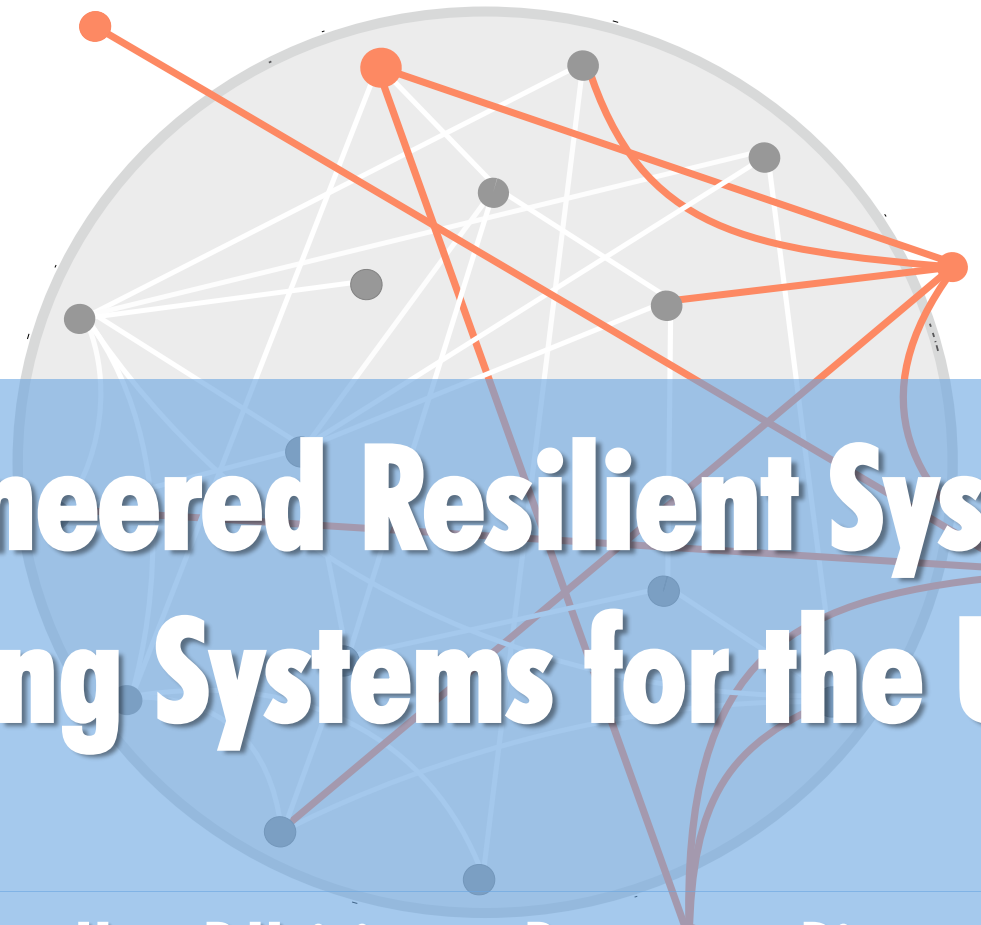


Engineered Resilient Systems - Engineering Systems for the Unexpected

Hans R Heinimann, Programme Director
Future Resilient Systems @ CREATE
Singapore

Key Messages

1. Resilience: framework and strategy to cope with **ambiguity** and **unexpectedness**
2. Building resilience: (1) making systems **more robust**, (2) **recoverable**, and (3) **reconfigurable**
3. **Interconnectedness**: driver for ambiguity and unexpectedness (emergence)
4. **Regime shifts** cannot be predicted with historic data

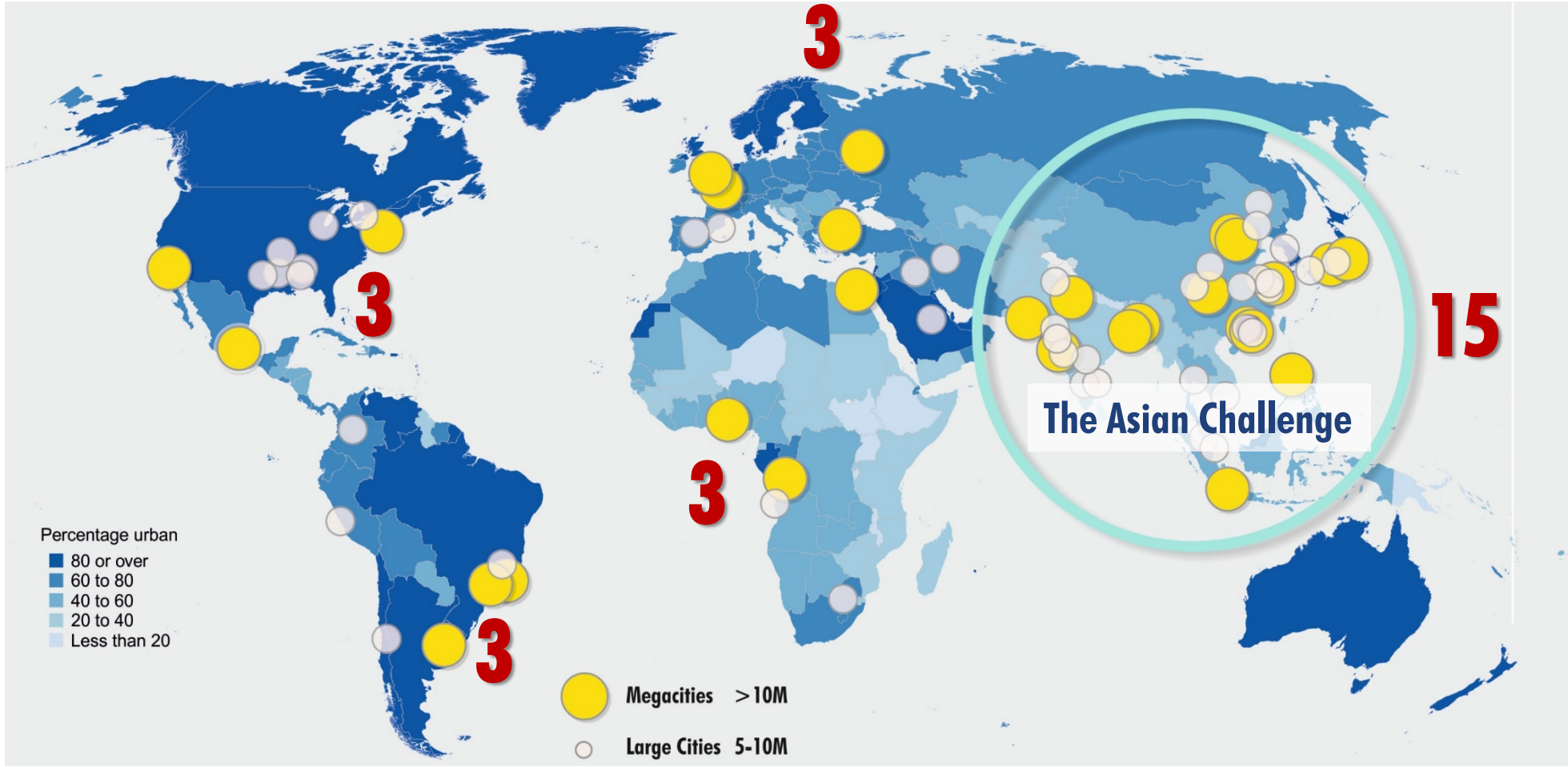
Outline

- SIN CREATE programme “Future Resilient Systems”
- 4 overarching trends
- Regime shifts, “Dragon Kings”
- Generic Resilience Framework
- Design for Robustness and Flexibility
- Organizational Behaviour Matters

Singapore-ETH Centre

- Established 2010 under CREATE Initiative
- SIN providing "urbanization lab"
  - High-density "urban habitats"
  - Urbanization challenges
- SIN 1st Class Research Ecosystem
  - NUS & NTU among World Top 15
  - ~10 International Uni's @ CREATE
- SEC Platform
  - FCL Future Cities Laboratory
  - FRS Future Resilient Systems

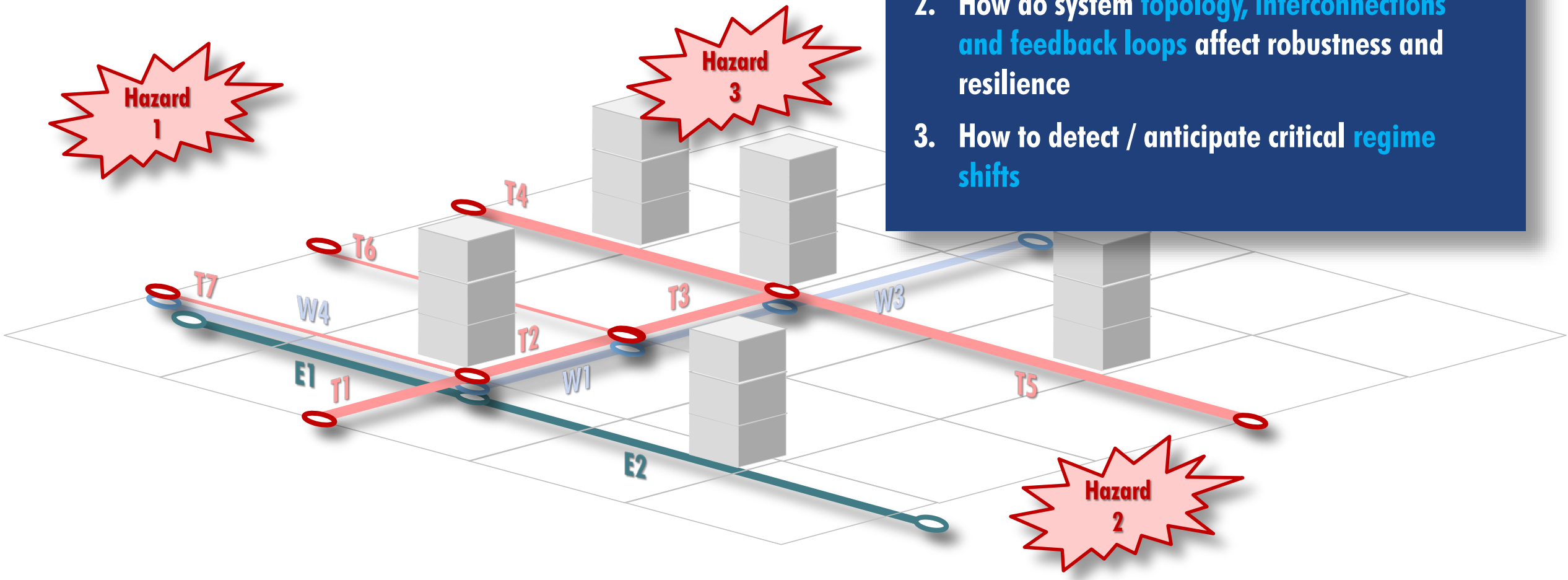
Urbanisation – The Main Driver



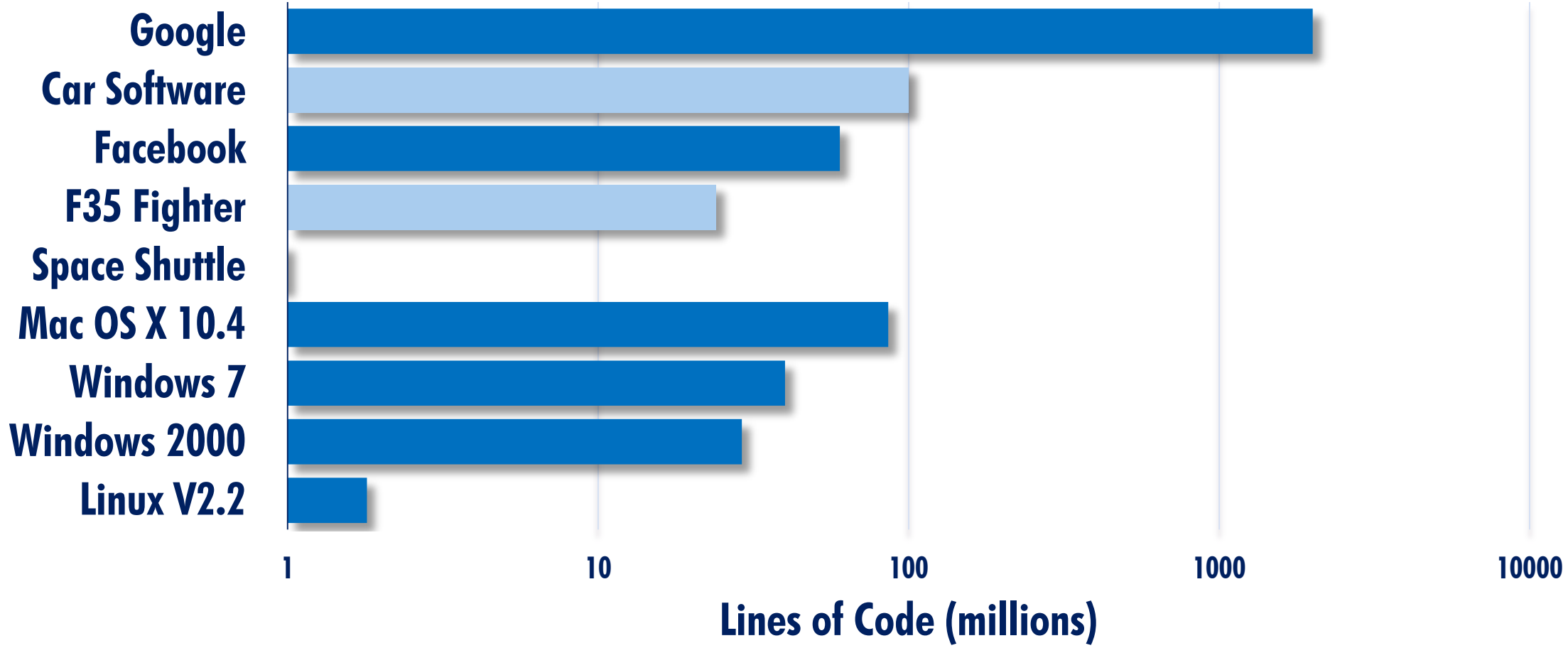
UN (2014). World Urbanization Prospects The 2014 Revision. Highlights. 27 p.

Interdependencies of Infrastructure Systems

1. How robust and resilient against a set of multi-hazard disruptions
2. How do system topology, interconnections and feedback loops affect robustness and resilience
3. How to detect / anticipate critical regime shifts



Cyber-Part Trends | Lines of Software Code

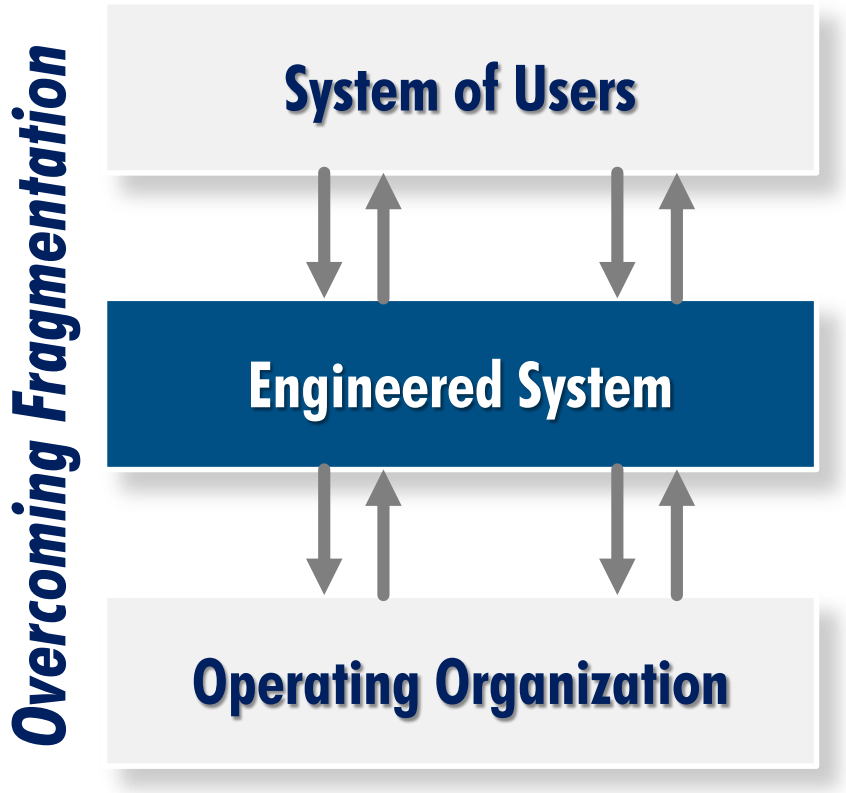


Artificial Intelligence

Artificial / Augmented

- Perception
- **Sensemaking**
- Action design
- Choice
- Action release
- Action control

Socio-Technical Perspective



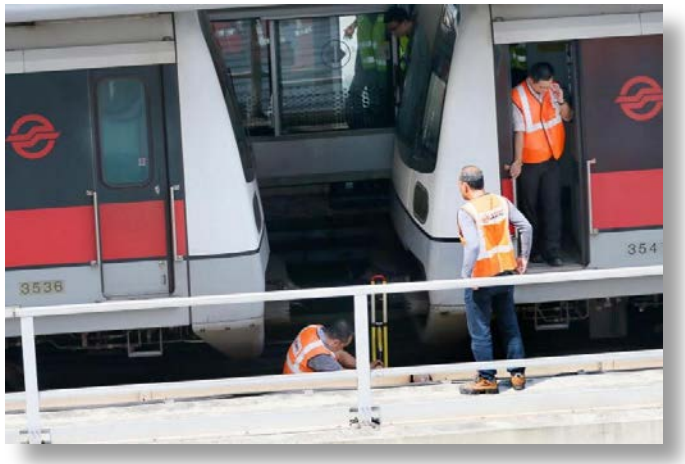
Engineered Resilient Systems

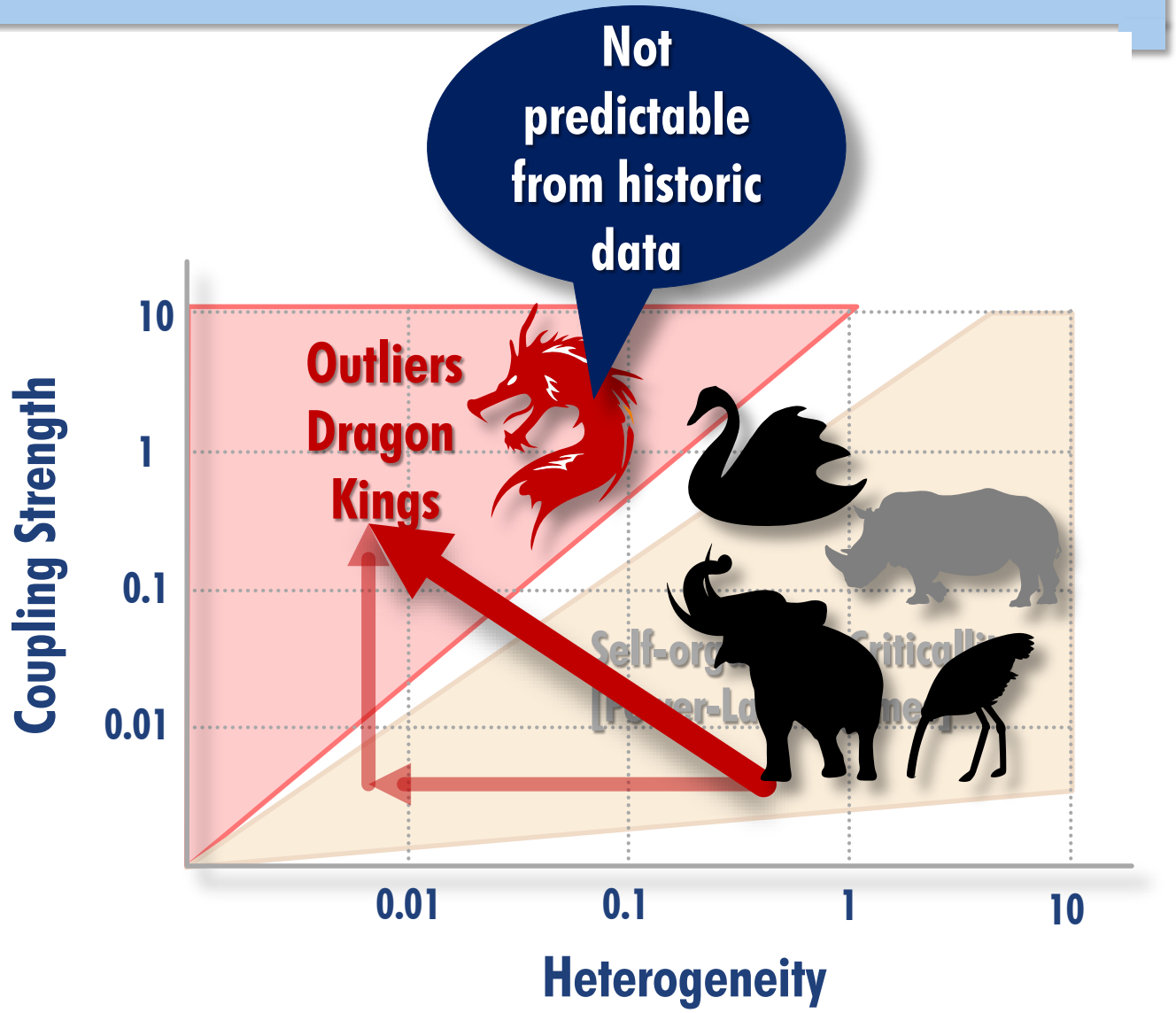
[DoD, since 2012]

Regime Shifts (Osorio et al. 2010)

"Even if it is of *low likelihood*, SINGAPORE will do something about it if the *consequence is very high*"

Joo Koon train collision, Nov-15-2017

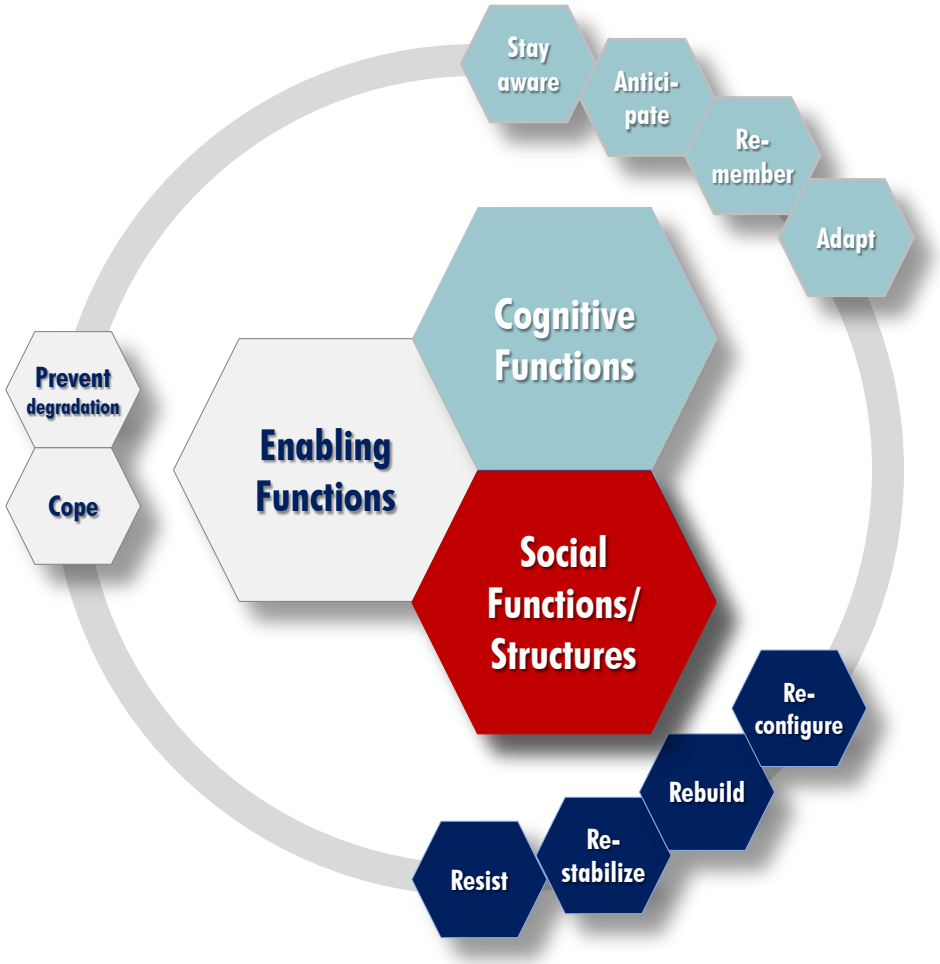




Increasing Ambiguity and Unexpectedness

MURRAY, R.M., J.C. DAY, M.D. INGHAM, L.J. REDER, and B.C. WILLIAMS. 2013. Engineering Resilient Space Systems. Pasadena, CA: Keck Institute for Space Studies. Accessed [Aug-22-2016]. [http://www.kiss.caltech.edu/study/systems/] 82 p.

Resilience – Building Blocks

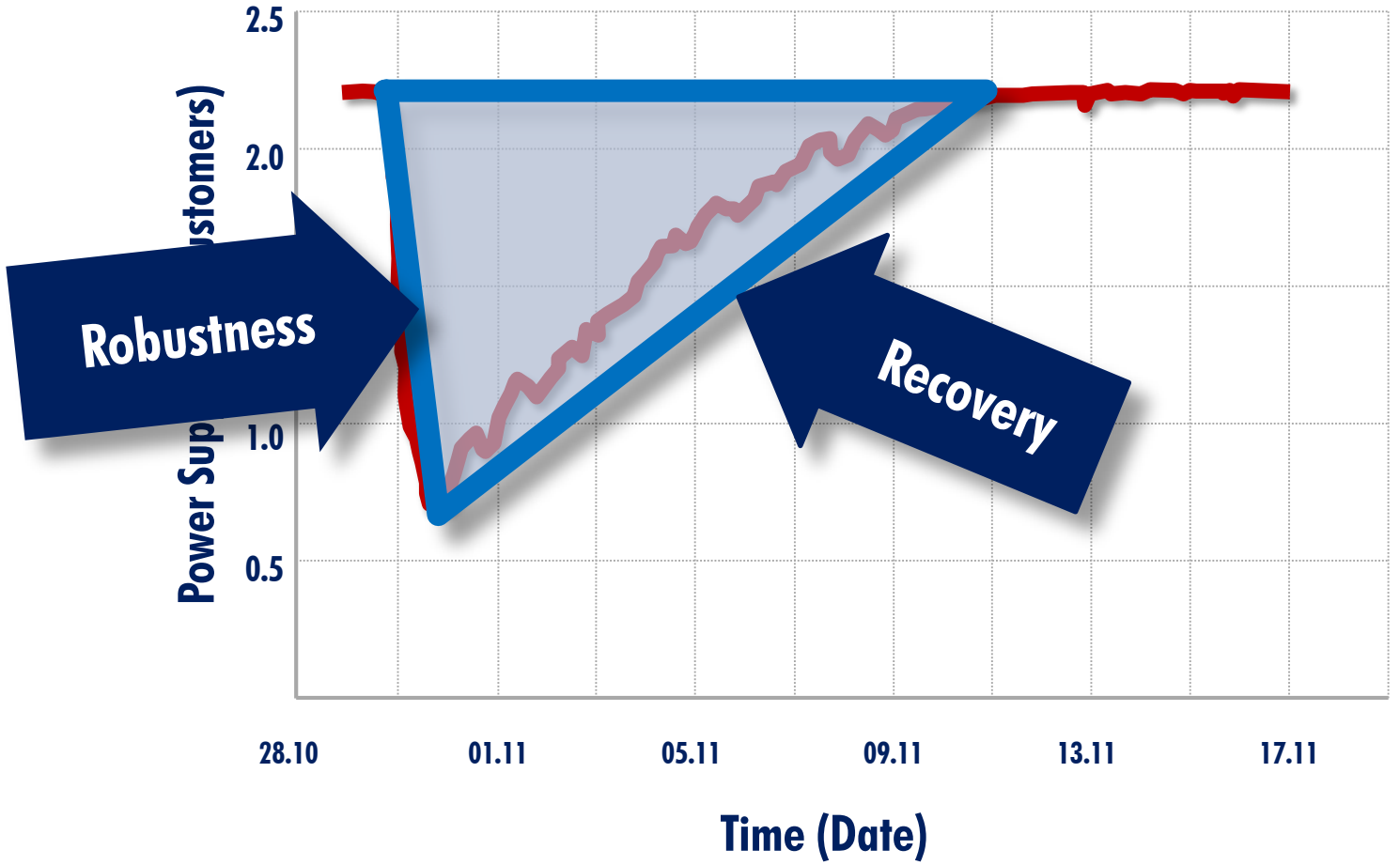


1. resist within acceptable limits of degradation,
2. restabilize critical functions,
3. rebuild functions, and
4. reconfigure the flow of substances, energy and services.

COUPLED with

5. staying aware,
6. anticipate,
7. respond,
8. update and adapt.

Building Resilience

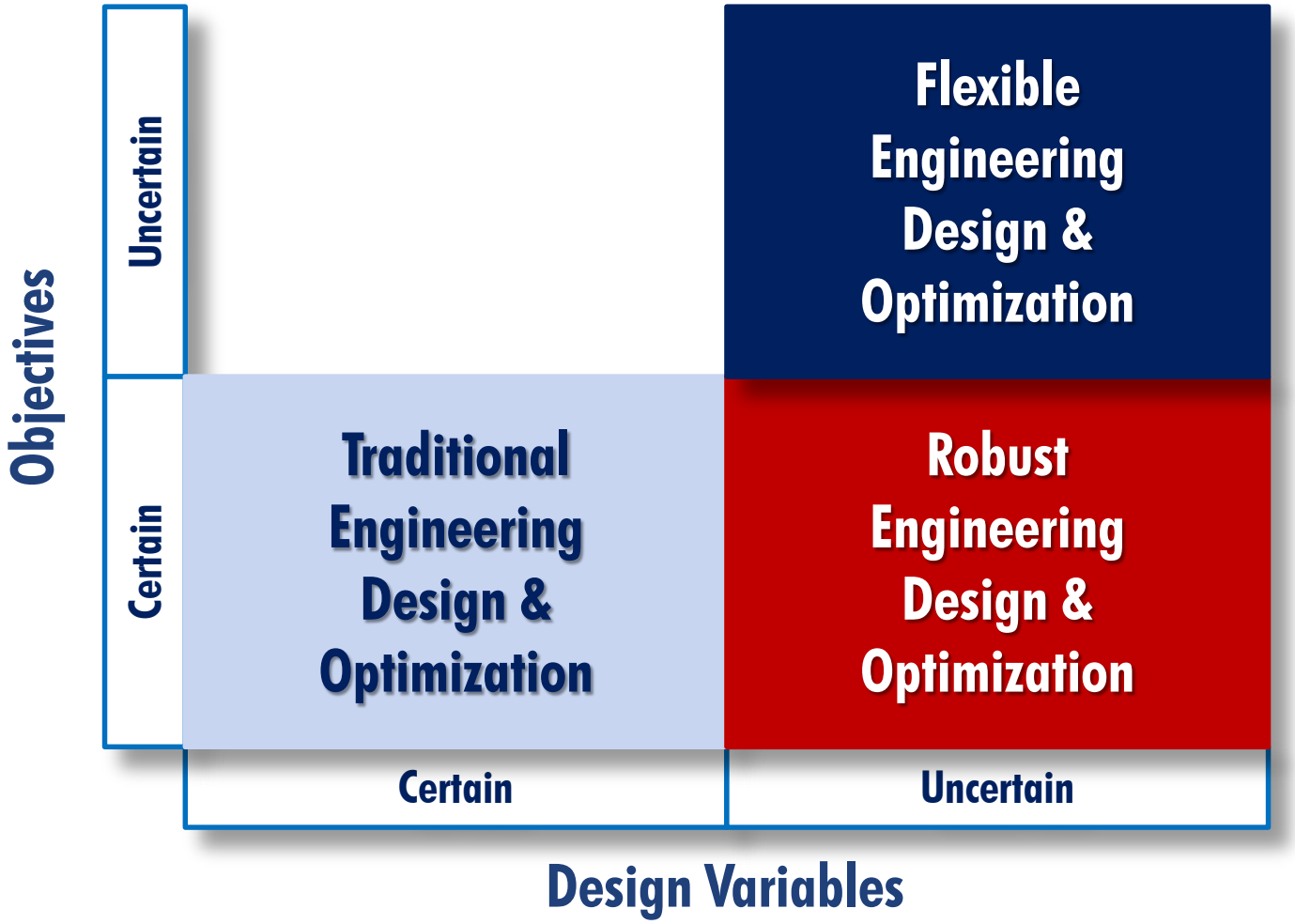


Flexibility, Robustness…

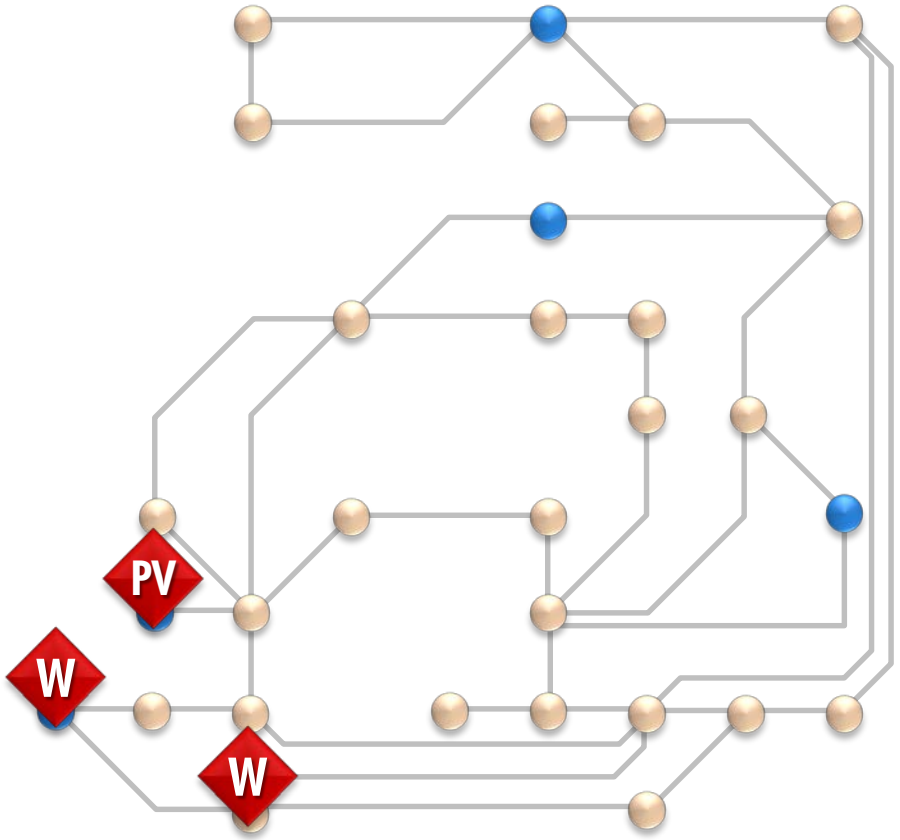
B52
1955-2044

B59
1956-1965

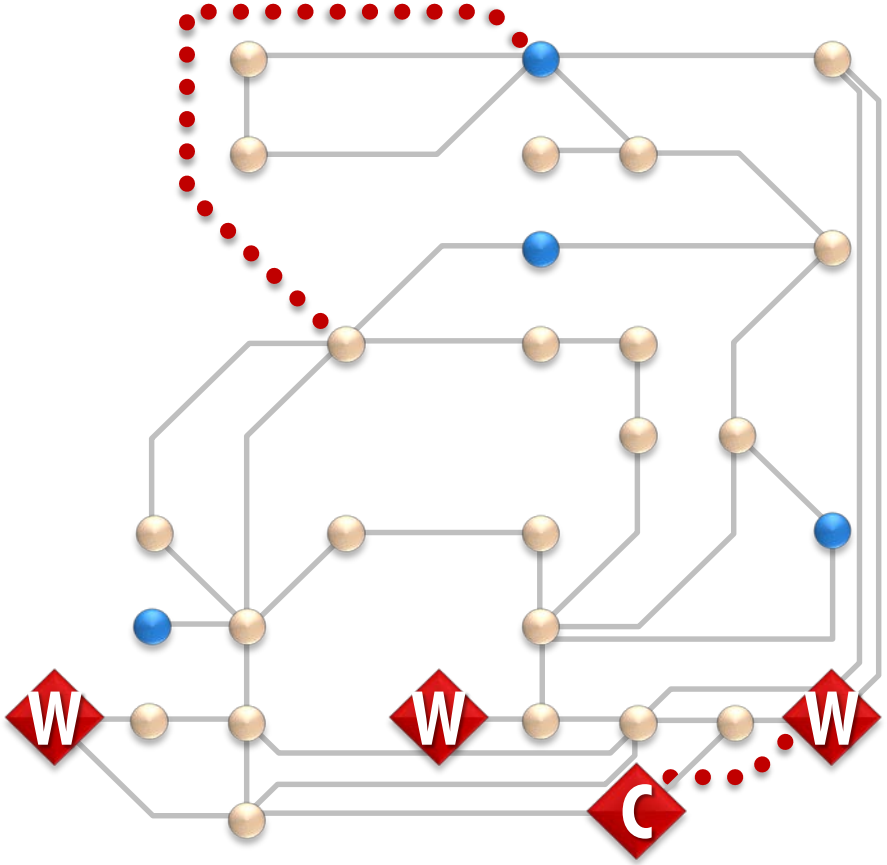
Robust Design



Robust Design – Key to Resilience IEEE-30

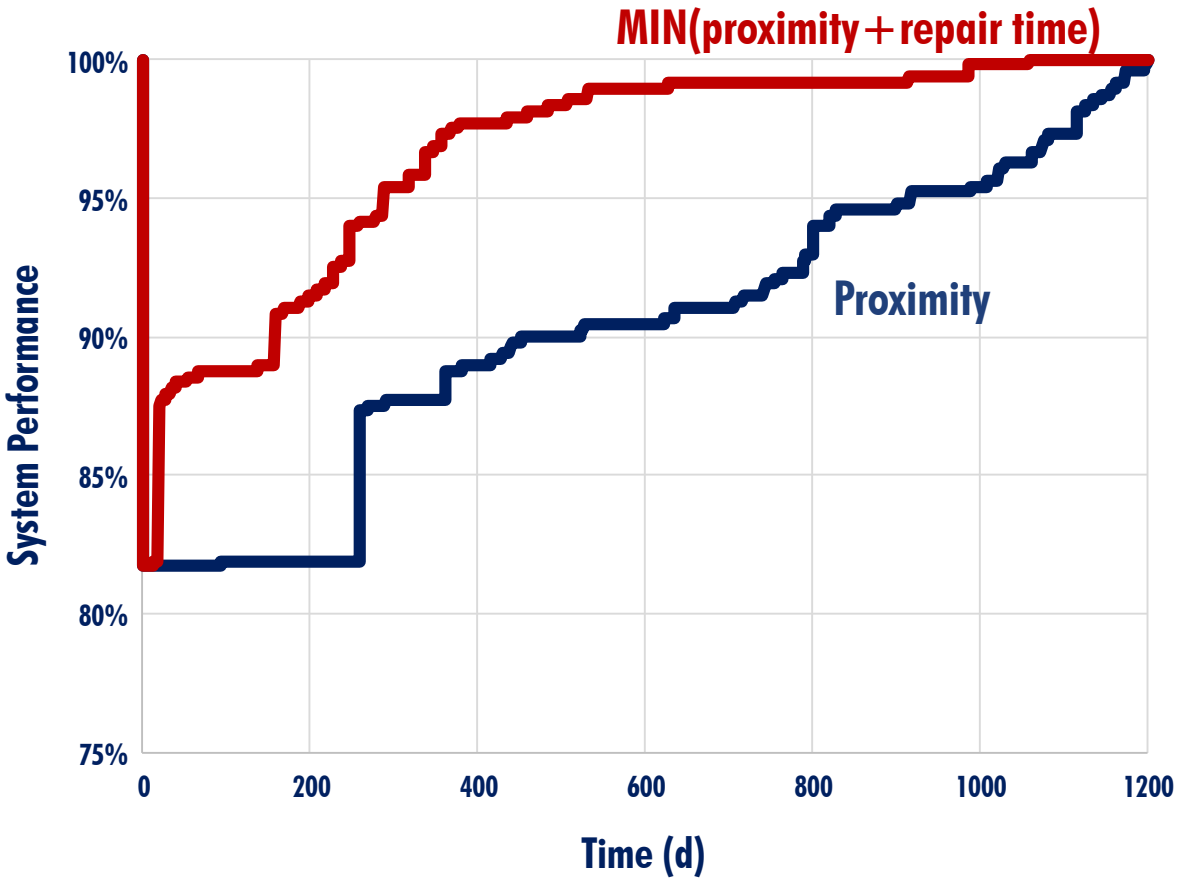


Traditional Optimization



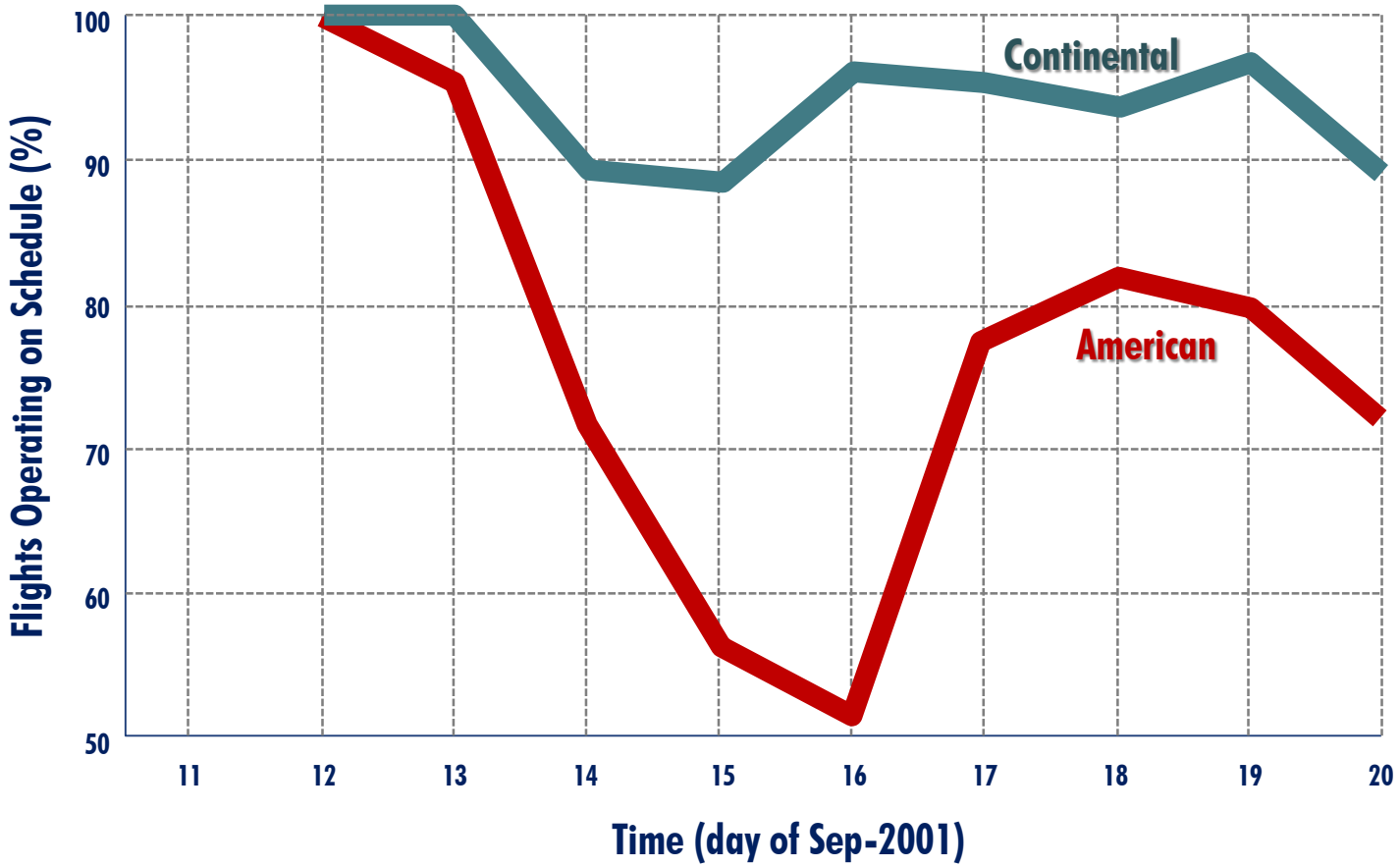
Robust Optimization

Influence of Repair Tactics on Recovery



Nazli Yonca Aydinl, H. Sebnem Duzgun, Hans Rudolf Heinimann, Friedemann Wenzel , Kaushal Raj Gnyawali (forthcoming): Evaluation of operational resilience enhancement strategies for rural transport networks und geohazards

Flight Operations Recovery After 9/11



YU, G. and X. QI. 2004. *Disruption management : framework, models and applications. Singapore ; River Edge, NJ. World Scientific. 294 p.*

Social Resilience

Problem Framing

Capture cues → make sense

Intelligence

Sensing, anticipating, sensemaking and the identification of purposeful action options are crucial to cope with ambiguous, unexpected events.

Decision Making

develop options → choice

Design

Action

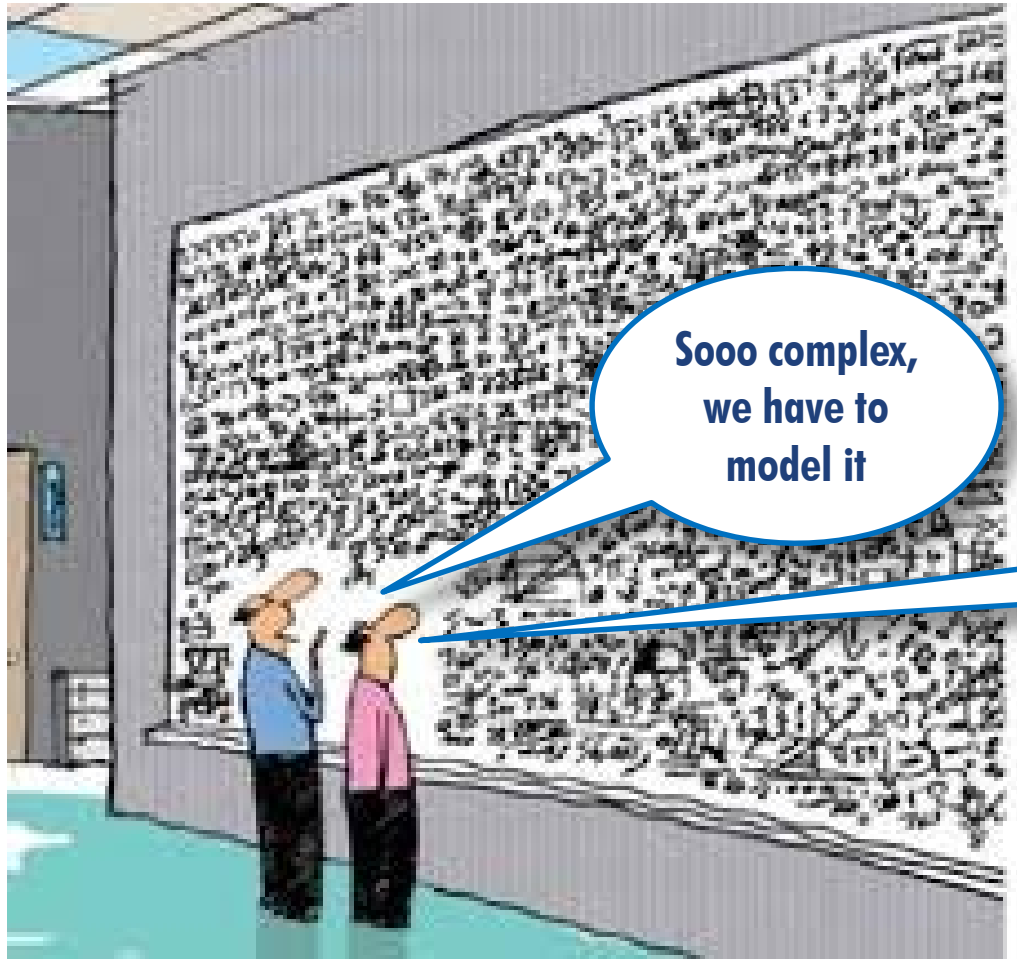
act

Act

- Update memory
- Reconfigure
- Rebuild
- Re-stabilize
- resist

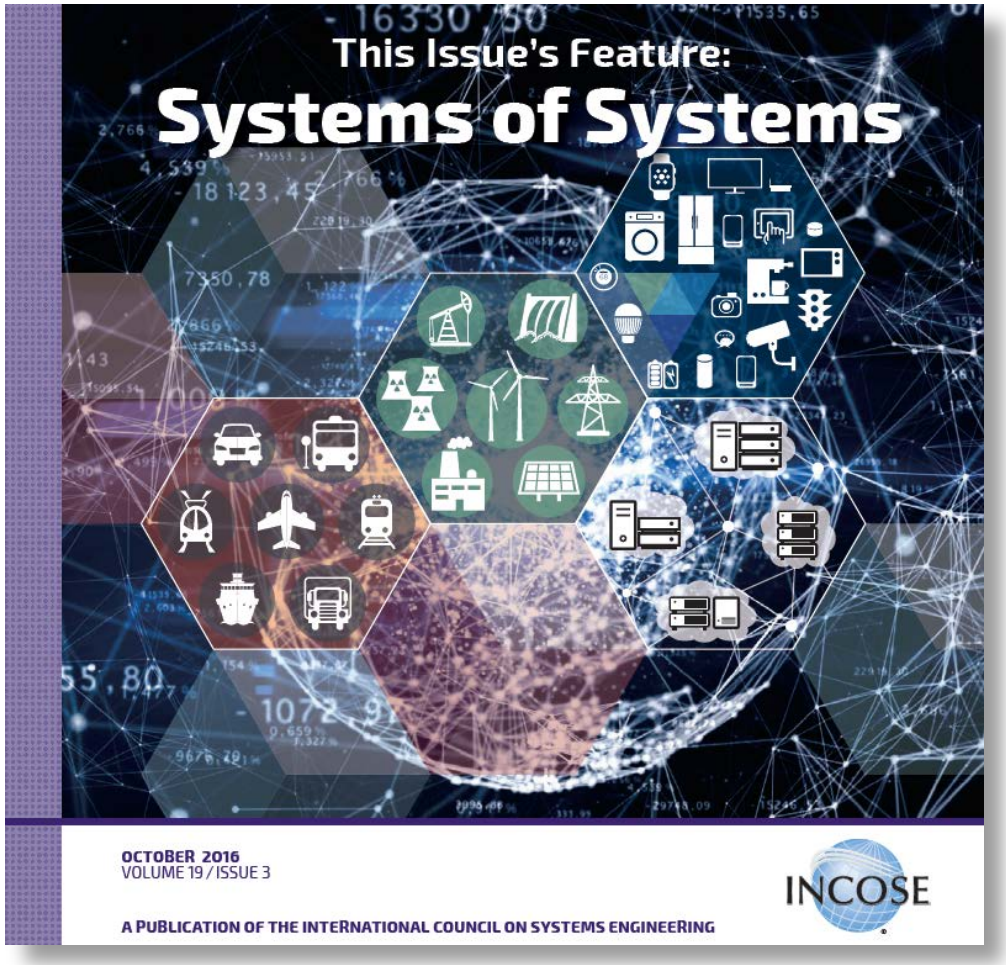
Resilience-building actions comprise of resistance, re-stabilizing critical social functions, recovery of social functions and reconfiguration of social interactions

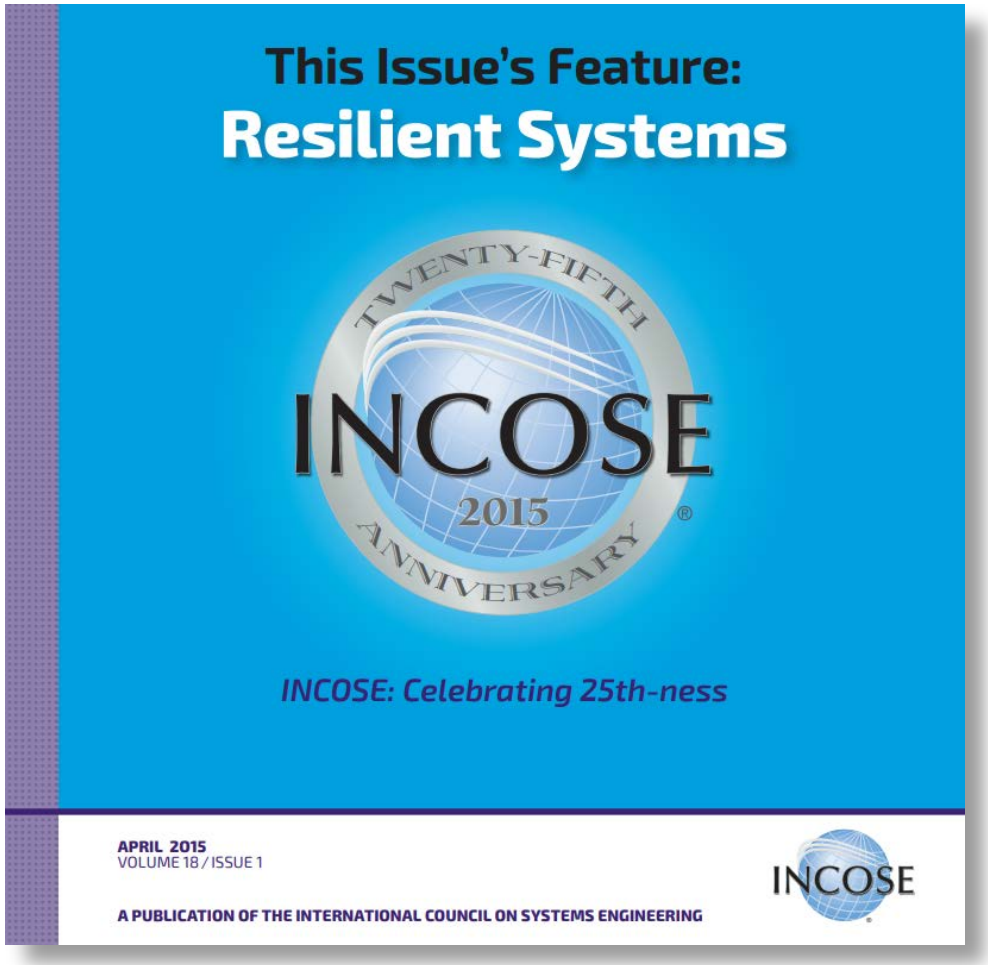
Pitfalls…



$$P = a \cdot x + b \cdot y + c \cdot z$$

INCOSE's Activities





To Sum Up…

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2. Building resilience: (1) making systems **more robust**, (2) **recoverable**, and (3) **reconfigurable**
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High Reliability Organisations (HRO)

[Weick, Hollnagel, Woods]