Defining Resilience for Emerging Technologies

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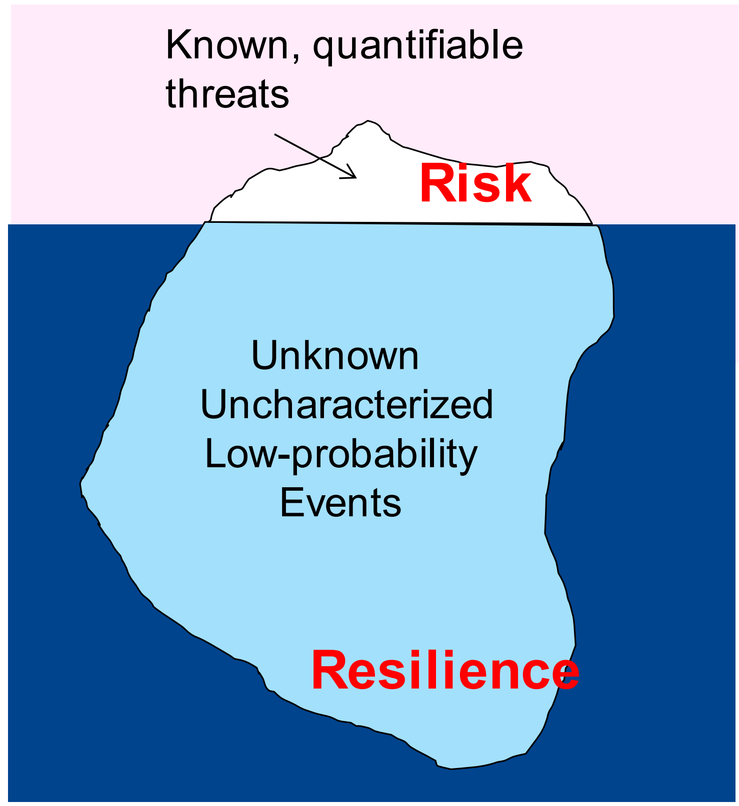
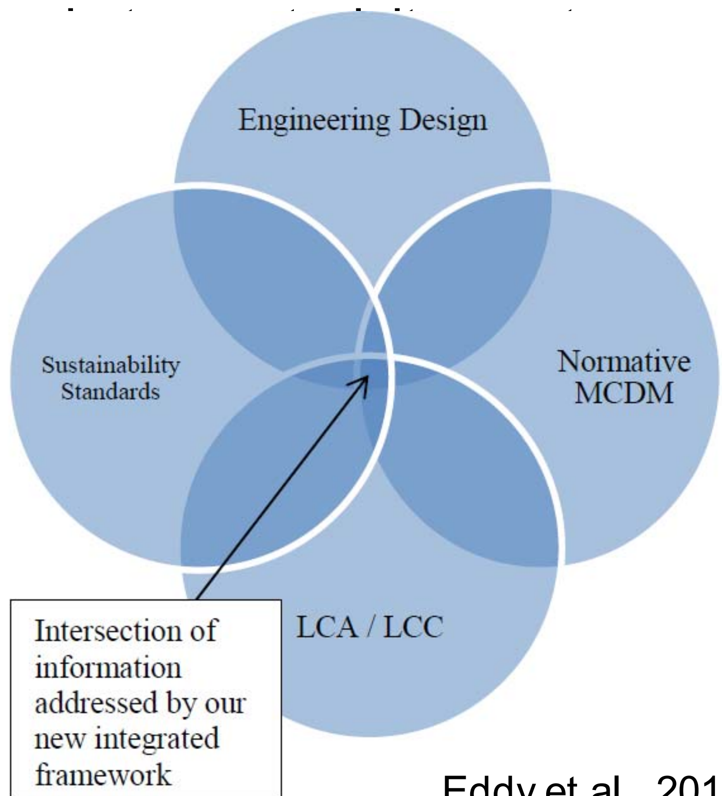


Future

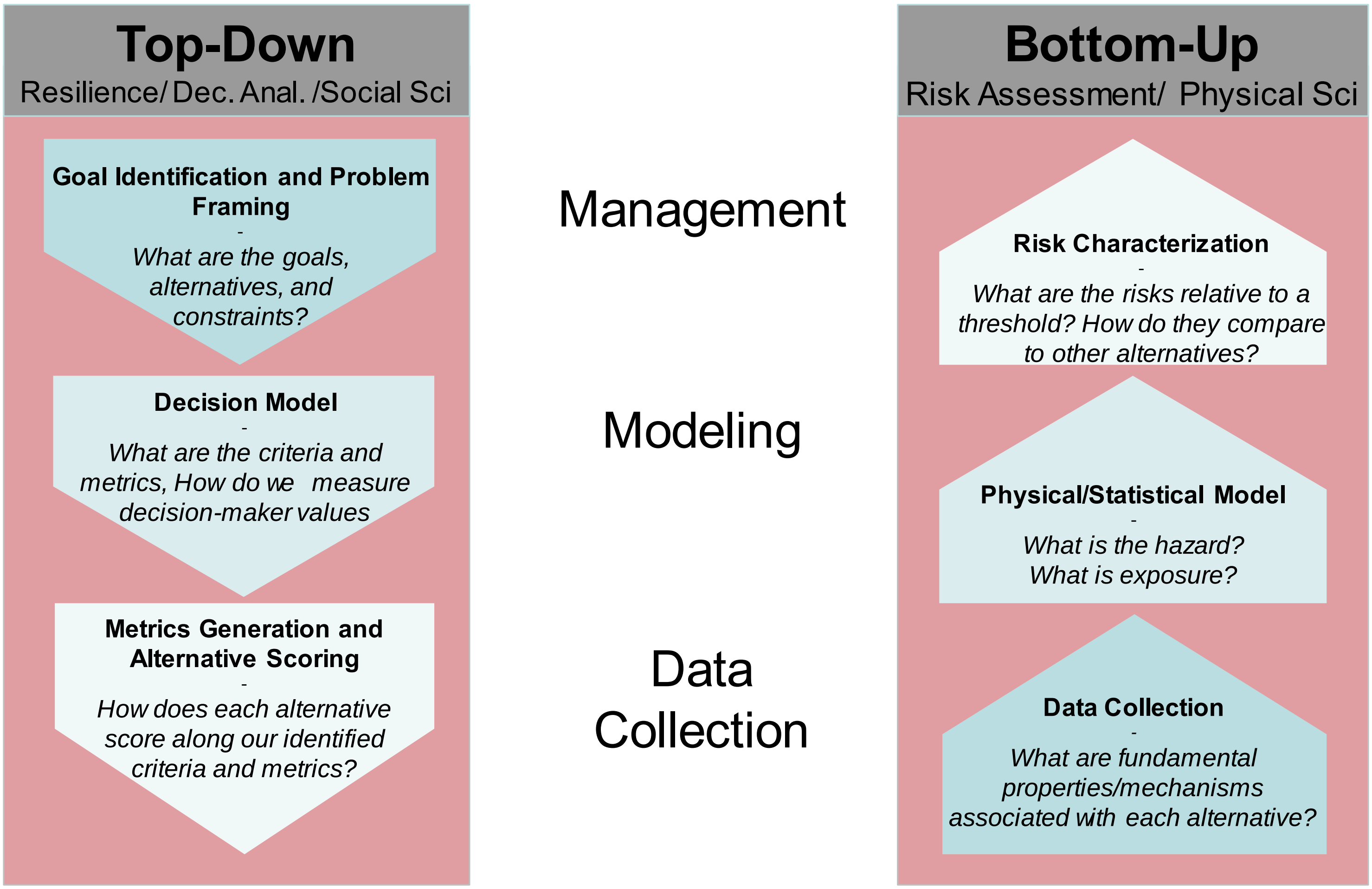
- **Sustainable Nanomanufacturing:** introduce sustainability/resilience considerations early into manufacturing process.
- **Challenge:** Conflicting objecti
and product performance.

- **Solution:** Integrated Top-Down Framework using tools
- **Tools:** Computational Chemistry, product design and Life Cycle *WITH* Decision Analysis



Eddy et al., 2013

Environment/Technology Challenges and Tools



Linkov et al., 2014

Outline

- From Risk to Resilience: Definitions
  - Risk
    - Conceptualization
    - Risk Assessment Case Studies
    - Problems with Risk-based Approaches
  - Resilience
    - Conceptualization
    - Resilience Matrix Approach and Jamaica Bay Case
    - Network Science Approach
- Relevance to Emerging Technologies
- Discussion

Risk Management Challenges

[illegible]

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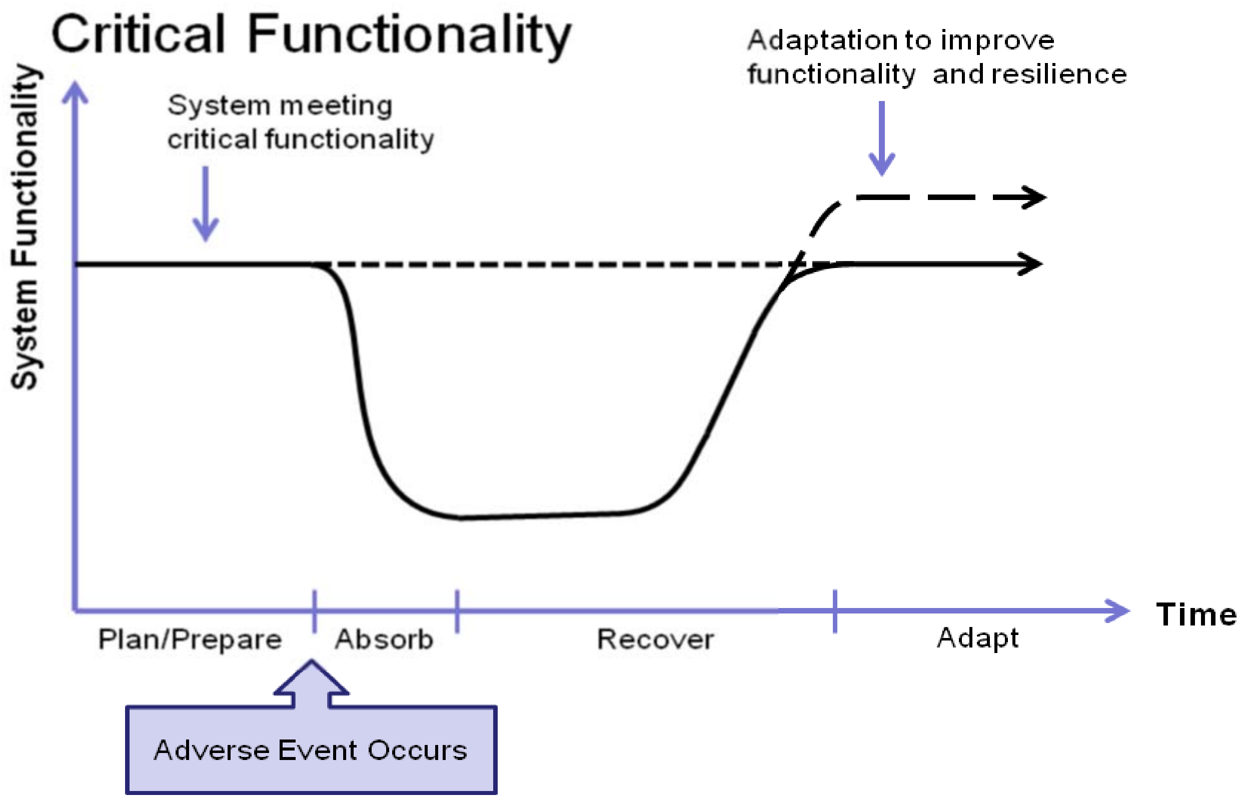
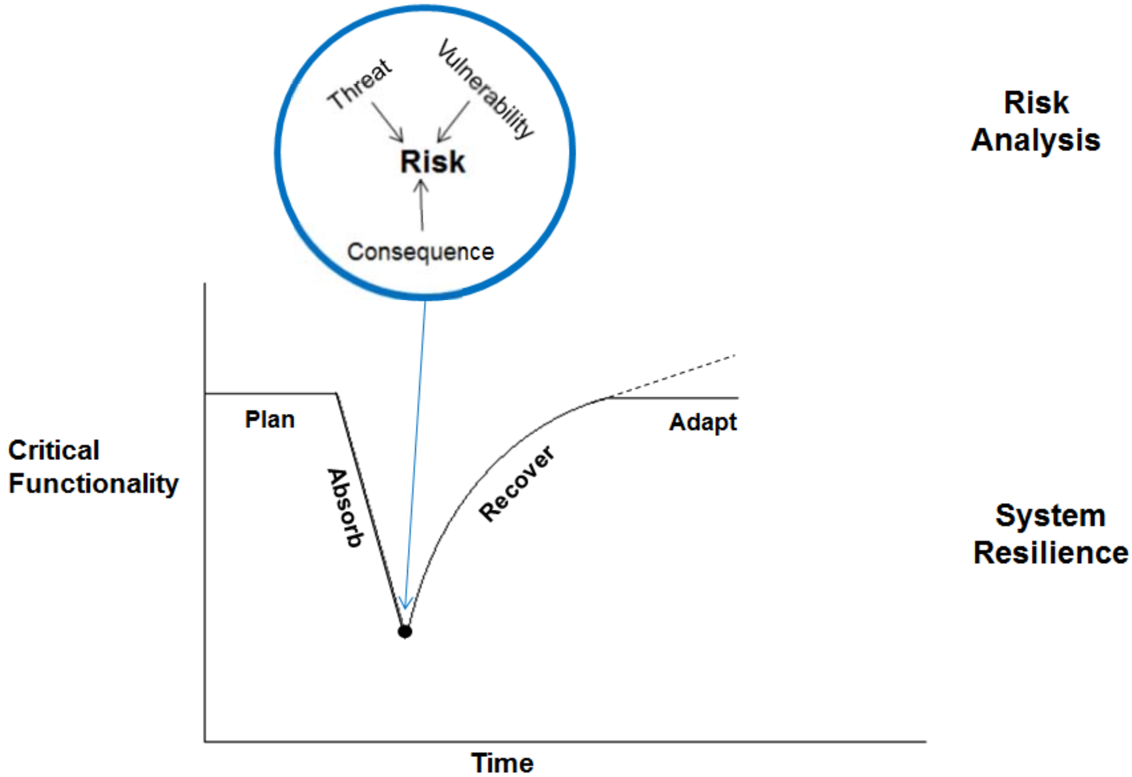
- Requires specific knowledge and quantification of all three components
- No temporal component
- Modern system complexity and threat uncertainty make risk management difficult and expensive.

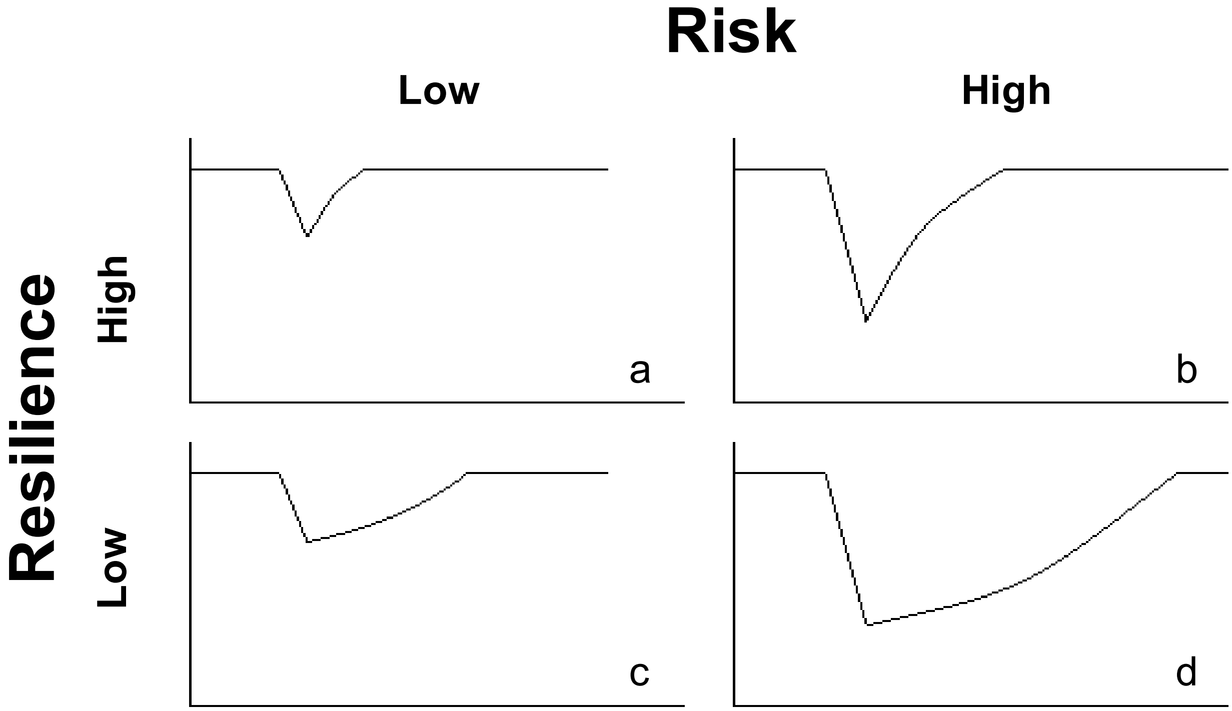
rΣsilience metrics



Risk and Resilience are Different, but Complimentary



After Linkov et al, Nature Climate Change 2014



Traditional risk management focuses on planning and reducing vulnerabilities. Resilience management puts additional emphasis on speeding recovery and facilitating adaptation.

After Linkov et al, Nature Climate Change 2014

Resilient Design in the Context of Nano

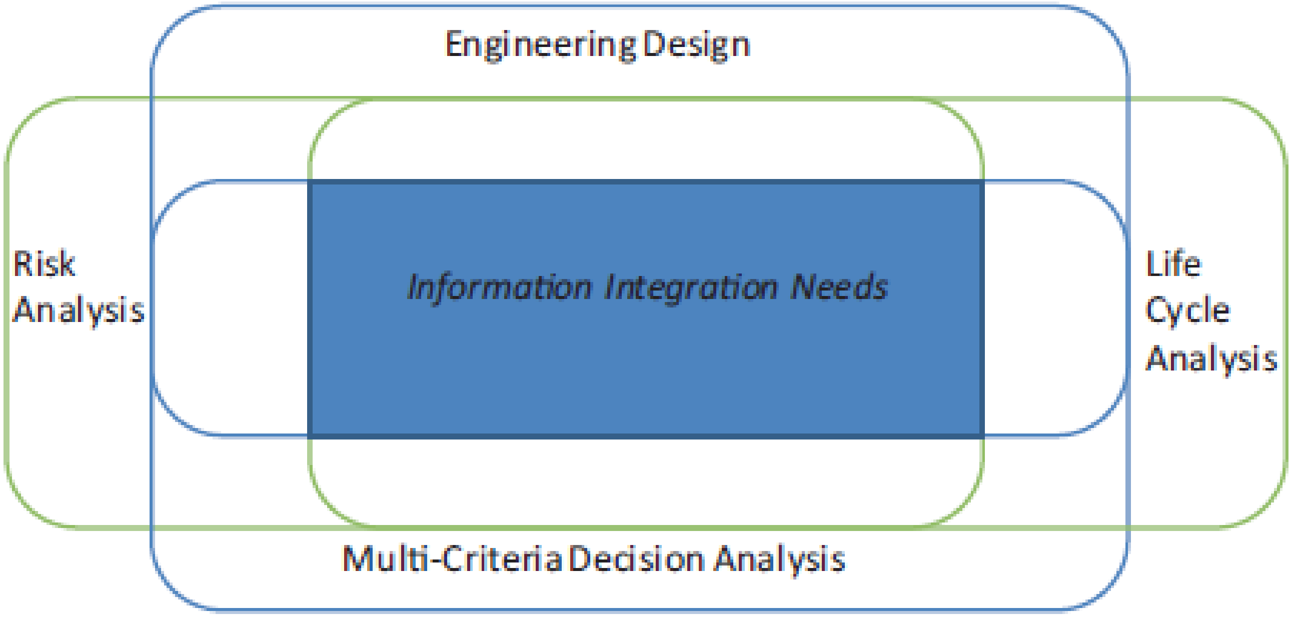
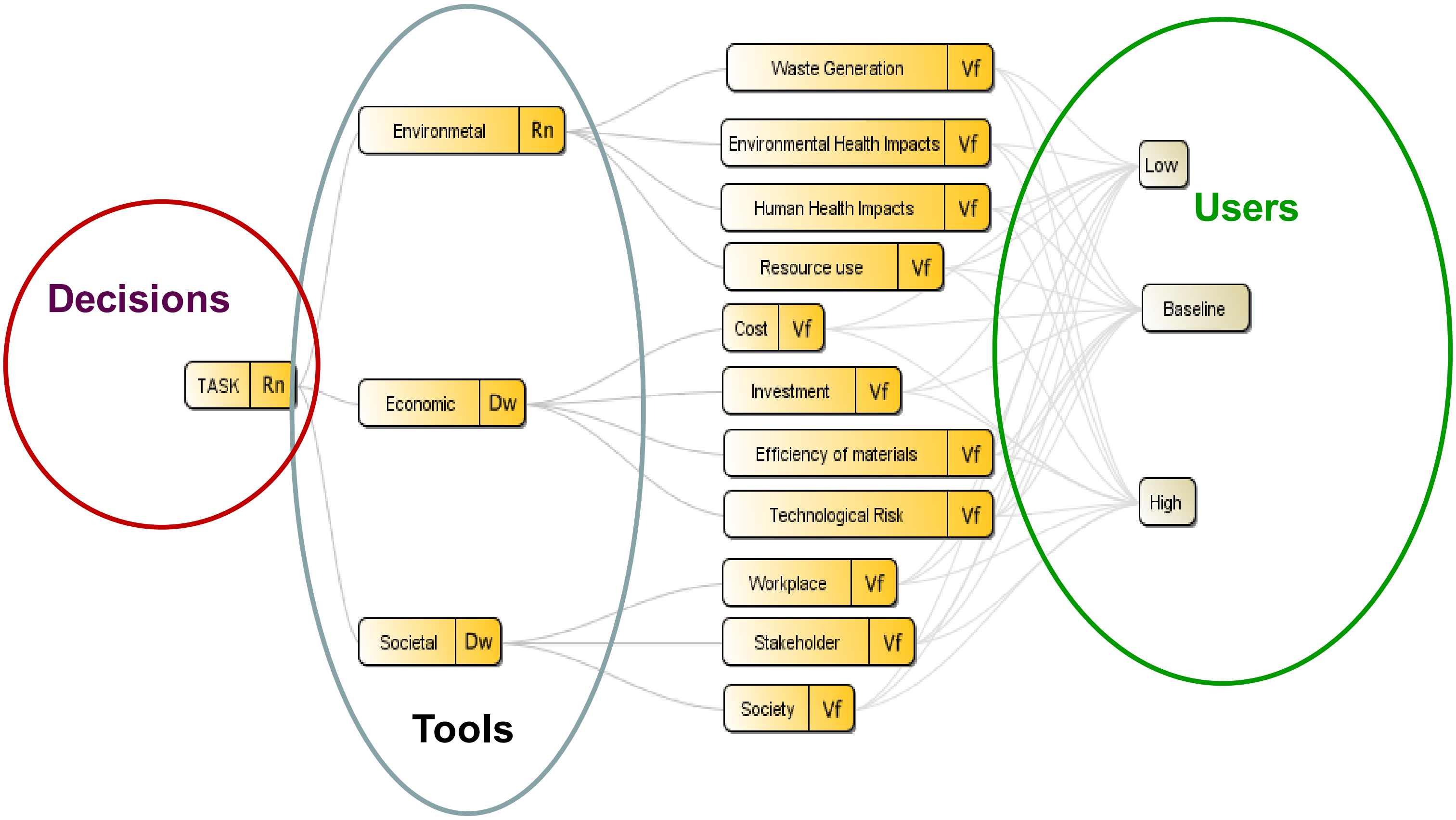


Figure 2 Integration of risk and life cycle analyses to guide engineering design using multi criteria decision analysis (after [21]).

After Fadel et al, Nano Today, 2014

Sustainable Nanomanufacturing as Triple Bottom Line



Subramanian, Linkov et al (2014), Nano Today

Resilience: Matrix Approach

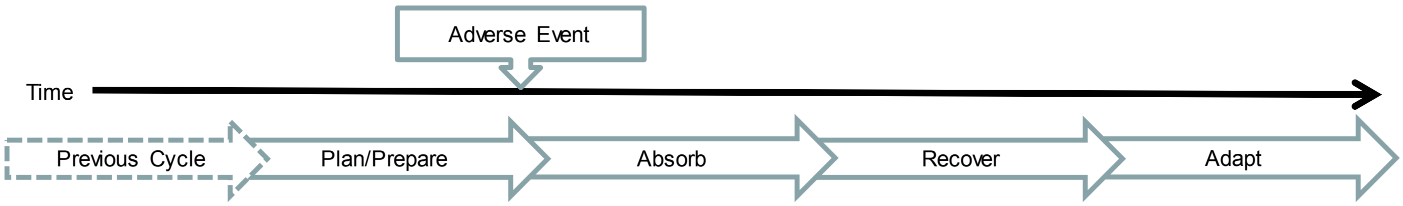
<u>Resilience Matrix:</u>

Analyze the functionality of each **domain** of the system across each **stage** of the event timeline

	Prepare	Absorb	Recover	Adapt
Physical				
Information				
Cognitive				
Social				

- Uses general metrics for measuring relative system resilience
- Different from vulnerability assessment – threats unknown
- Useful for identifying weak areas and prioritizing investment to improve overall resilience

General Form of Resilience Matrix



	Plan/Prepare	Absorb	Recover	Adapt
Physical	• State and capability of equipment and personnel, network structure	• Event recognition and system performance to maintain function	• System changes to recover previous functionality	• Changes to improve system resilience
Information	• Data preparation, presentation, analysis, and storage	• Real-time assessment of functionality, anticipation of cascading losses and event closure	• Data use to track recovery progress and anticipate recovery scenarios	• Creation and improvement of data storage and use protocols
Cognitive	• System design and operation decisions, with anticipation of adverse events	• Contingency protocols and proactive event management	• Recovery decision-making and communication	• Design of new system configurations, objectives, and decision criteria
Social	• Social network, social capital, institutional and cultural norms, and training	• Resourceful and accessible personnel and social institutions for event response	• Teamwork and knowledge sharing to enhance system recovery	• Addition of or changes to institutions, policies, training programs, and culture

From Linkov et al, Env. Sci. & Tech 2013

Assessment using Decision Analysis

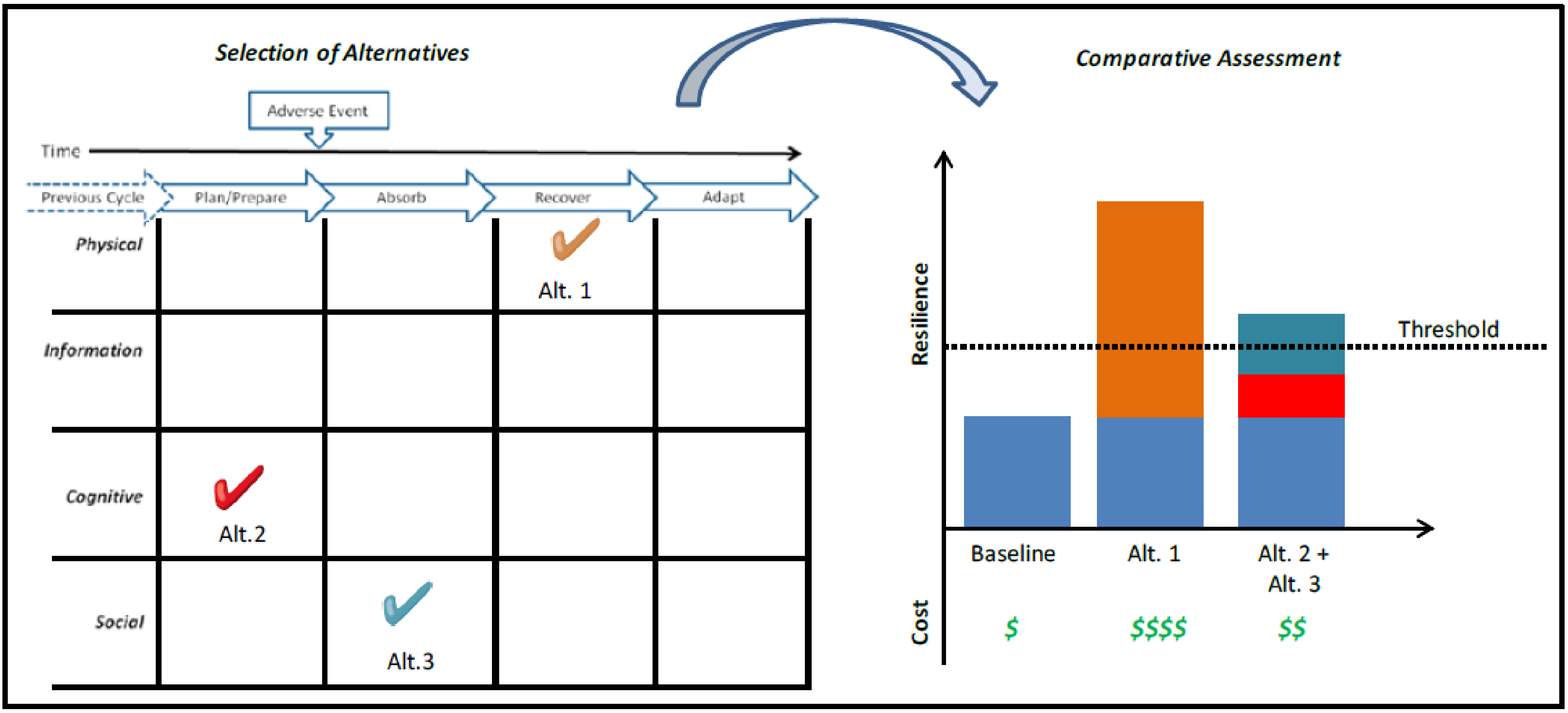


Figure 5: Comparative Assessment of Resilience-Enhancing Alternatives

Use developed resilience metrics to comparatively assess the costs and benefits of different courses of action

Prioritize Efforts

- Use matrix form to identify weaknesses in resilience.
- Ex:

Limiting Bioavailability in Environment

	Prepare	Absorb	Recover	Adapt
Physical	90%	81%	62%	10%
Information	80%	19%	23%	75%
Cognitive	68%	95%	22%	40%
Social	76%	88%	92%	34%

(Hypothetical Values)

How it works: Material/Technology Evaluation

- Baseline assessment can be used to evaluate proposed materials/technologies

	Prepare	Absorb	Recover	Adapt
Physical	71	16	60	10
Information	63	45	21	18
Cognitive	90	49	38	27
Social	82	54	12	52

43

Material/technology 1

	Prepare	Absorb	Recover	Adapt
Physical	+10	+18	+9	+32
Information	+8		+17	
Cognitive				
Social				

	Prepare	Absorb	Recover	Adapt
Physical	81	34	69	42
Information	71	45	38	18
Cognitive	90	49	38	27
Social	82	54	12	52

51

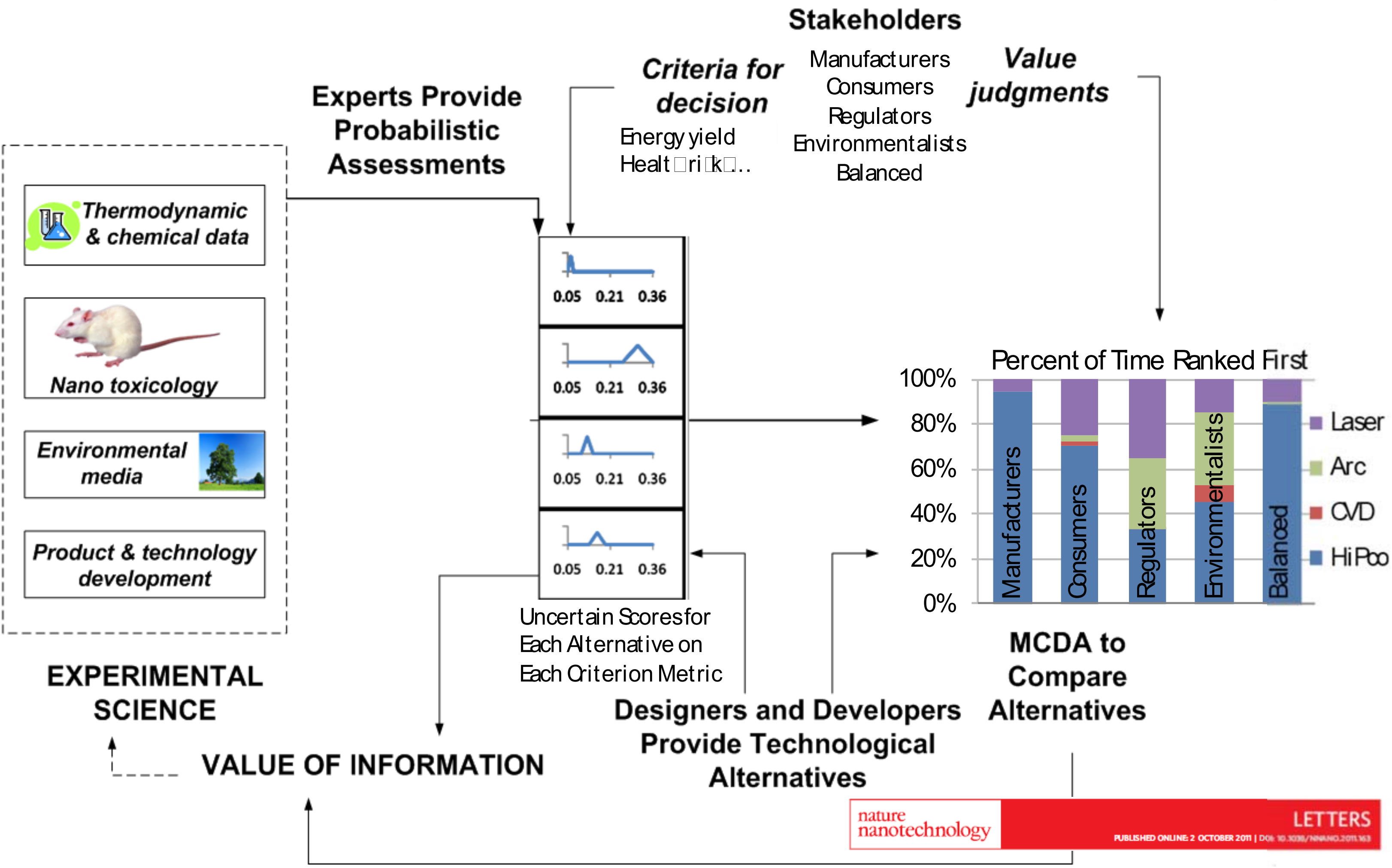
Material/Technology 2

	Prepare	Absorb	Recover	Adapt
Physical				
Information		+5	+15	+22
Cognitive				
Social	+3		+12	+21

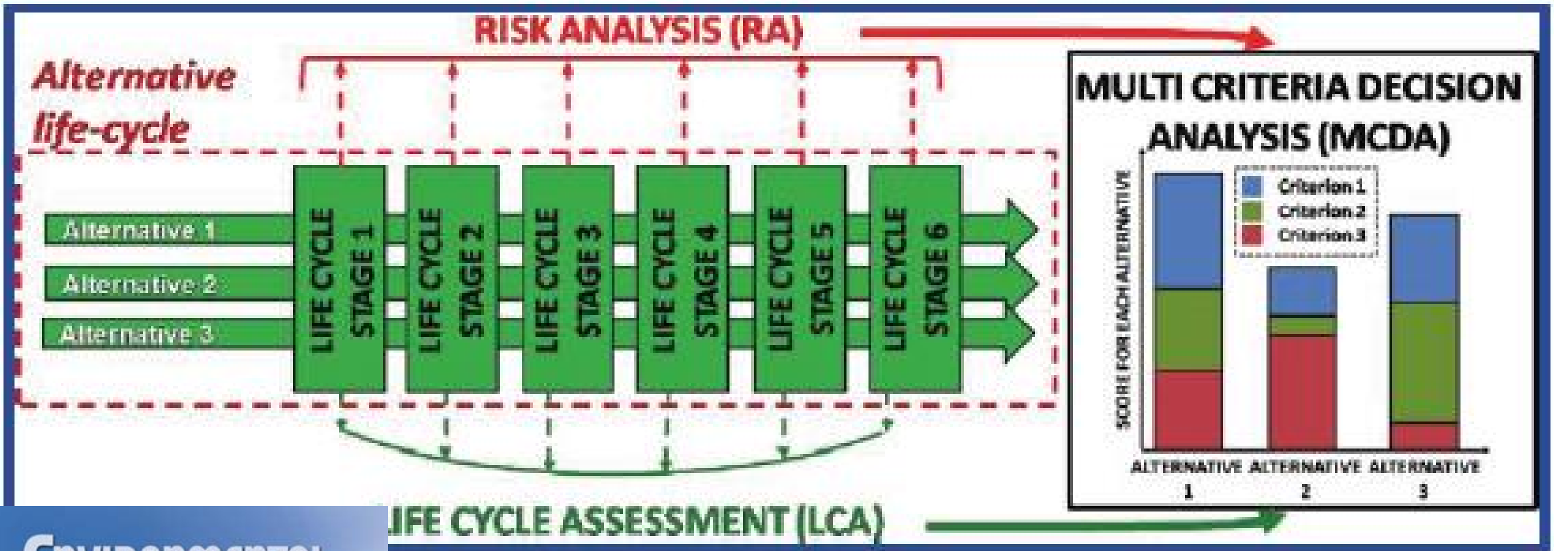
	Prepare	Absorb	Recover	Adapt
Physical	71	6	60	10
Information	63	50	36	40
Cognitive	90	49	38	27
Social	85	54	24	73

47

Framework for Integrating Physical & Social Science To Guide Product Design and Manufacturing



Framework for Tools Integration



Integration of RA, MCDA and LCA allows selection of sustainable management alternatives for emerging risks

after Linkov and Seager, 2011

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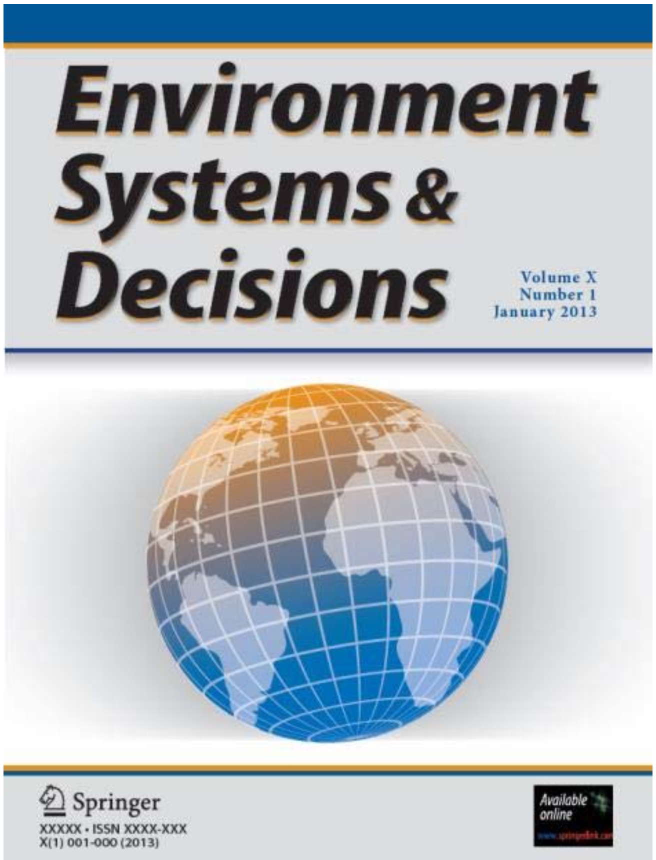

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