



# Resilience - concept and strategy to cope with unexpected and ambiguous disruptions

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



# Disruptive Technology



# Disruptions

## Perspective



# CPS

**Cyber-Physical Systems**

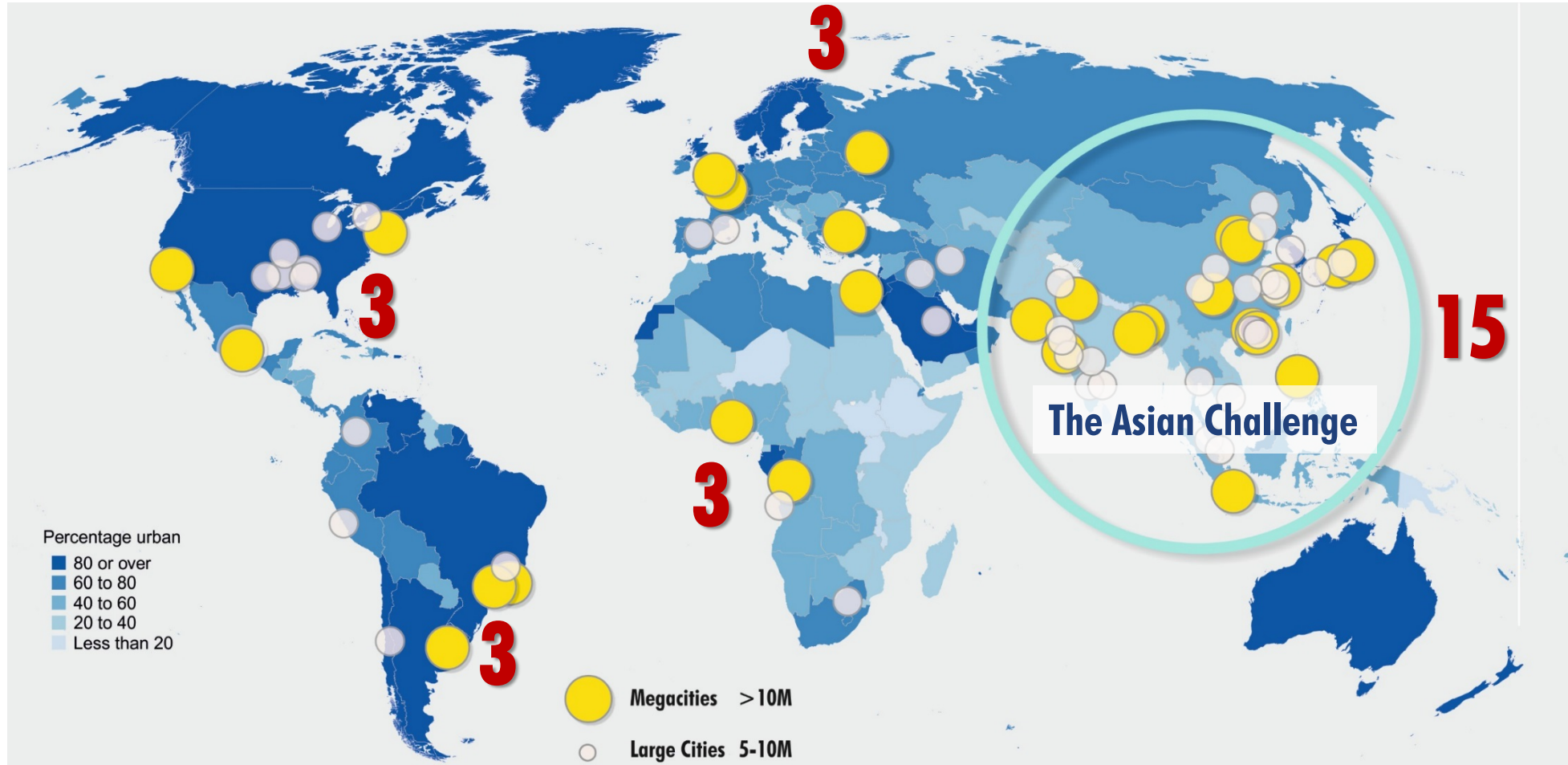
# CPHS

**Cyber-Physical-Human Systems**

## Key Messages

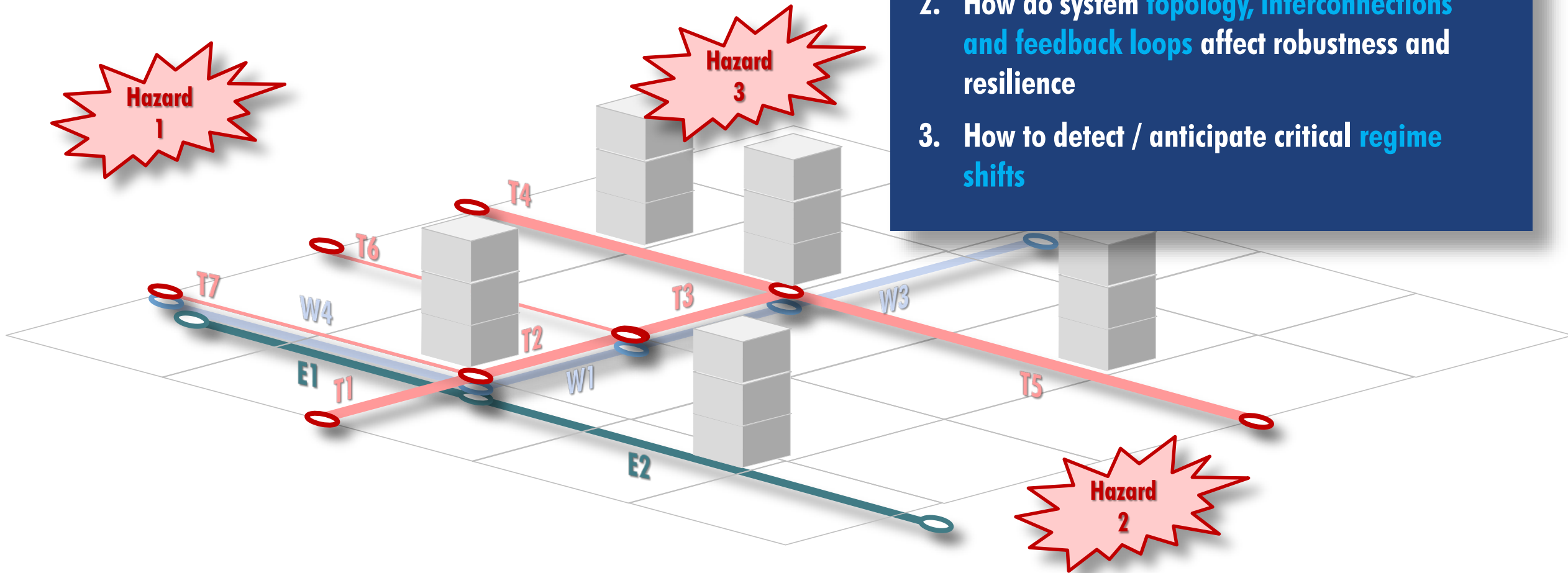
1. Resilience: framework and strategy to cope with **ambiguity and unexpectedness**
2. Building resilience: (1) making systems **more robust**, (2) **recoverable**, and (3) **reconfigurable**
3. **Interconnectedness**: driver for ambiguity and unexpectedness (emergence)
4. **Regime shifts** cannot be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

# Urbanisation – The Main Driver



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

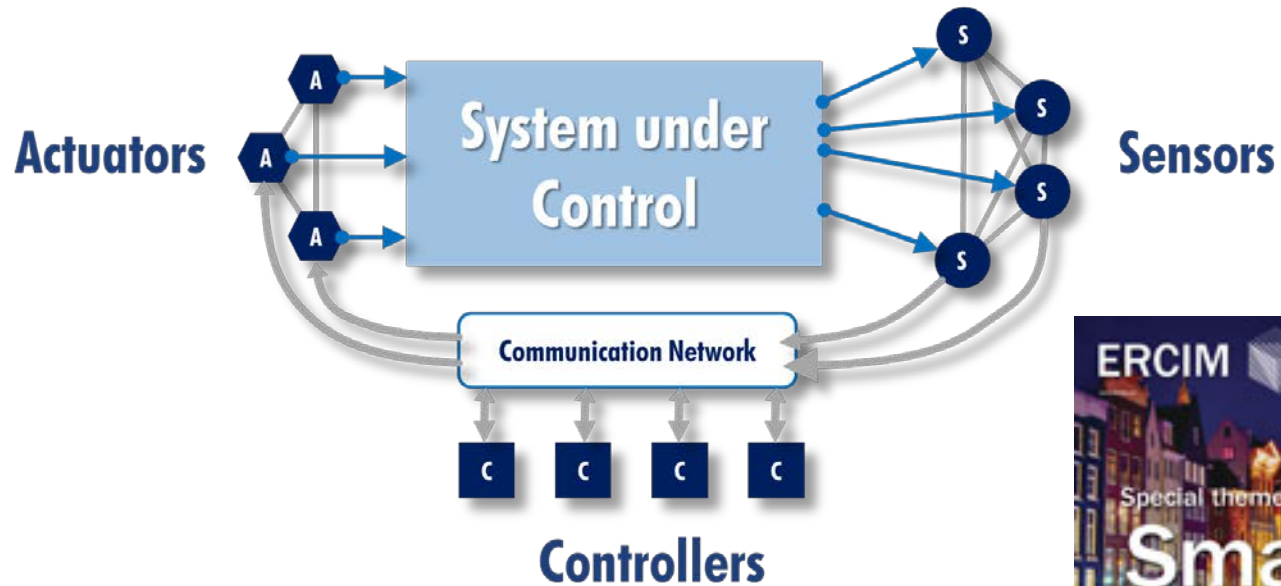
# Interdependencies of Infrastructure Systems



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-Physical Systems

## Cyber-Physical-Human Systems

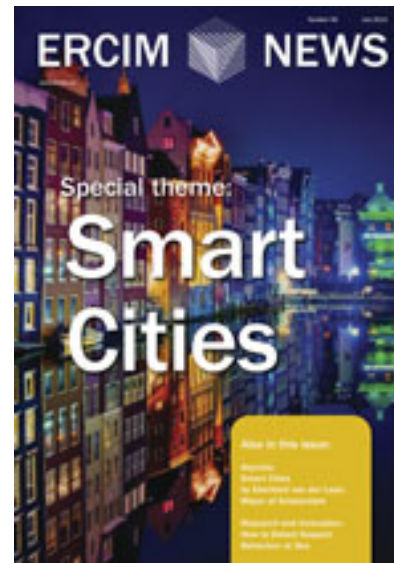


### Focus on

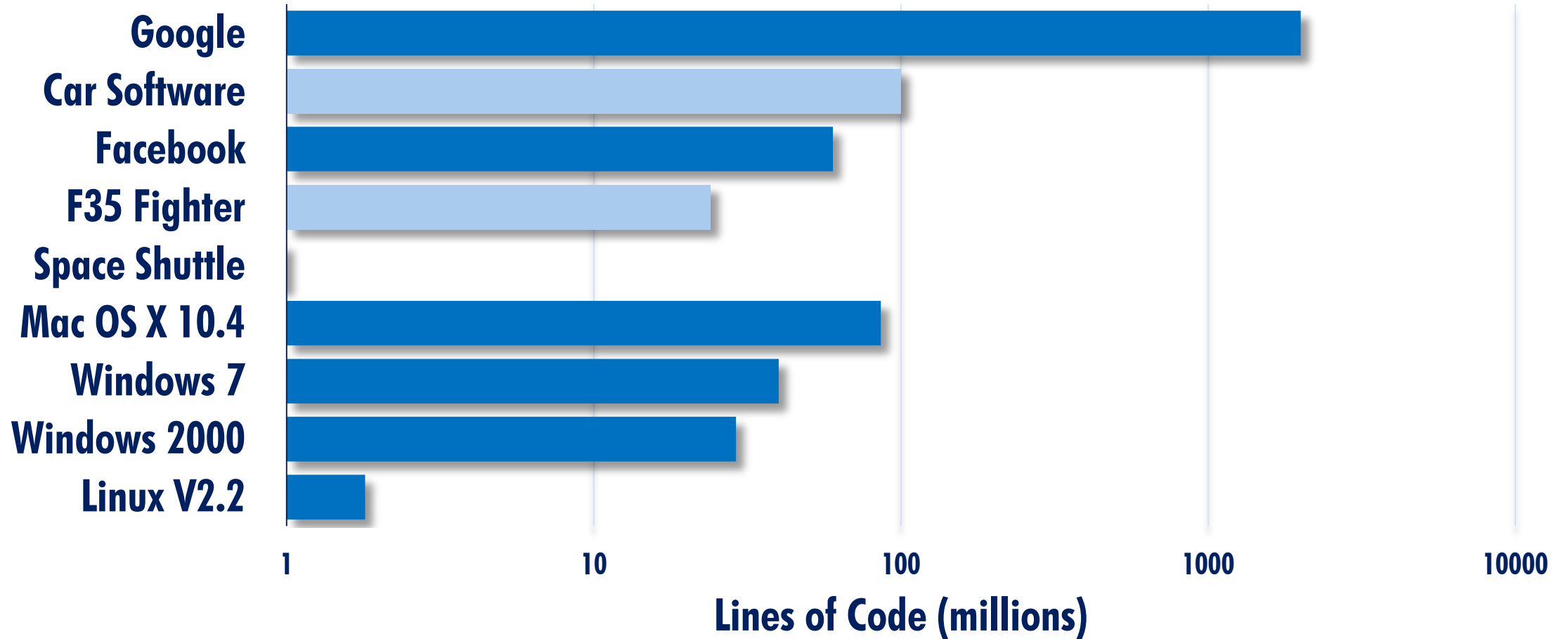
- Algorithms
- Physical components
- Human agents

### Capabilities

- Shared perception
- Shared decision-making
- Shared learning and adaptation
  - Machine learning
- Sensing from sensors, networks, people



## Cyber-Part Trends | Lines of Software Code





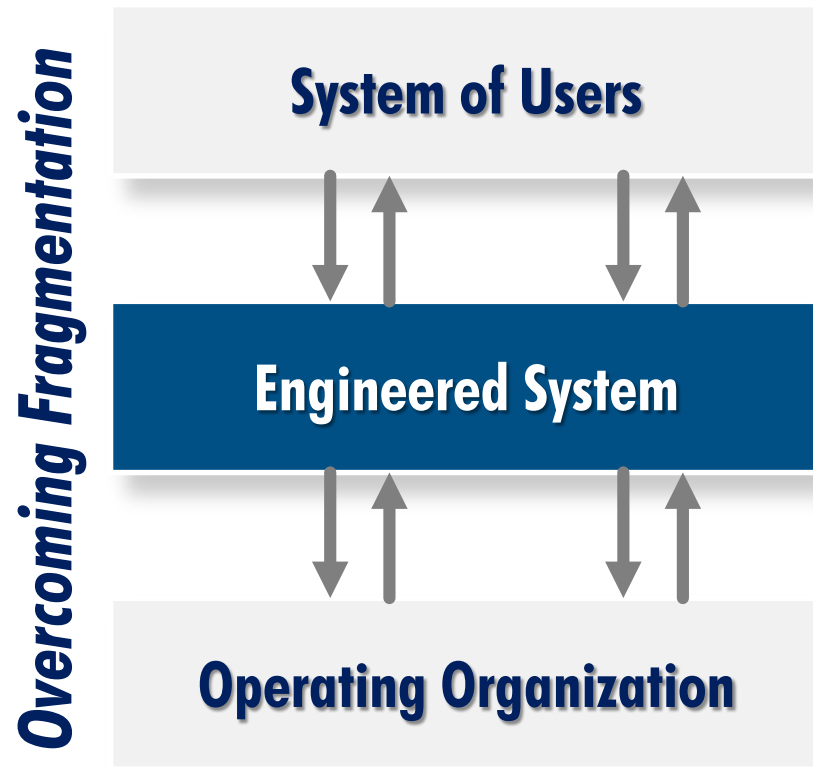
# Artificial Intelligence



## Artificial / Augmented

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

## Socio-Technical Perspective



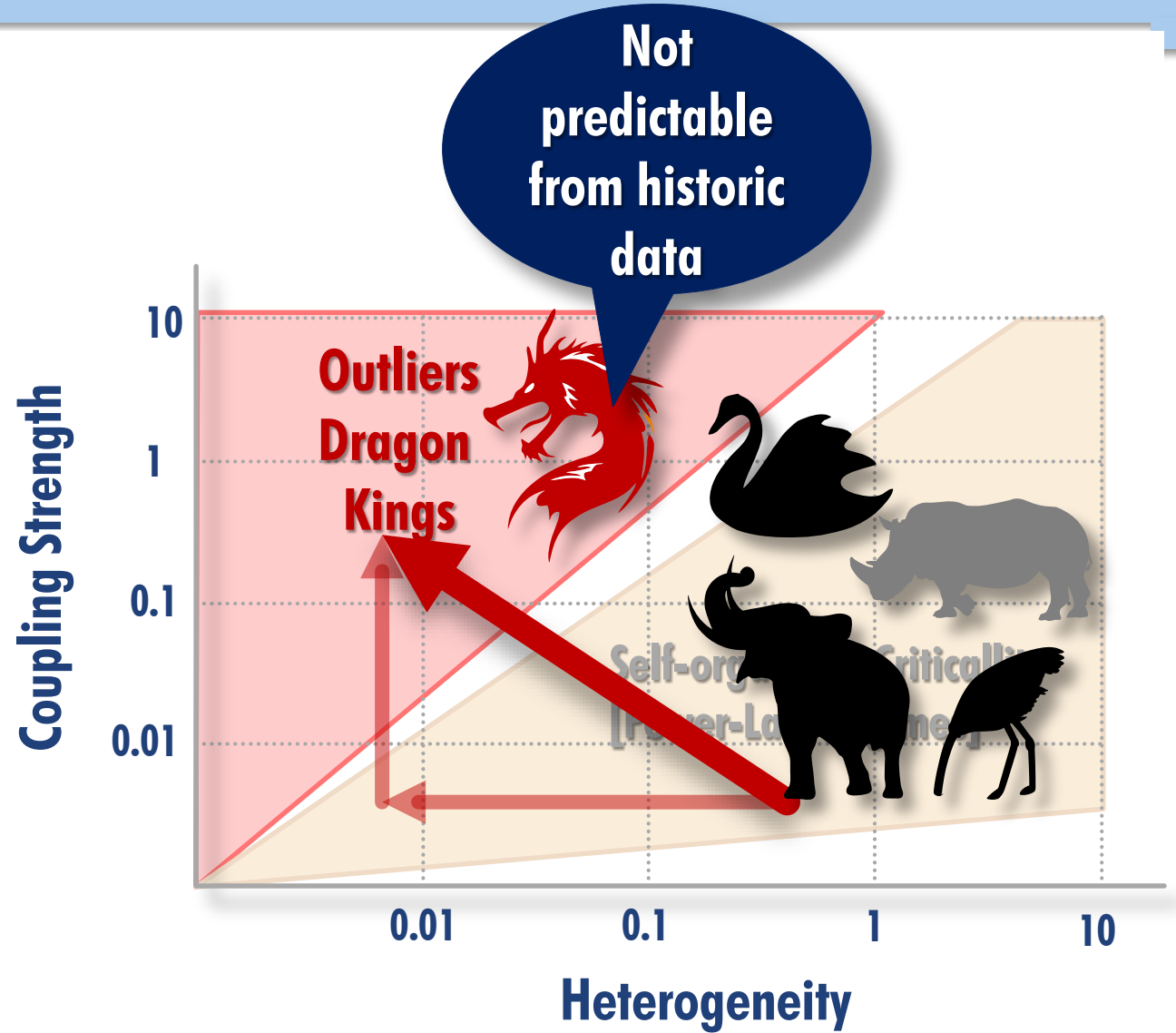
# Engineered Resilient Systems

[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

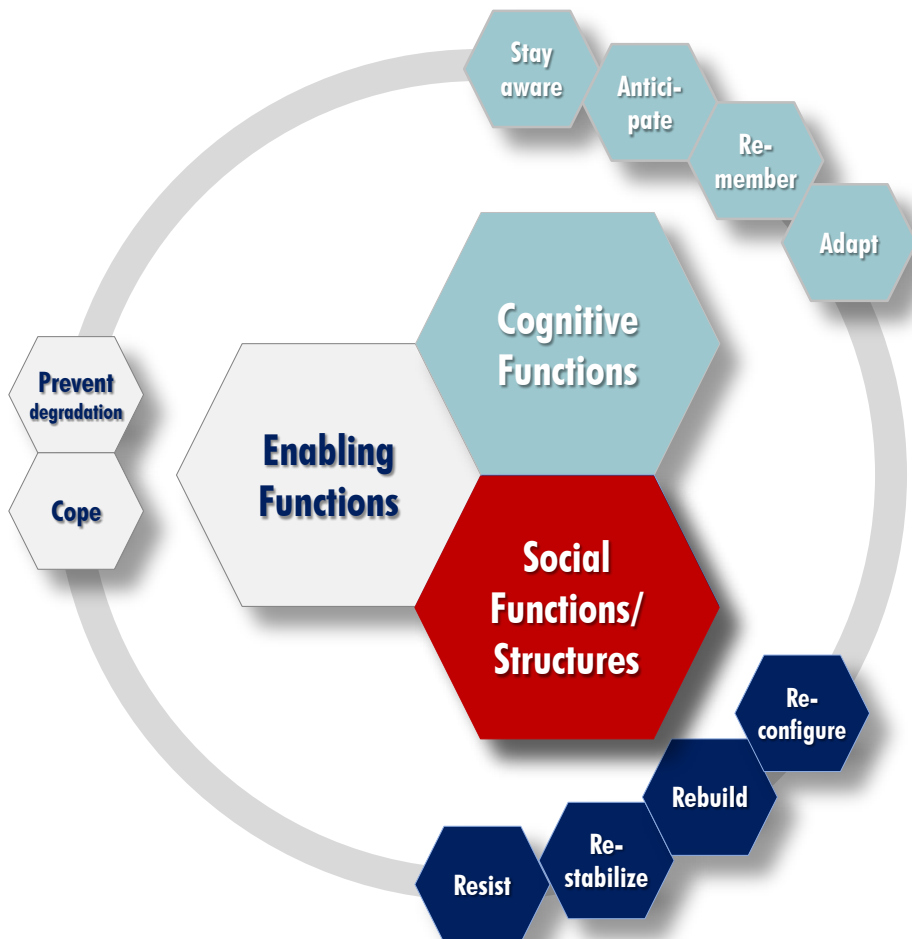


## Increasing Ambiguity and Unexpectedness



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

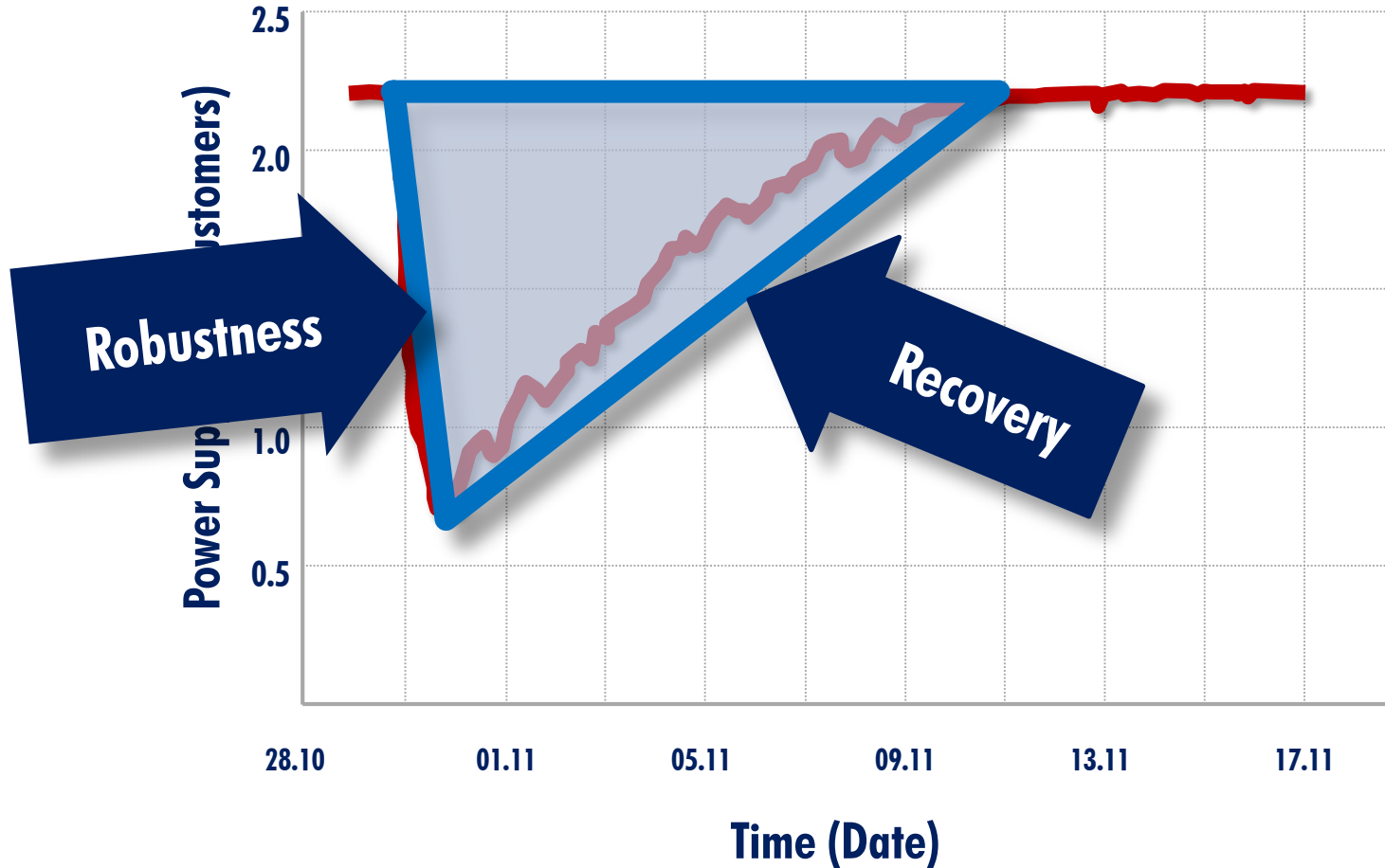


1. resist within acceptable limits of degradation,
2. restabilize critical functions,
3. rebuild functions, and
4. reconfigure the flow of substances, energy and services.

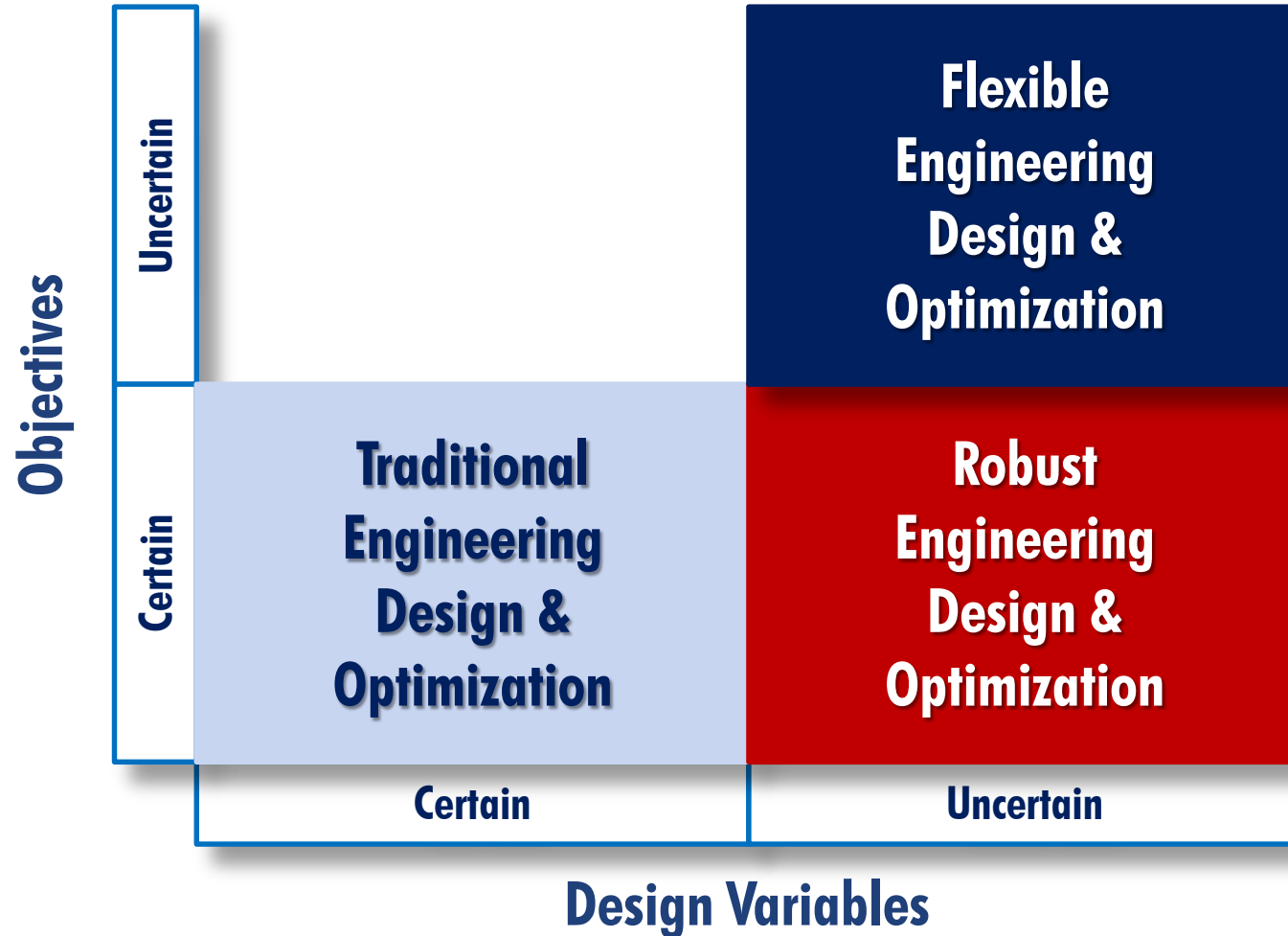
### COUPLED with

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

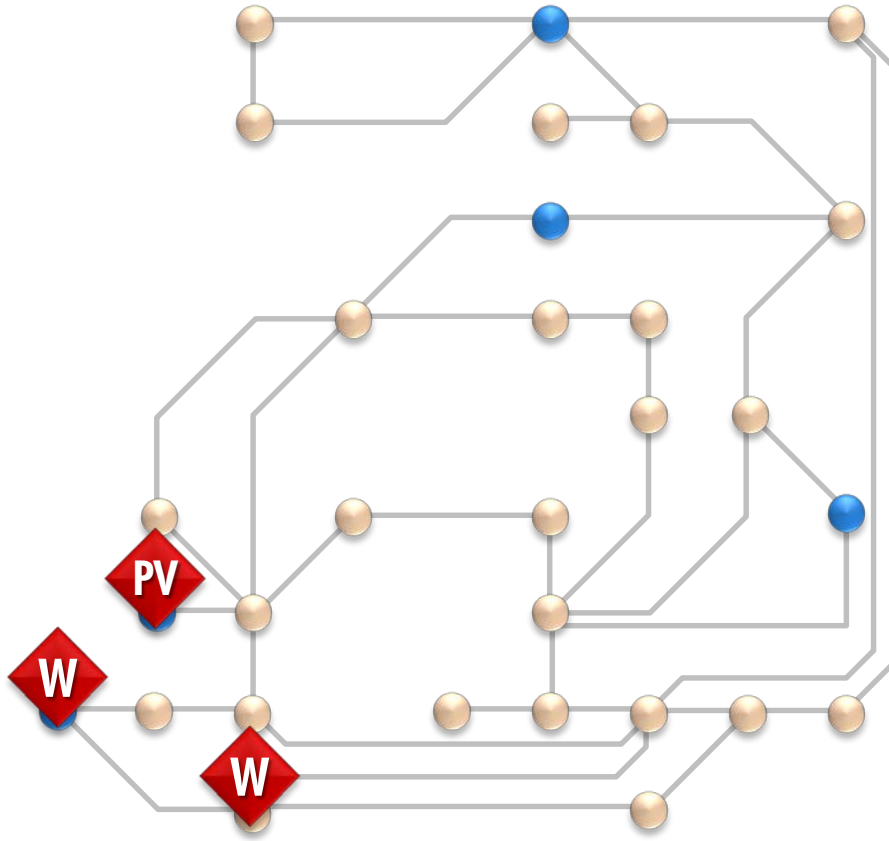
# Building Resilience



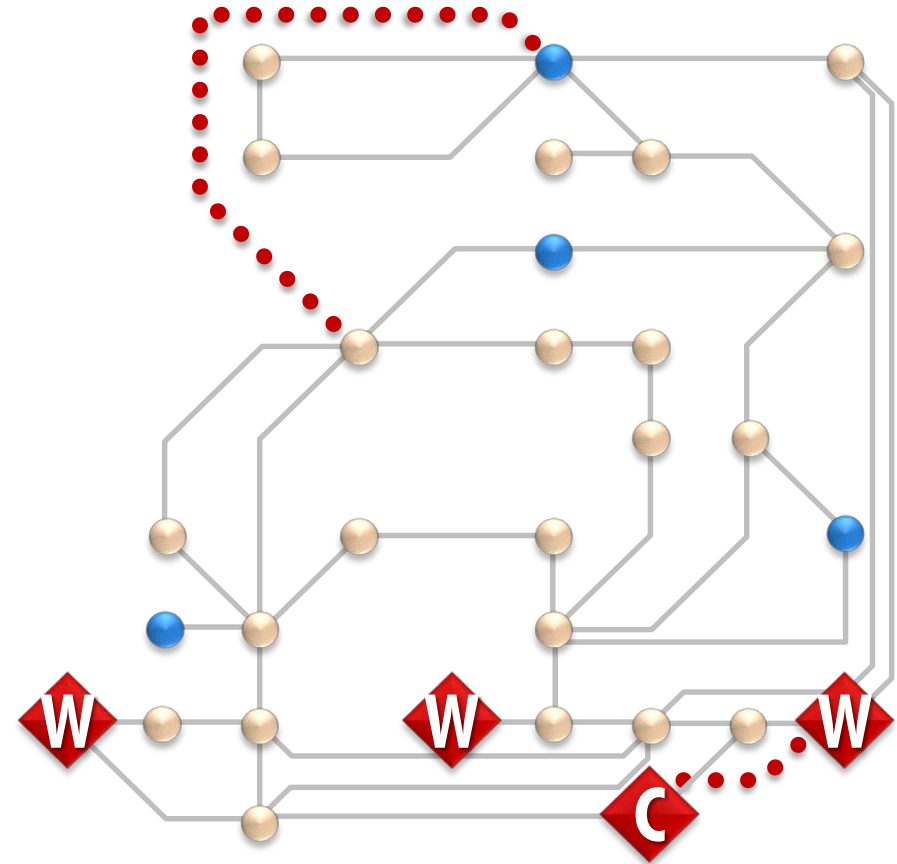
# Robust Design



# Robust Design – Key to Resilience IEEE-30



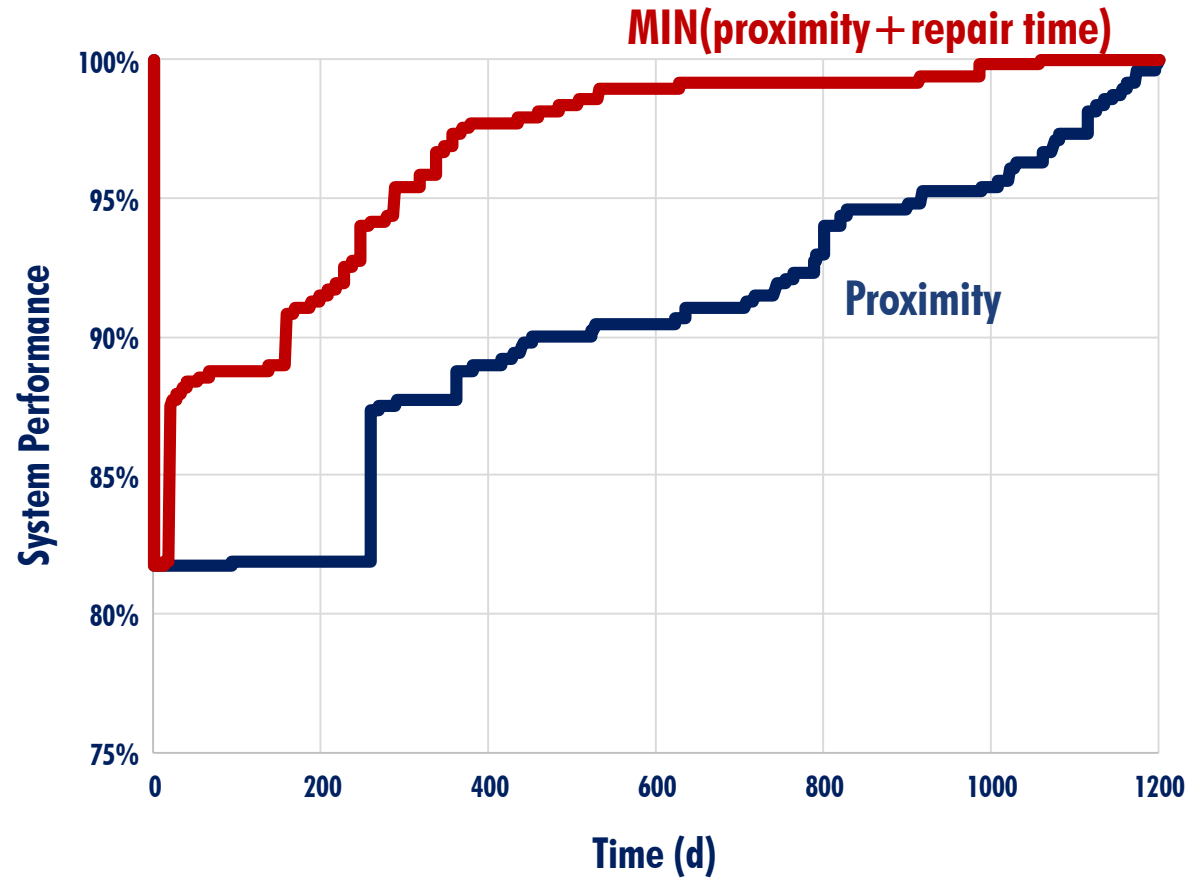
Traditional Optimization



Robust Optimization

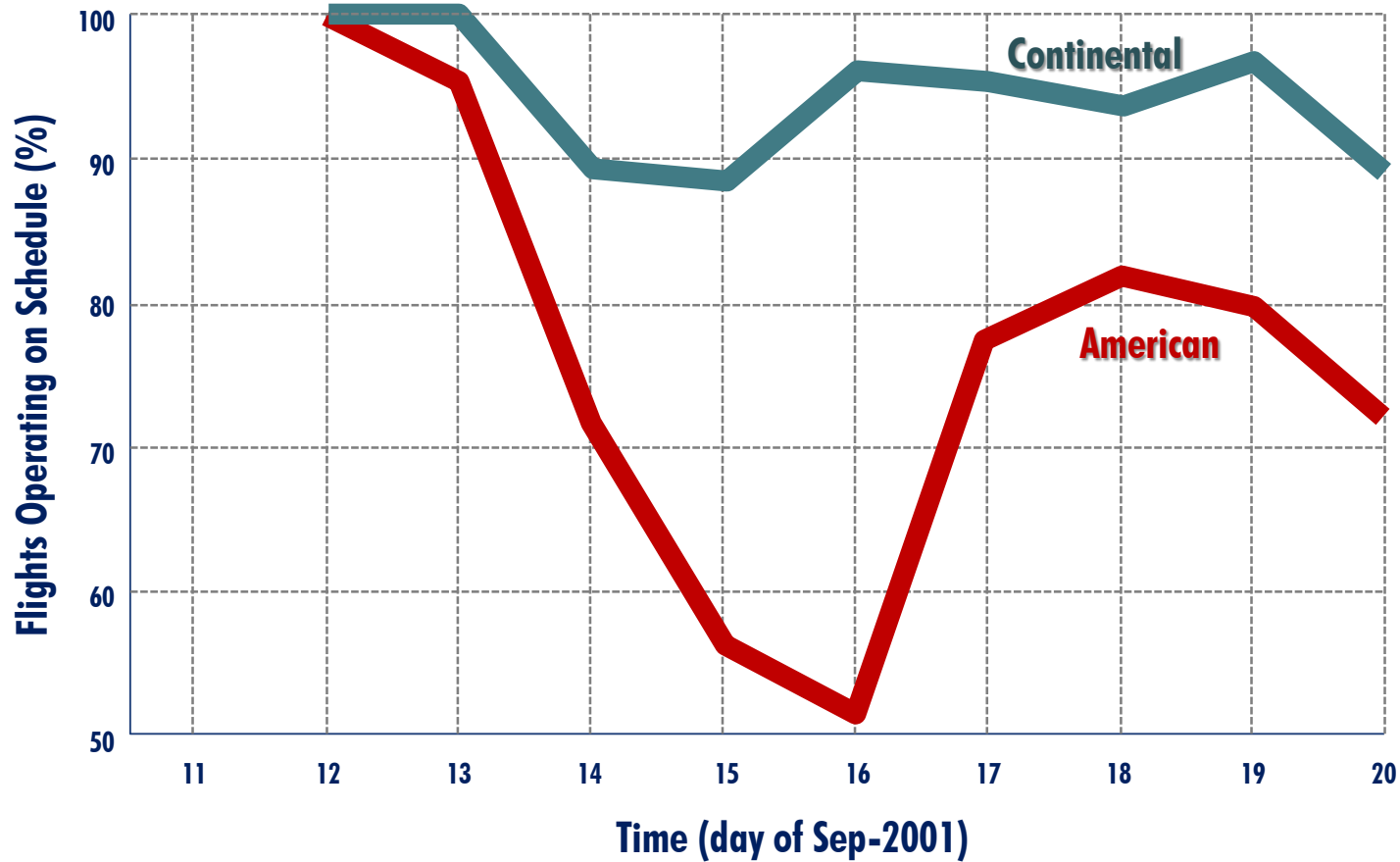


# Influence of Repair Tactics on Recovery



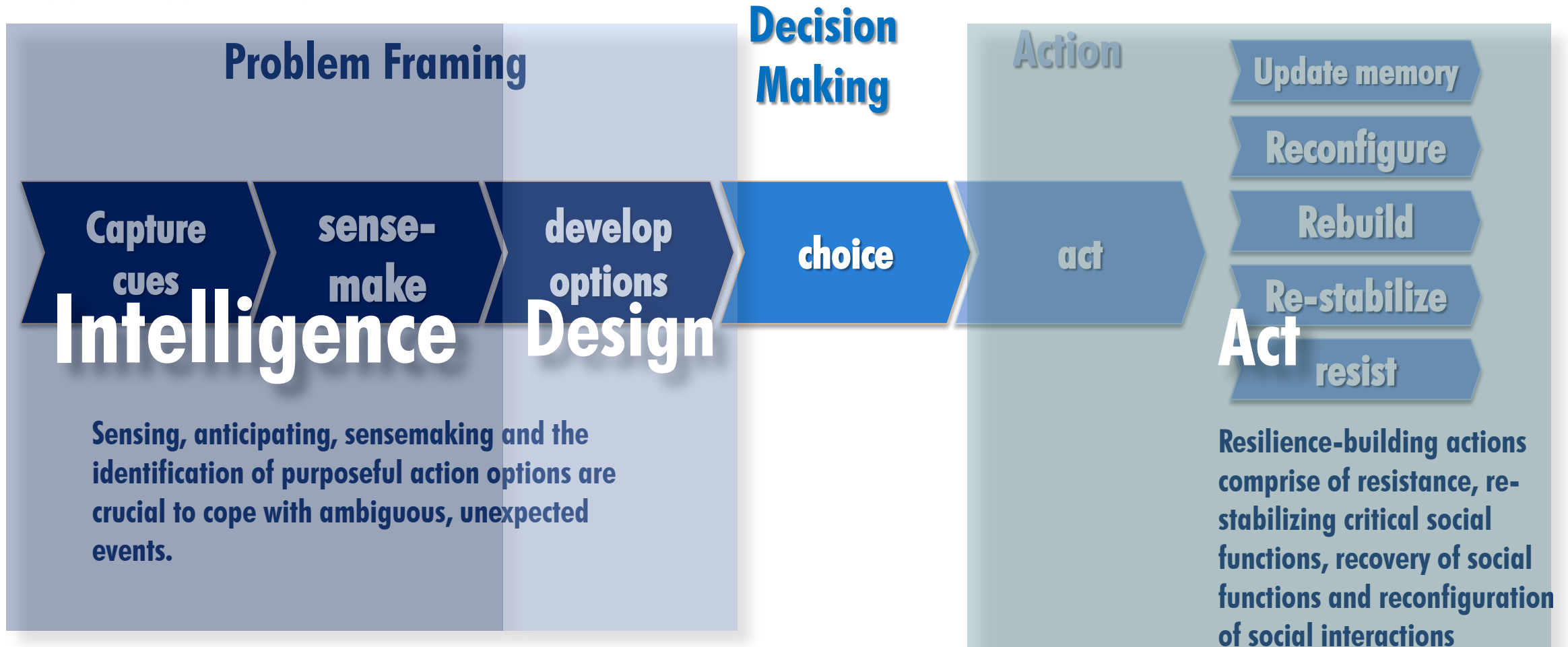
Nazli Yonca Aydinl, H. Sebnem Duzgun, Hans Rudolf Heinemann, Friedemann Wenzel, Kaushal Raj Gnyawali (forthcoming): Evaluation of operational resilience enhancement strategies for rural transport networks und geohazards

# Flight Operations Recovery After 9/11

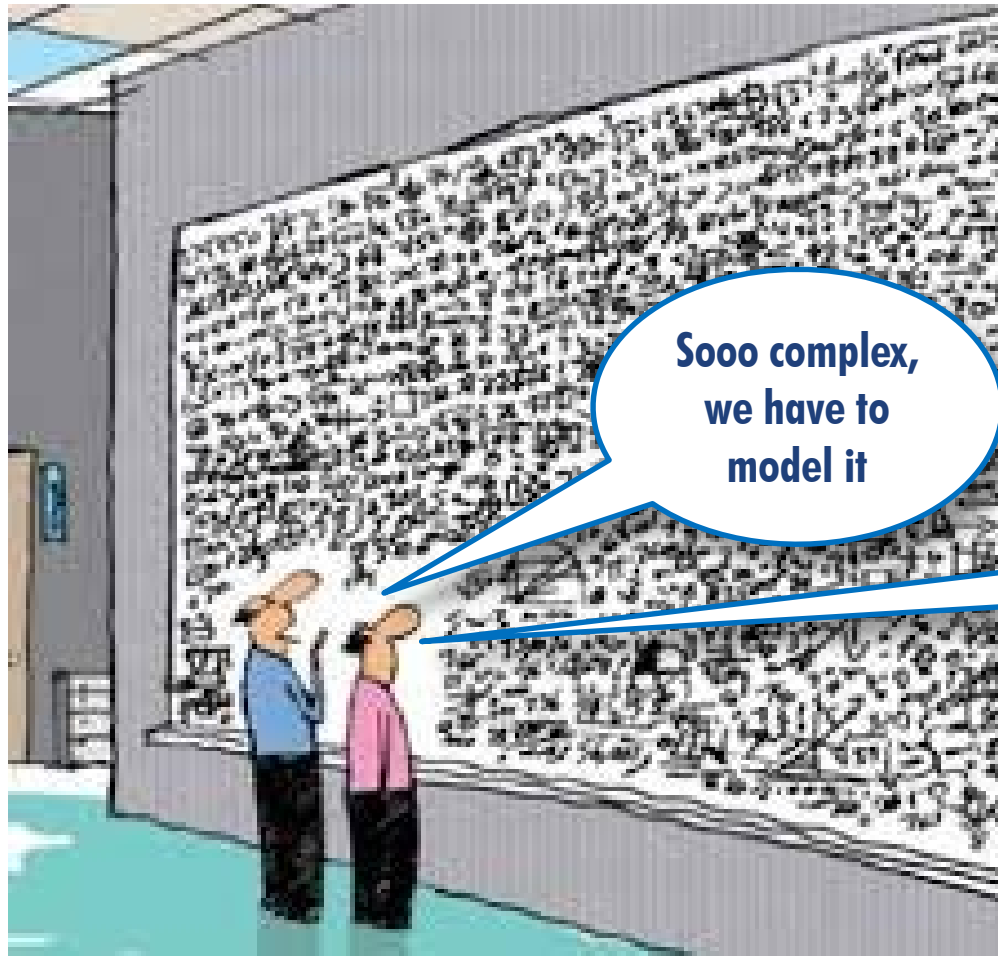


YU, G. and X. QI. 2004. *Disruption management : framework, models and applications*. Singapore ; River Edge, NJ. World Scientific. 294 p.

# Social Resilience



## Pitfalls...



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

Really nice  
model !

## 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**
5. **Resilience - change to no to be changed [B Walker 2018]**

# High Reliability Organisations (HRO)

[Weick, Hollnagel, Woods]

