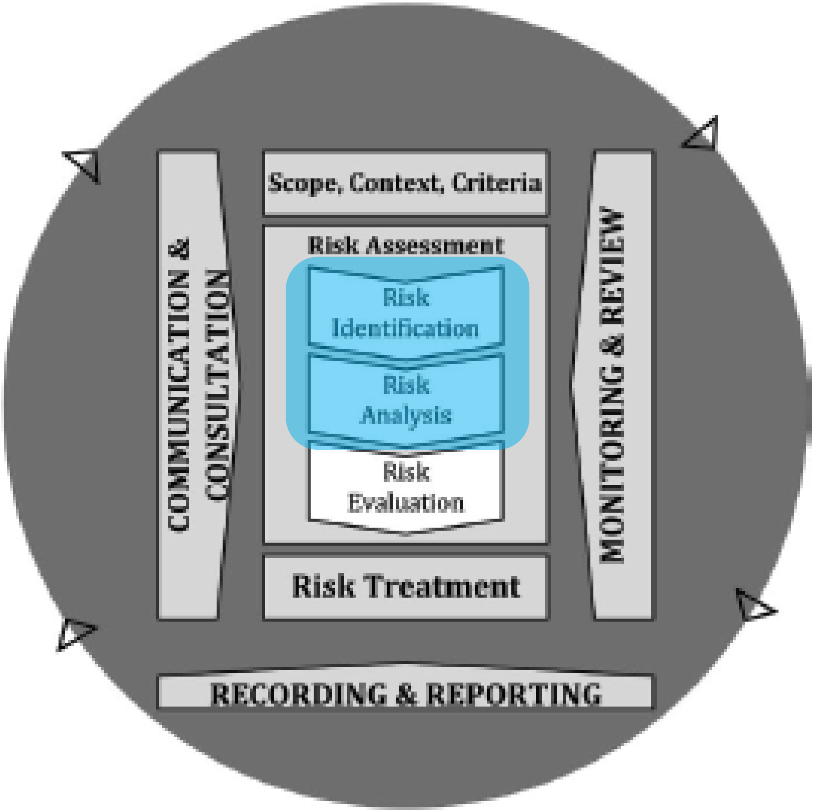
Big questions!

Challenges of the future

- Rapid changes
- Large uncertainties
- Digitalization
- Increased system complexity
- Access to 'big data'
- Autonomous systems
- Artificial Intelligence

- Are traditional risk assessment approaches **obsolete**?
- What topics should risk assessment **research** prioritize?

Let’s focus the talk a bit



Source: ISO 2018. ISO31000

Redefining the question When is a method suitable?

We need **criteria** and **approaches** to assess whether a given

- Risk identification technique
- Risk analysis technique
- or a specific *application* of such techniques

… is **fit for purpose**.

Validation

Source: OpenAI 2025

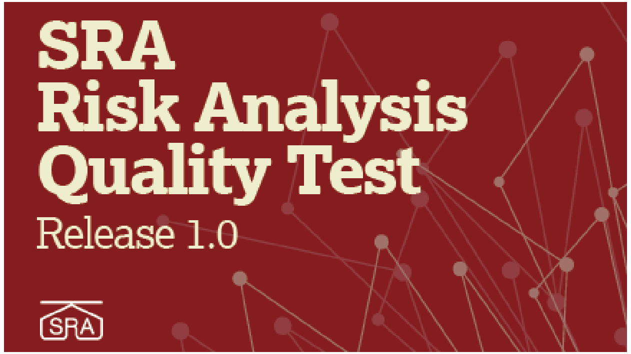
Validating a specific RI or RA application
Generic approaches

- Benchmark exercise
- Independent peer review
- Validity tests
- Reality check
- Quality assurance
- Illustration

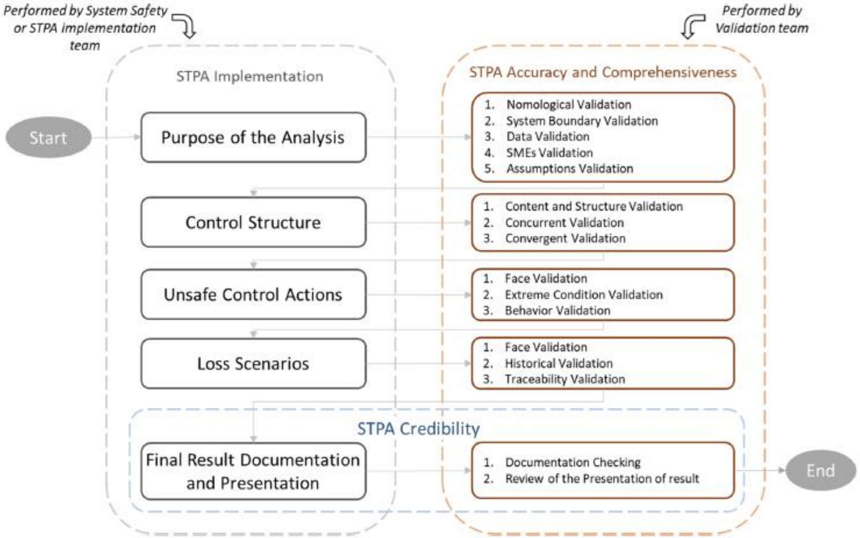
Source: Goerlandt et al. 2017. Safety Science 99:127-139 | Sadeghi and Goerlandt 2021. Safety 7:72

Validating a specific RI or RA application
Example guidance

Quality tests for risk analyses



Independent peer review framework for validating application of STPA technique



Source: SRA 2025 | Sadeghi and Goerlandt. 2023. Safety Science 162:106080

Validating generic RI or RA techniques
Criteria b/o systems view on accident causation

ID	Criterion
C1	Multiple actors and levels
C2	Multiple contributing factors
C3	Vertical integration
C4	Feedback
C5	External pressure
C6	Work practice migration
C7	Erosion of defenses

Application for selected techniques

	C1	C2	C3	C4	C5	C6	C7
Checklist	x	x	x	x	p	p	p
HAZOP	x	x	x	p	p	p	x
FMEA	x	x	p	p	p	p	x
STPA	✓	✓	✓	✓	✓	✓	✓

✓ yes p possibly x no

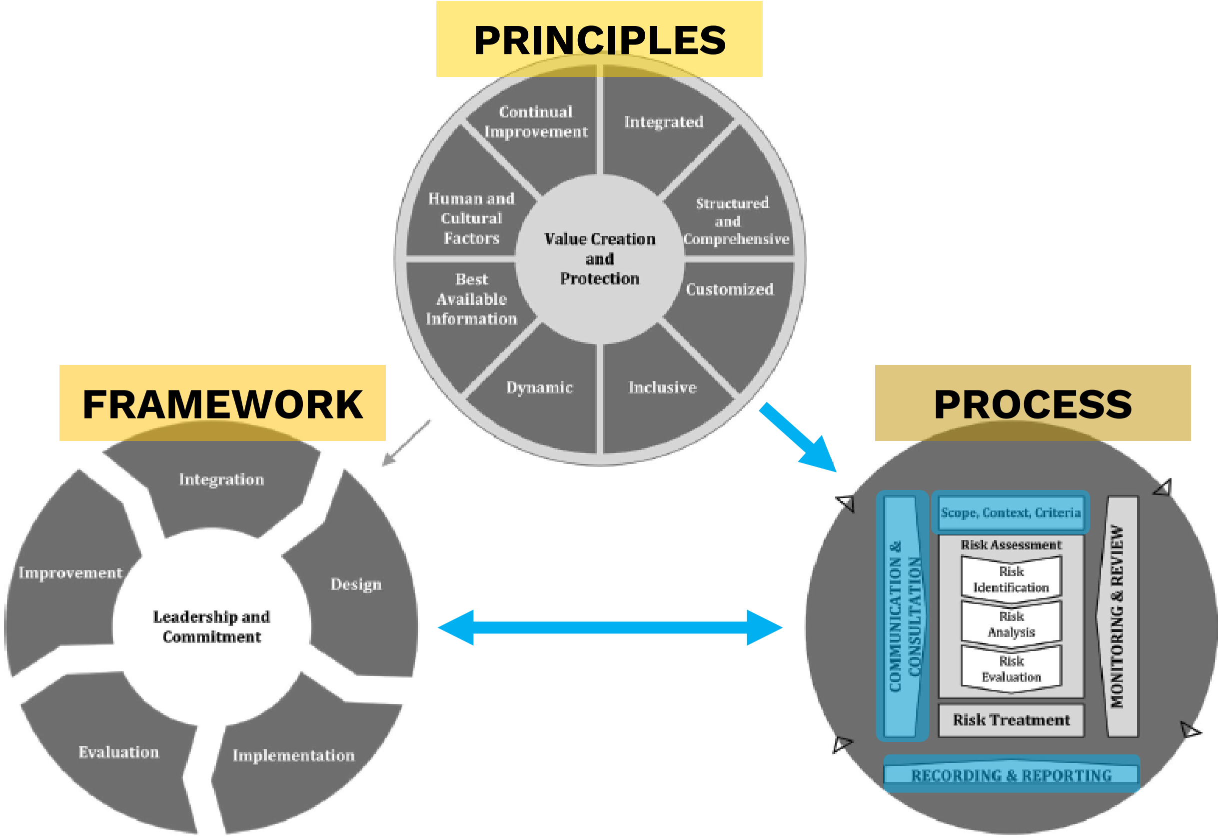
Based on: Rasmussen 1997. Safety Science 27(2-3):183-213 | Dallat et al. 2019. Safety Science 119:266-279

RI and RA in context: ISO31000

PRINCIPLES
Underlying values and considerations

FRAMEWORK
Embedding risk management in organization

PROCESS
Steps to assess risk and take action

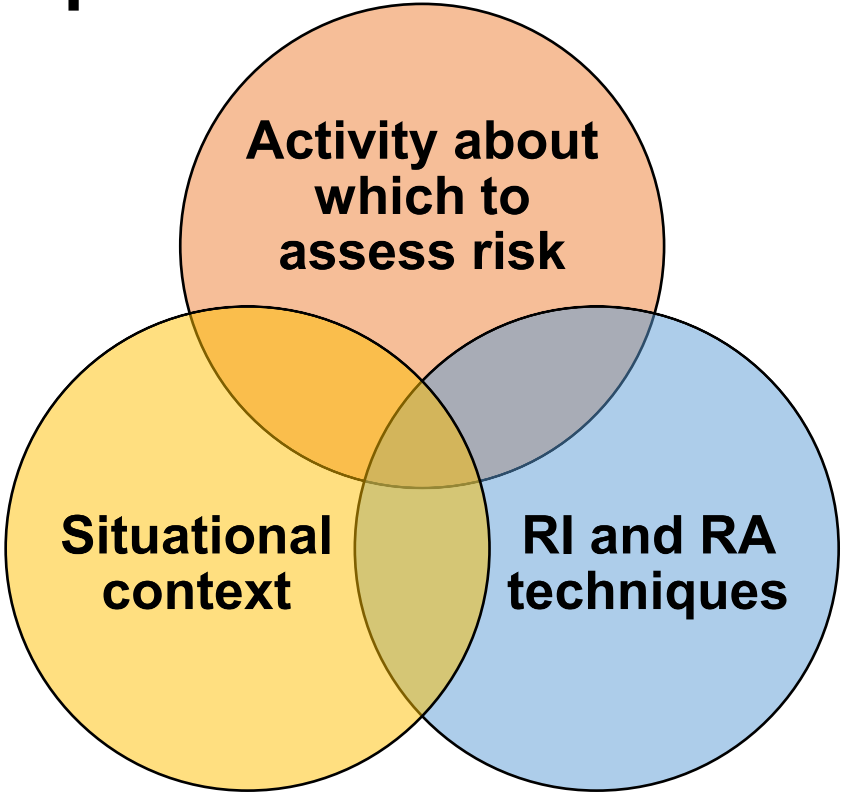


Source: ISO 2018. ISO31000

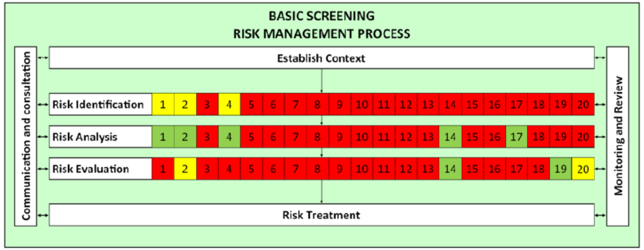
The need for a **contextual view** on validation of RI and RA techniques

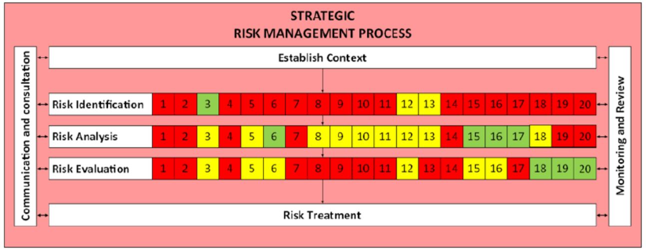
Factors in situational context:

- Internal to organization
- External to organization
- Aims and significance of decision
- Risk management principles to be prioritized
- Engagement with different types of stakeholders
- Reporting requirements



Contextual validation of RI or RA techniques
Example for maritime authority decision making





	Basic screening	Strategic
Aim	Shipping risk trend detection	Assess preparedness and response effectiveness to maritime pollution risk
Decision	Determine need for in-depth risk process	Major investments outside existing budgets
Periodicity	Annually	Ad hoc, based on other risk processes
Resources	Low	High
Competence	Low	High

Source: HELCOM 2018. OpenRisk Guideline | Laine et al. 2021. Marine Pollution Bulletin 171:112724

What are future research needs?

- Assess adequacy of current validation approaches in light of future challenges
  - For specific RI and RA applications
  - For generic RI and RA techniques
- Develop and test new criteria which account for the effects of these challenges on changes to activities, systems, and situational contexts
- Develop and test RI and RA techniques which align with these criteria
- Linking research with practice
  - Understand real-world practices and practitioner needs
  - Conditions for uptake of new techniques

Final note: pragmatism over principle?

Source: OpenAI 2025 | Imgur 2025

Thank you!
Questions?

floris.goerlandt@dal.ca

Risk assessment for the future: challenges and directions for the research

Myrto Konstantinidou

Systems Reliability and Industrial Safety Laboratory –NCSR Demokritos

ex. General Secretary European Safety and Reliability Association

Risk assessment of the future. How it will be?

1. **Dynamic and Real-Time Analysis**

- Shift from static reports to real-time reporting and AI-powered monitoring.
- Digital twins of complex systems either industrial or societal will simulate risks before they actually occur.

Example: Using satellite data and AI to predict wildfires or flood risks instantly.

2. **Integration of Emerging Technologies**

- AI & Machine Learning: Automate detection of risk patterns, cyber threats and natural phenomena.
- Quantum computing: May eventually model highly complex risk systems like climate feedback loops.

Risk assessment of the future. How it will be?

3. **Holistic Thinking**

- Future risk assessment will not evaluate risks in one sector (e.g. just financial or environmental).
- Instead, it will account for interdependencies and interactions e.g.:

A cyberattack → disrupts society → causes financial issue → triggers political instability

- Multi-domain risk modeling will become the norm.

4. Simulation-Based Planning

- In the past we had Monte Carlo simulations, and agent-based modeling, eventually we will shift to real time simulations even for complex systems.
- The traditional old time methods of asking: “What happens if...” will be applied across many sectors simultaneously.

Risk assessment of the future. How it will be?

5. Incorporating Human and Behavioral Risks

- Psychological and social behaviors (e.g., panic, misinformation spread, intentional acts) will be part of formal risk models.
- The role of perception, trust, and misinformation will be accounted
- Autonomous systems will be incorporated in risk assessment

6. Ethical and Emerging Risk Assessment

- Emerging risk evaluation especially for low-probability but high-impact threats to society.
- Ethics and long-term consequences will become part of risk evaluation—especially in AI, biotechnology, and climate decisions.

Tools & Techniques of Future Risk Assessment

Tool/Approach	Function
AI/ML prediction models	Real-time anomaly and trend detection, data-driven decision making, improve compliance, detect threats
Digital twins	Simulate complex systems at scale, remotely and safely, test extreme scenarios, train people
Integrated risk platforms	Connect operational, strategic, societal and financial risks, holistic approach
Behavioral analytics	Understand human errors, social instability, intentional acts, take into account misinformation
Autonomous systems	Include interactions with robots and autonomous multi-agent systems in risk assessment

Challenges in Future Risk Assessment

- The main challenge is that the same capabilities that make AI so powerful and useful induce serious safety and security risks.
- The dynamic nature of AI impose dynamic risks; new threats may emerge as systems adapt to the new reality and we should be prepared for that.
- Safety and security have to be unseparated in future risk assessments.

Conclusion

Risk assessment in the future will be:

- AI-enhanced
- Interdisciplinary
- Even more predictive (and creative!) than it used to be
- Participatory and holistic
- Focused not just on loss prevention—but on resilience , sustainability and adaptation

Things to take into account:

- Data overload vs. insight clarity
- Bias in AI models on decision systems
- Ethical concerns in data use and surveillance

What else???

X THE PLACE OF USEFUL LEARNING

University of Strathclyde Glasgow

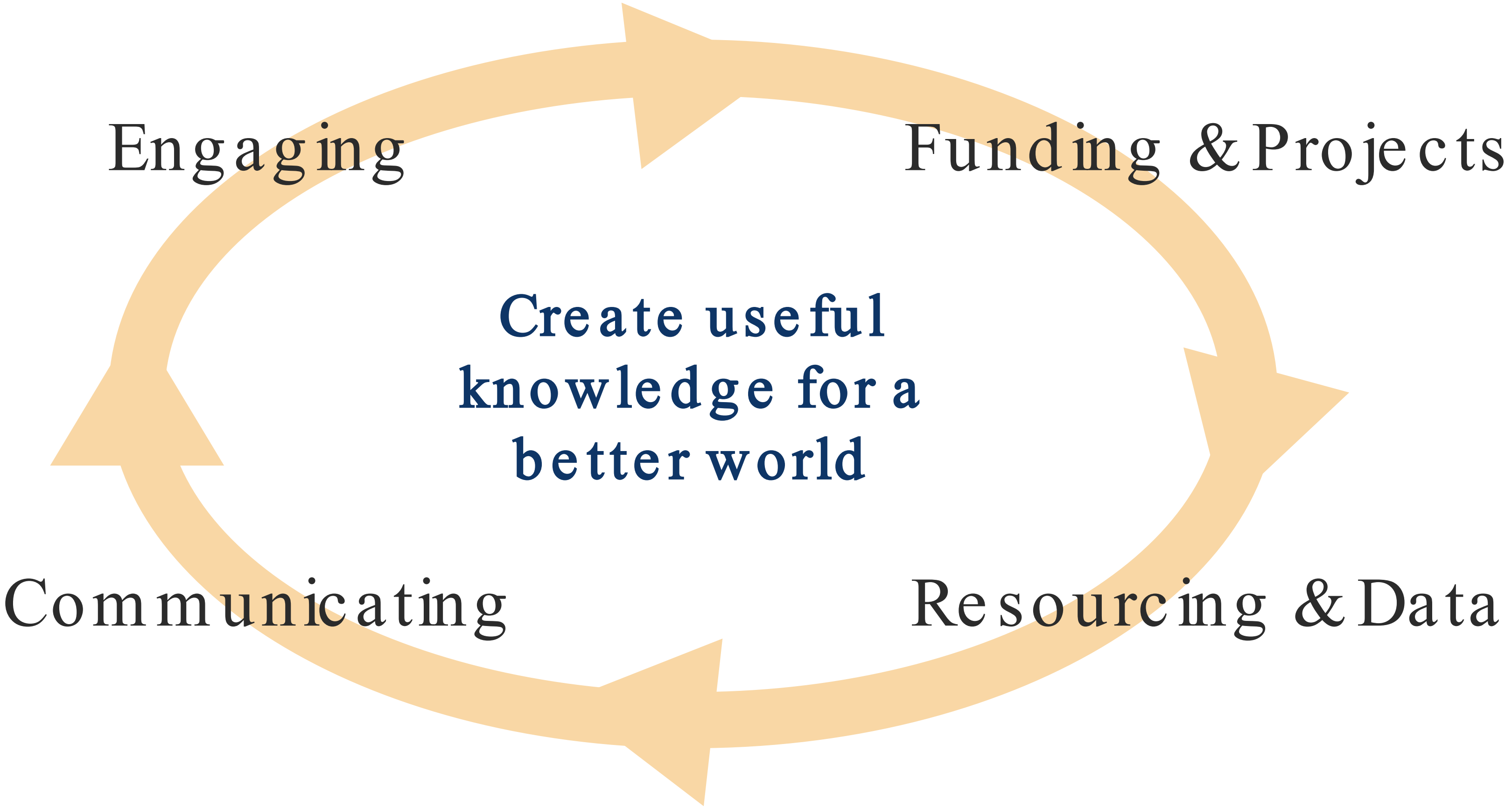
Risk Assessment for the Future: Research Challenges & Directions

Lesley Walls
Management Science

lesley.walls@strath.ac.uk

How might we identify and structure future challenges to shape research and development that contributes useful knowledge?

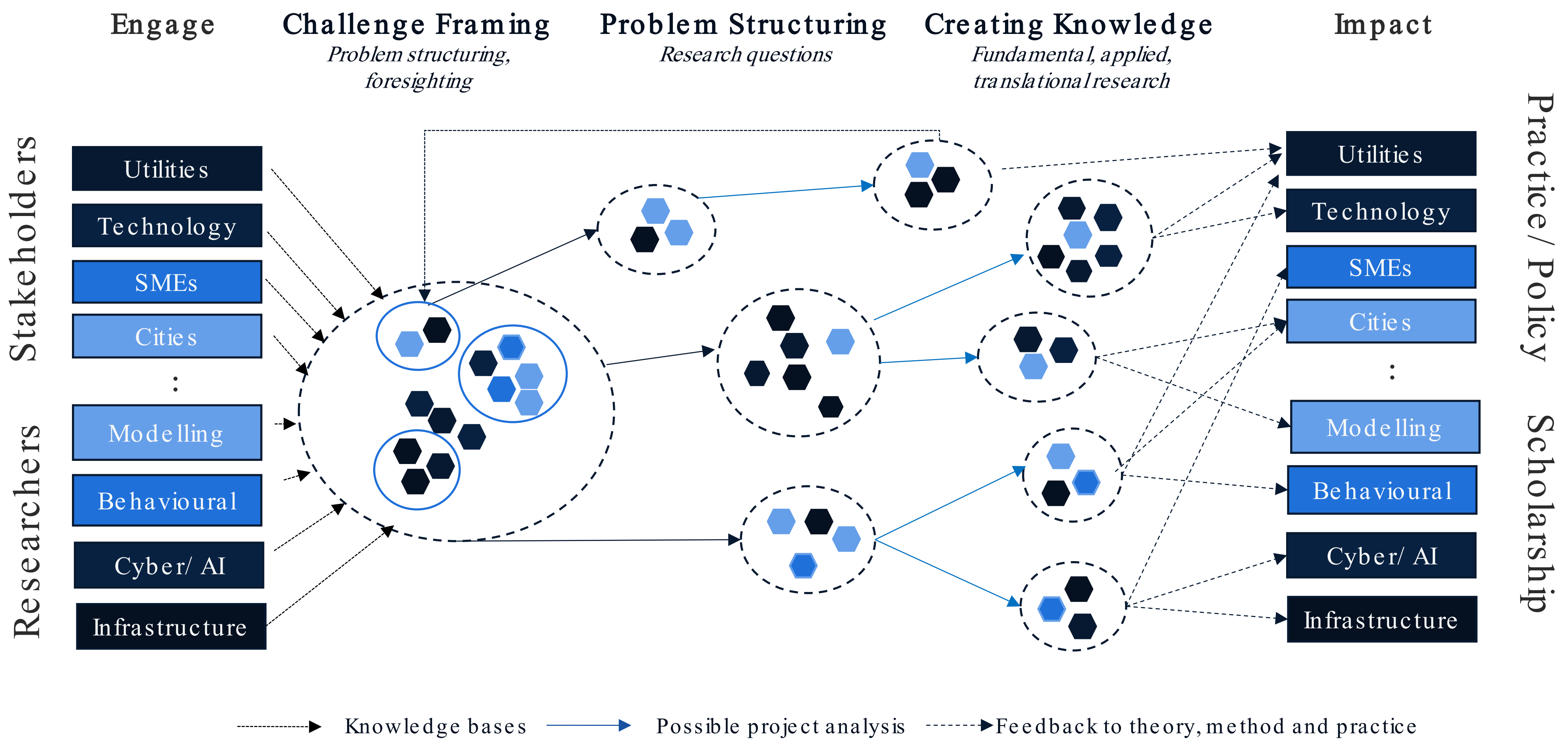
What is the Purpose of Research?



Adapted from: MacIntosh et al (2021) Delivering Impact in Management Research and Informed by Abstraction of University of Strathclyde Impact Cases

NOTE: Research can start at different points, traverse different paths and evolve at different speeds

How Scale Large and Small World Challenges?



Illustrative example for resilient digitalised infrastructure challenge

Adapted from Pohl et al, 2021

How Create Good Future Histories?

Challenge

Why are our traditional risk assessment frameworks, thinking & methods of today …"traditional"?

How do we build upon sound principles and create novel methods to enable our research beneficiaries to assess risk associated with future challenges?

Past | 2025 | Future

Time

So What?

What topics should risk assessment research and development now give priority to?

Process for thinking through how we might identify research problems, grounded in large-world challenges, likely to lead to the creation of useful knowledge capable of enabling those with the power and influence to make positive change

Are the traditional risk assessment approaches obsolete?

It depends ..for example

- *on the extent to which they fail to be fit for purpose*
- *the value of new methods/ frameworks in supporting better decisions*
- *on how existing principles/ theories can be revitalised by new ways of thinking/ doing*

X THE PLACE OF USEFUL LEARNING

University of Strathclyde Glasgow