POLITECNICO DI MILANO

A Modern Vision of Risk Assessment for Modern Industry

Enrico Zio

Chair on Systems Science and the Energy Challenge, CentraleSupelec, Fondation Electricité de France (EDF), France

Energy Department, Politecnico di Milano, Italy

RISK-INFORMED DECISION MAKING

(George Apostolakis
Former Commissioner of the US Nuclear Regulatory Commission)

PSAM 13, Seoul, 3 October 2016

Risk-Informed Decision Making (1)

- **Decision making must be based on the current state of knowledge of the decision maker (DM)**
  - **The current state of knowledge regarding design, operation, and regulation is key.**
  - **The current state of knowledge is informed by science, engineering, and operating experience, including past incidents.**

- **What we know about plant behavior is not easily available to the DM**
  - **Accident sequences, human performance, risk significance of systems, structures, and components, etc**

Risk-Informed Decision Making (2)

- PRAs provide this information to the DM
  - PRAs do not predict the future
  - PRAs evaluate and assess potential accident scenarios to inform the decision makers' current state of knowledge.

PRA = Probabilistic Risk Assessment

PROBABILISTIC RISK ASSESSMENT

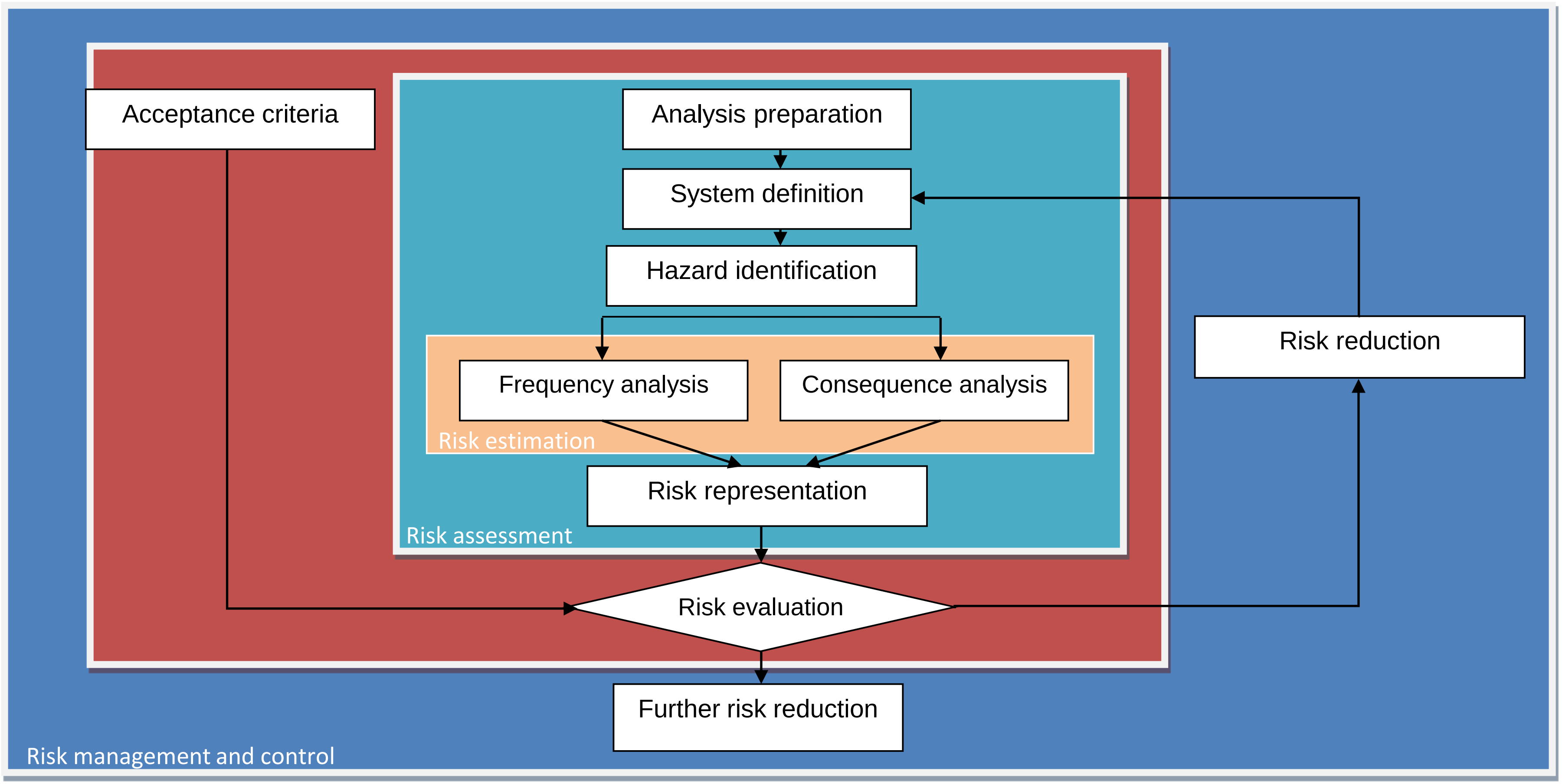
Probabilistic Risk Assessment

1) What undesired conditions may occur? → Accident Scenario, S
2) With what probability do they occur? → Probability, p
3) What damage do they cause? → Consequence, x

$$\text{RISK} = \{S_i, p_i, x_i\}$$

CentraleSupélec

Risk Assessment and Management Procedure

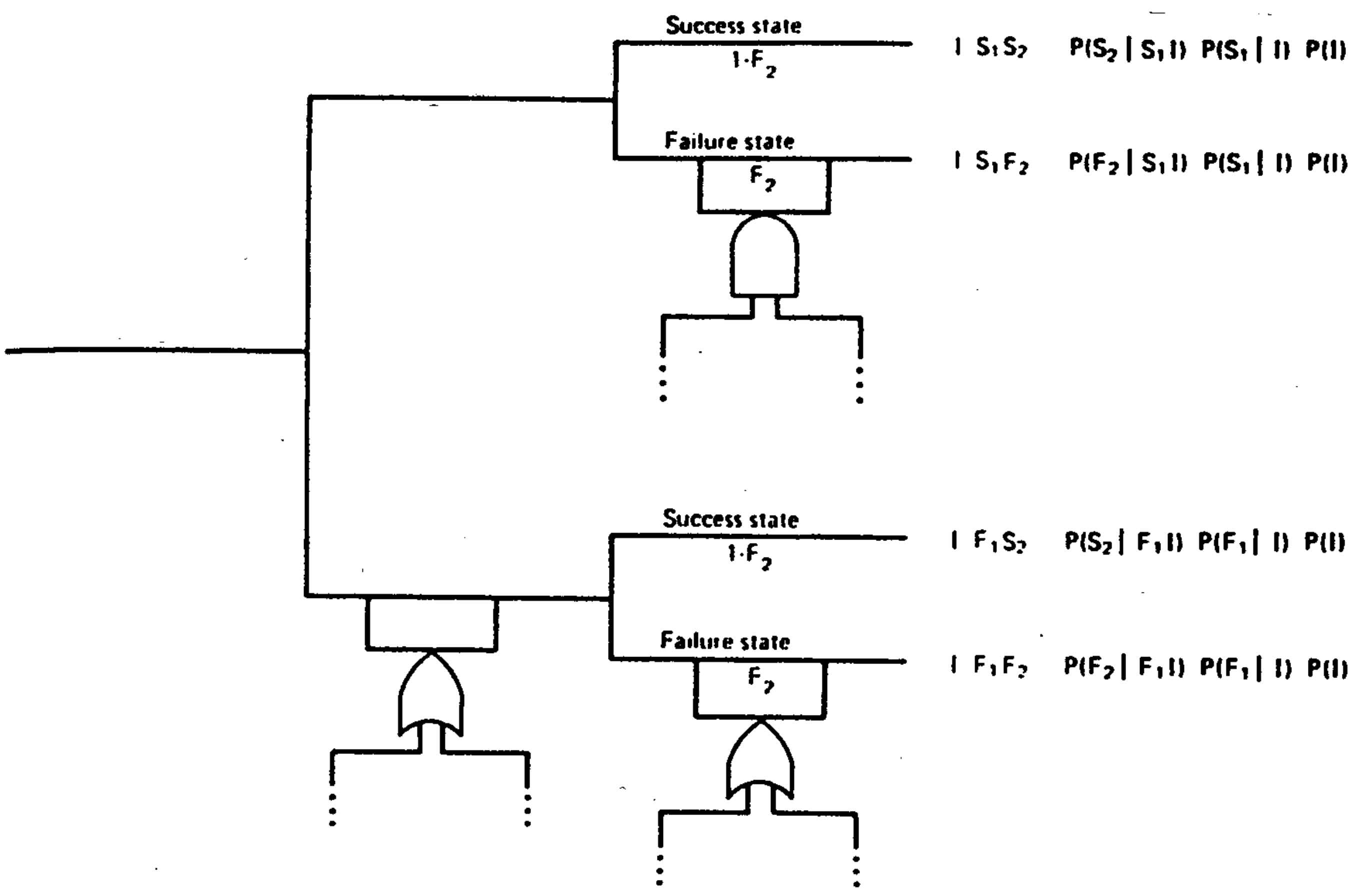


CentraleSupélec

Classical Techniques for Risk Assessment

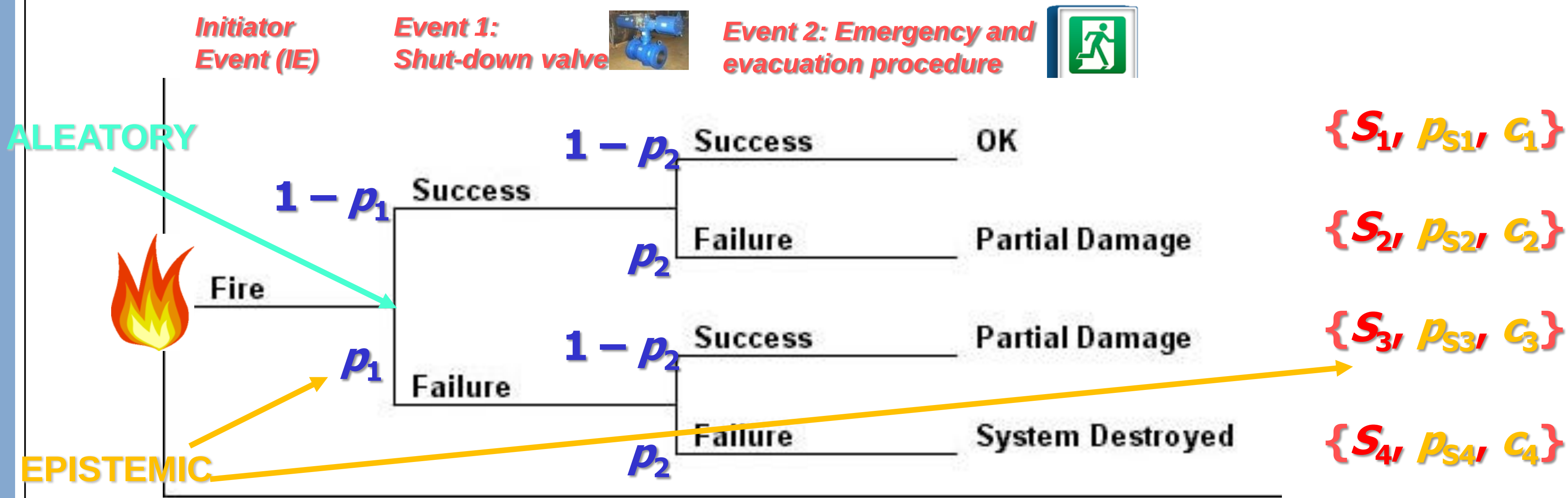
- Hazard identification: FMEA & HAZOP
- Accident Scenarios Identification: ETA, FTA
- System Failure Probabilty Assessment: ETA, FTA

ETA+FTA



Success state
1-F2
I S1S2 P(S2 | S1 I) P(S1 | I) P(I)
Failure state
F2
I S1F2 P(F2 | S1 I) P(S1 | I) P(I)
Success state
1-F2
I F1S2 P(S2 | F1 I) P(F1 | I) P(I)
Failure state
F2
I F1F2 P(F2 | F1 I) P(F1 | I) P(I)

(aleatory and epistemic) Uncertainty

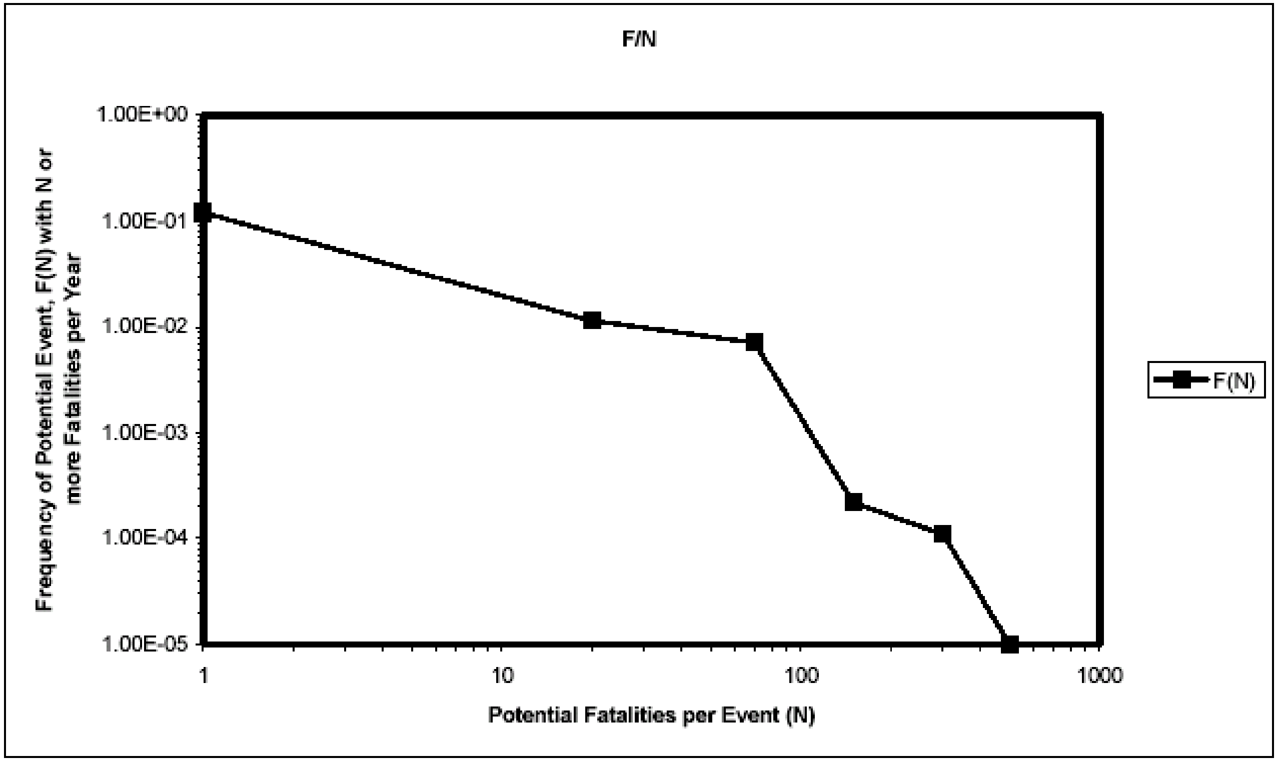


Aleatory: variability, randomness (in occurrence of the events in the scenarios)

Epistemic: lack of knowledge/information (on the values of the parameters of the probability and consequence models)

F/N graph

Scenario	Number (N) of Potential Fatalities	Frequency of Scenario per Year	Frequency of Incidents with Potential (N) or more Fatalities per Year
1	1	0.1	0.12021
2	20	0.014	0.01141
3	70	0.0075	0.00713
4	150	0.00023	0.00022
5	300	0.00009	0.00011
6	500	0.00001	0.00001



RISK MATRIX:

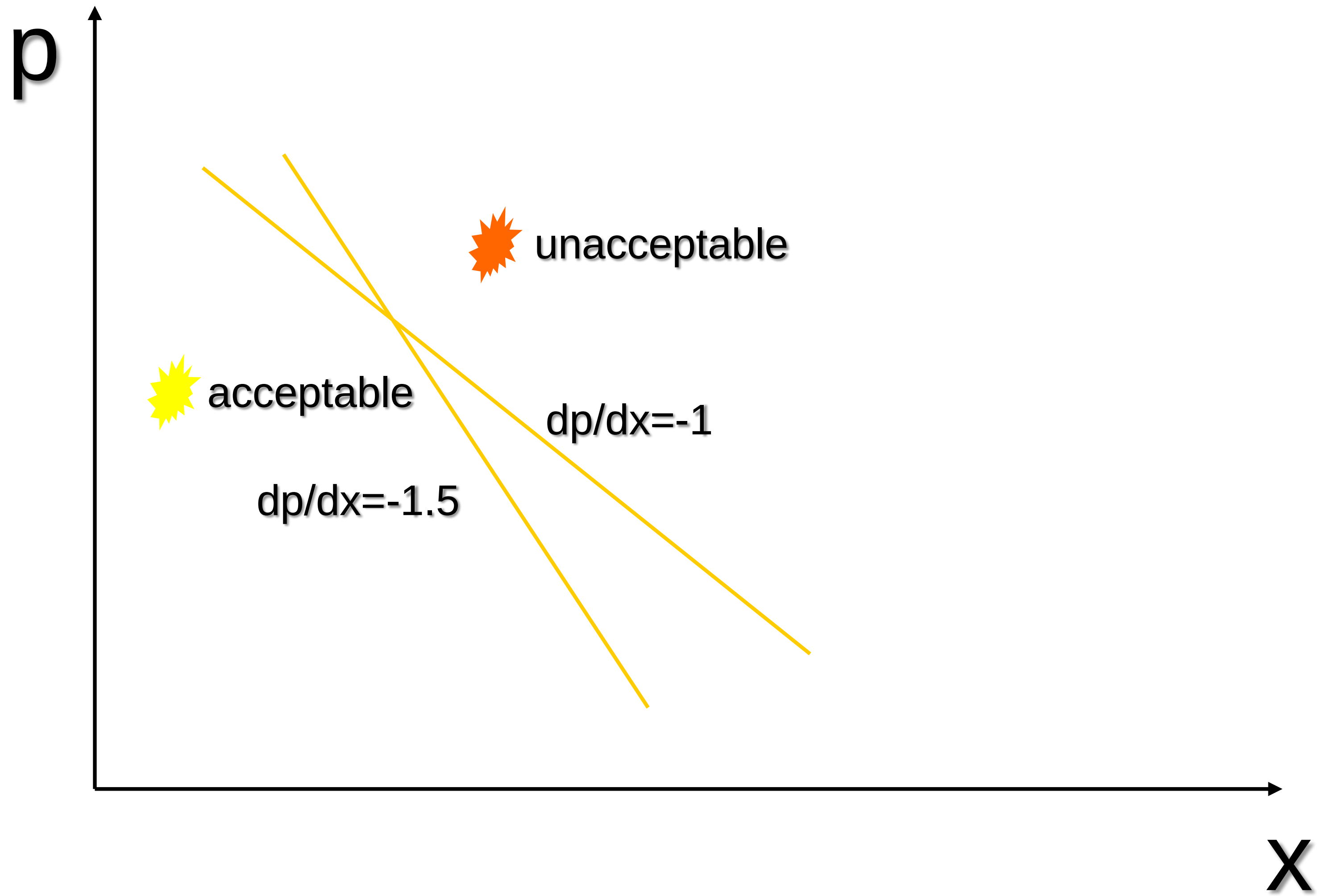
The level of risk is broadly acceptable and generic control measures are required aimed at avoiding deterioration.

The level of risk can be tolerable only once a structured review of risk-reduction measures has been carried out

The level of risk is not acceptable and risk control measures are required to move the risk figure to the previous regions.

Consequence					Increasing Annual Frequency					
Severity	People	Environ.	Assets	Reputation	0	A	B	C	D	E
					Practically non-credible occurrence	Rare occurrence	Unlikely occurrence	Credible occurrence	Probable occurrence	Likely/Frequent occurrence
					Could happen in E&P industry	Reported for E&P industry	Has occurred at least once in Company	Has occurred several times in Company	Happens several times/y in Company	Happens several times/y in one location
1	Slight health effect / injury	Slight effect	Slight damage	Slight impact			Continuous Improvement			
2	Minor health effect / injury	Minor effect	Minor damage	Minor impact					Risk Reduction Measures	
3	Major health effect / injury	Local effect	Local damage	Local impact						
4	PTD(*) or 1 fatality	Major effect	Major damage	National impact					Intolerable Risk	
5	Multiple fatalities	Extensive effect	Extensive damage	International impact						

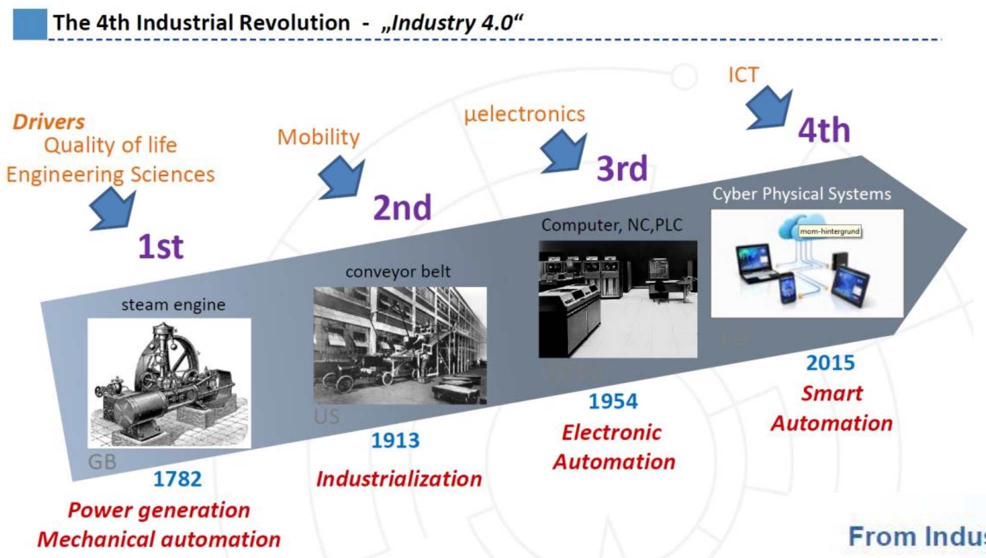
FARMER'S CURVE:

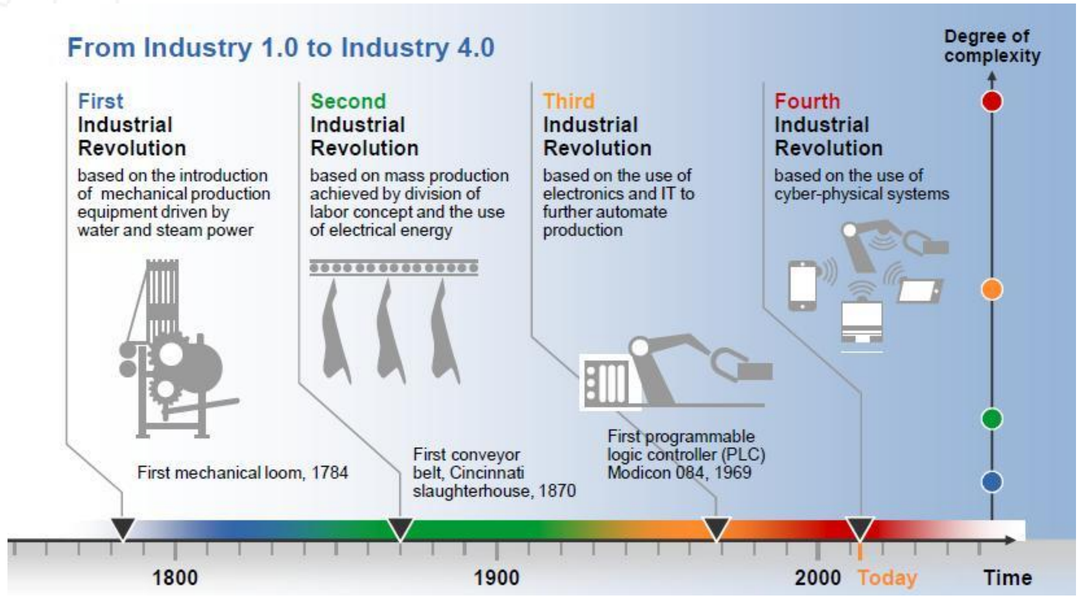


RISK PERCEPTION

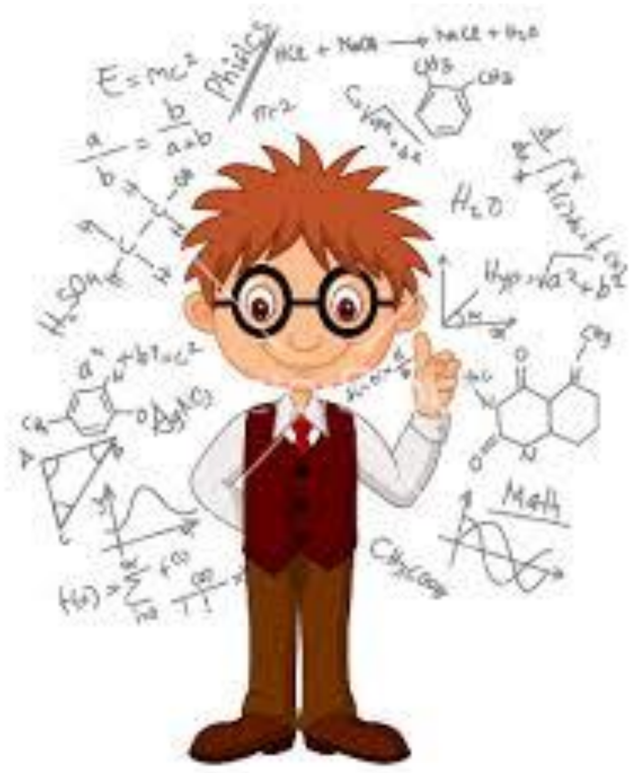
INDUSTRY

Industry 1-2-3-4



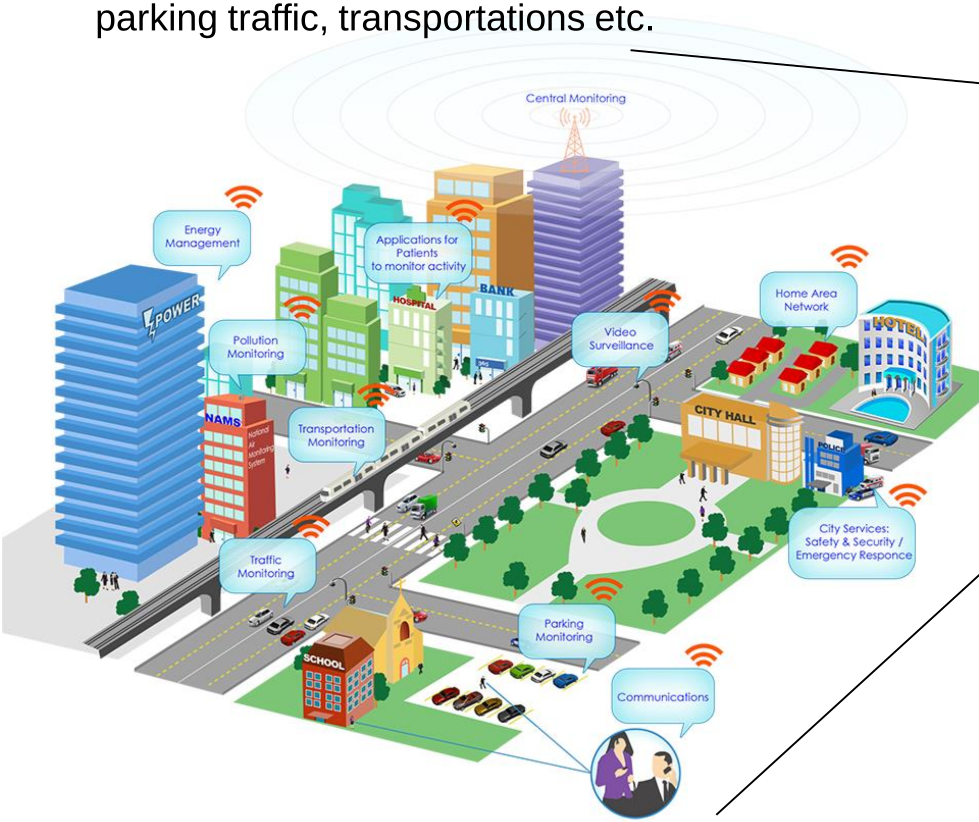


(The beauty of being) SMART


E=mc²
Physics
H₂O
Math

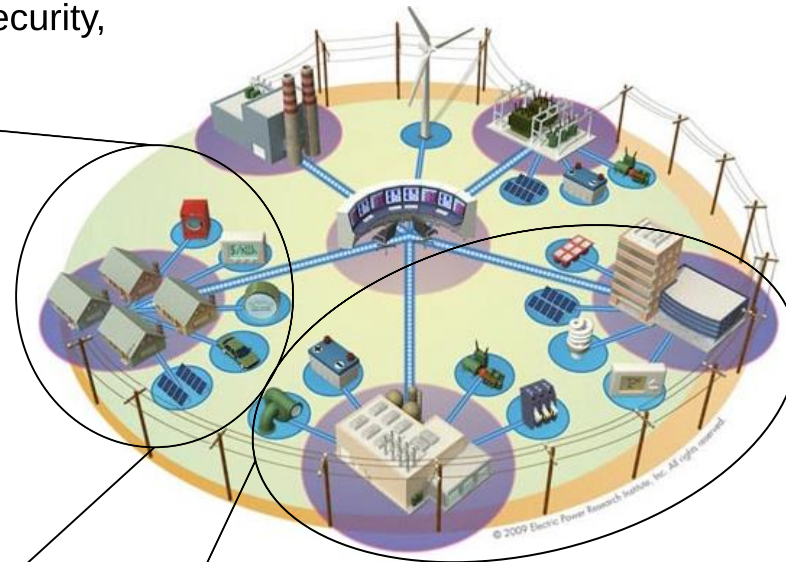
Smart grids, Smart Cities and Eco-Industrial Parks

Application of Internet of Things concept in Smart Cities to tackle urban challenges – pollution, energy efficiency, security, parking traffic, transportations etc.

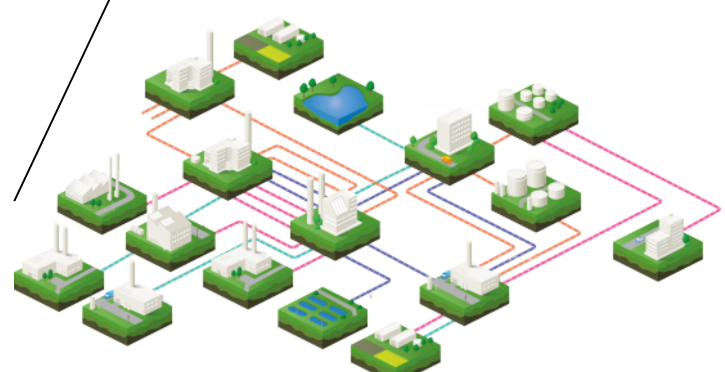


Source: *IOT Phillippines INC.*

Internet of Things in Smart Grids

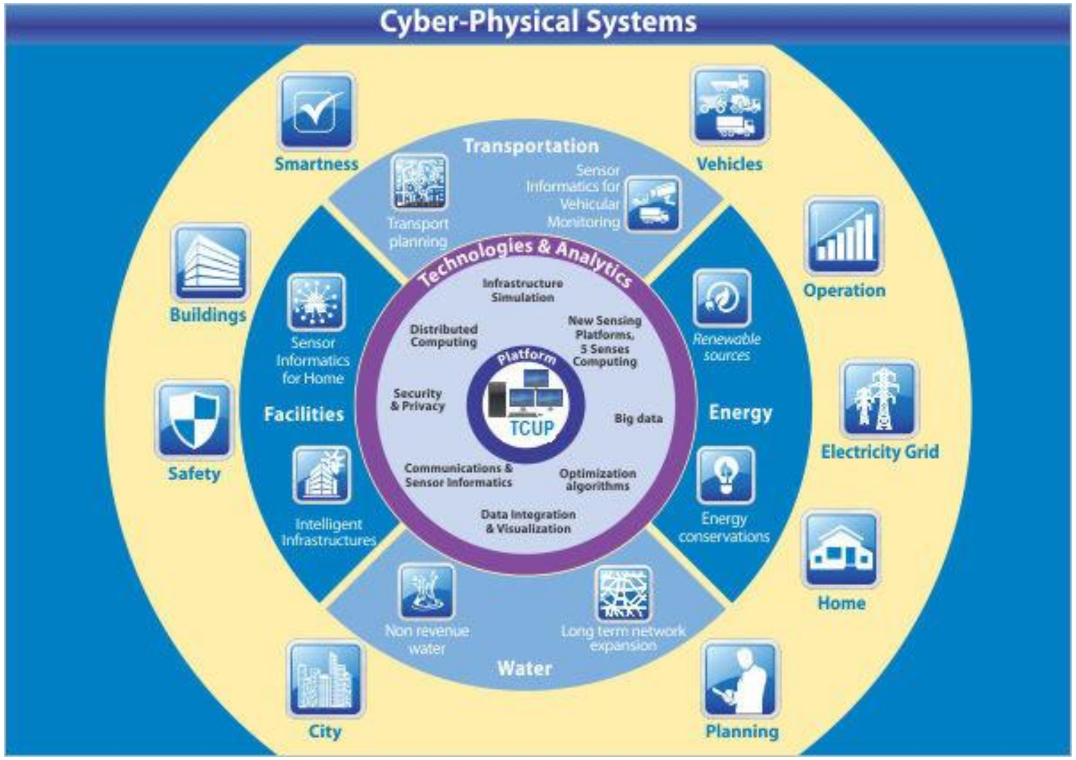


Eco-Industrial Parks



Source: Kalundborg Symbiosis

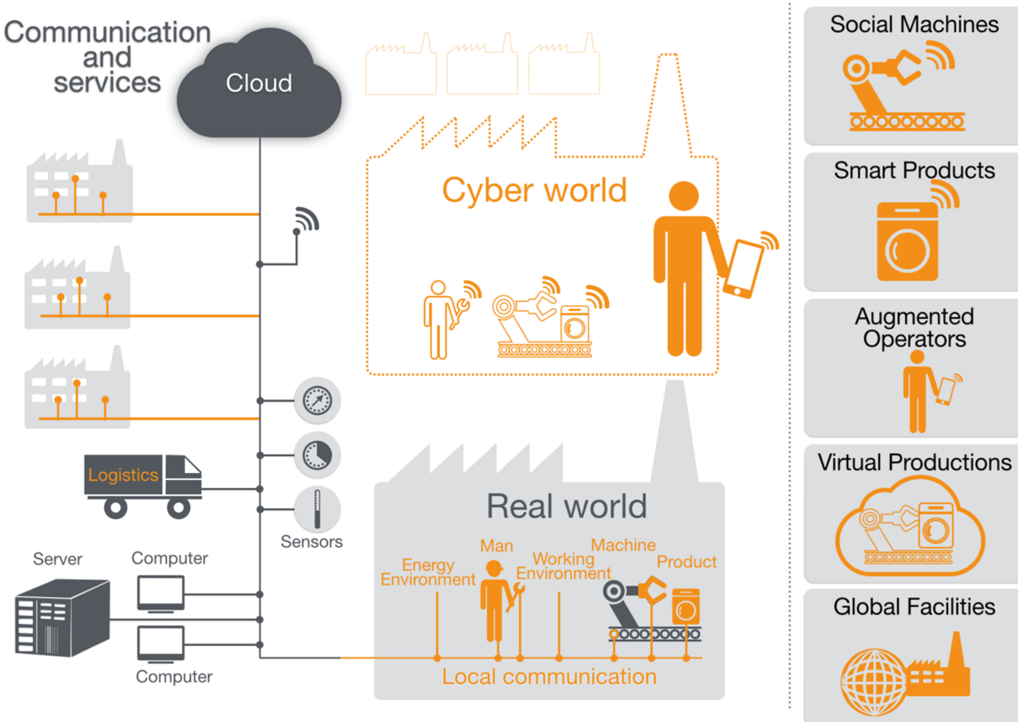
Cyber-Physical Systems

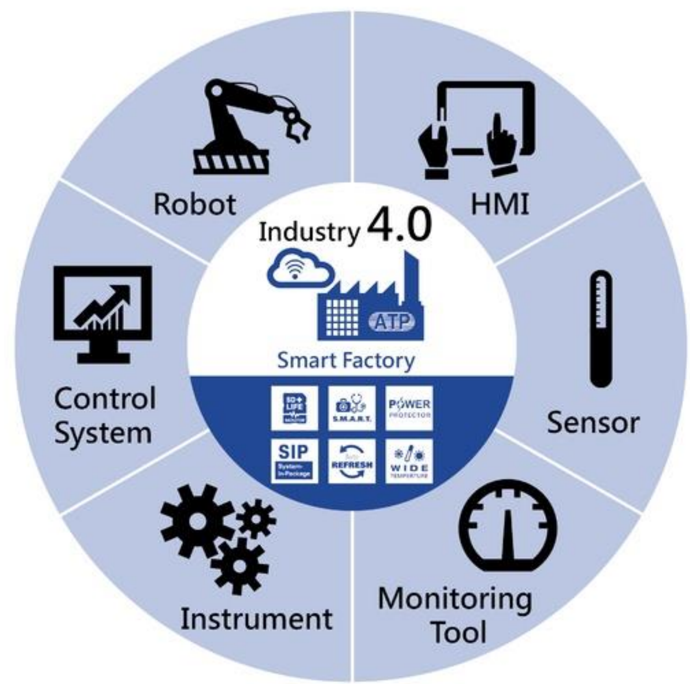


Source: TATA Consultancy Services

Source: BICC NET

Industry 4.0- (Cyber-Physical/Smart) Systems

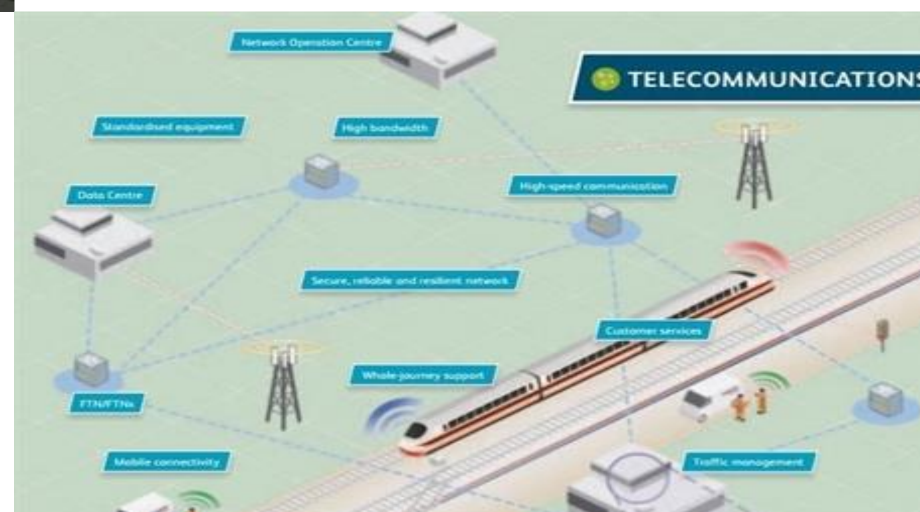




There are now TWO railway systems

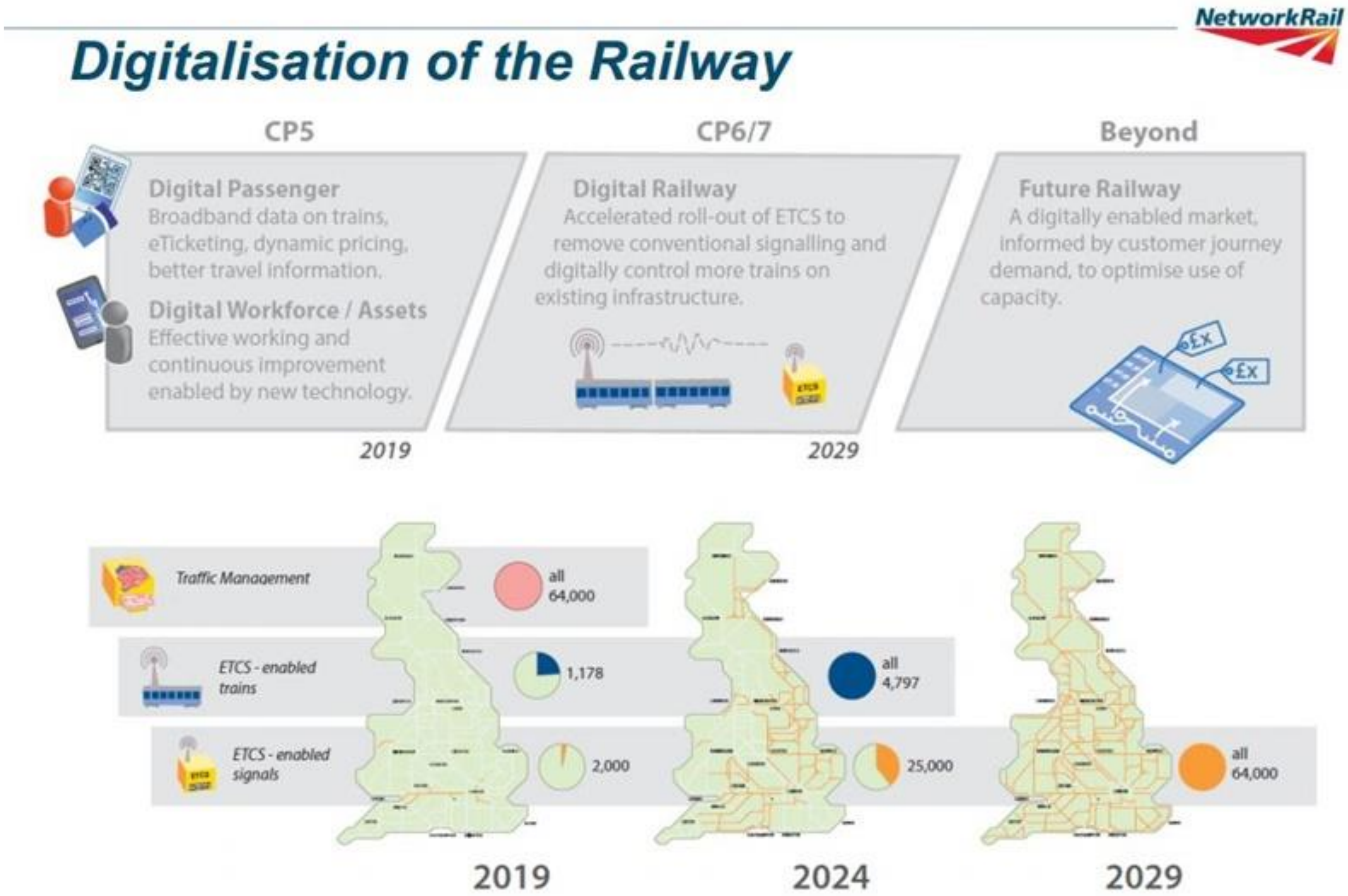
- Physical train systems
- Living passengers and freight
- Wear and tear
- Long term investments
- Answers to laws of physics

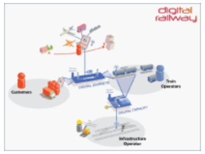
- Computer systems
- Bits and bytes
- Interfaces with the real world
- But behaves differently
- Quick fix and rapid change
- Answers to programmers' coding laws and practices



http://www.lemonde.fr/economie/article/2014/07/08/le-trafic-eurostar-toujours-perturbe_4452907_3234.html
http://www.railtechnologymagazine.com/Rail-News/digital-railway-business-case-available-within-months

Digital transformation in Great Britain





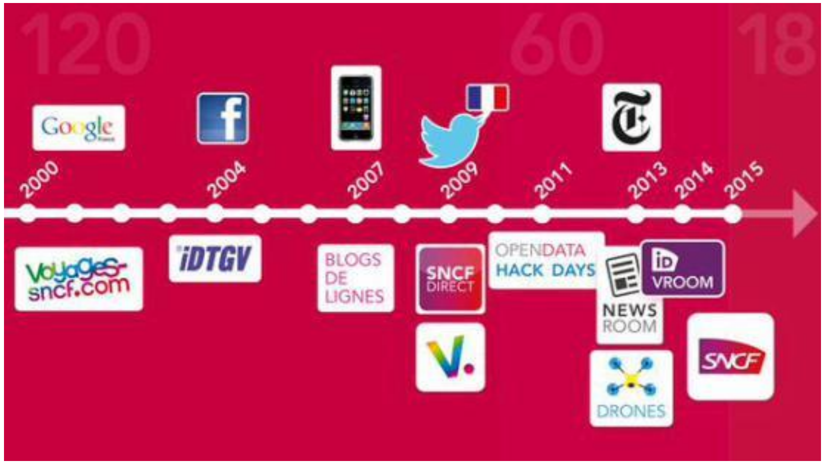
http://www.railtechnologymagazine.com/Rail-News/digital-railway-business-case-available-within-months
http://www.webdoc.org.uk/ihelp/page43.html

The Internet of Trains

- From reactive to predictive maintenance
  - Increased up-time through significant reduction of un-planned downtime.
  - Extension/flexibility of maintenance intervals because we understand the risk.
  - Reduced labour costs: quicker root-cause analysis, improved first-time-fix rate, etc.
- **Thameslink**: Performance-based maintenance contract requiring nearly-run-time analysis of diagnosis and process data.
- **Metro Riad**: availability targets (40 seconds arrival-departure per train) can only be reached with data-enabled services.

And it's not just Great Britain

#DIGITALSNCF

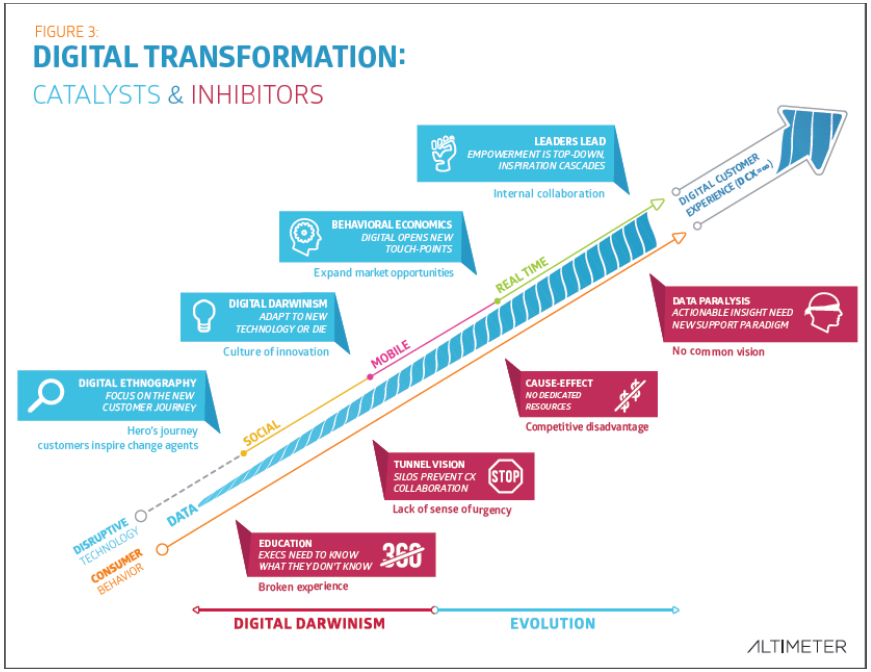


BAHN 4.0

http://www.rudebaguette.com/2015/02/10/sncf-launches-ambitious-transformative-digitalsncf-agenda/
http://www.dbregio.de/db_regio/view/zukunft/mob4_0/mobilitaet_4_0.shtml

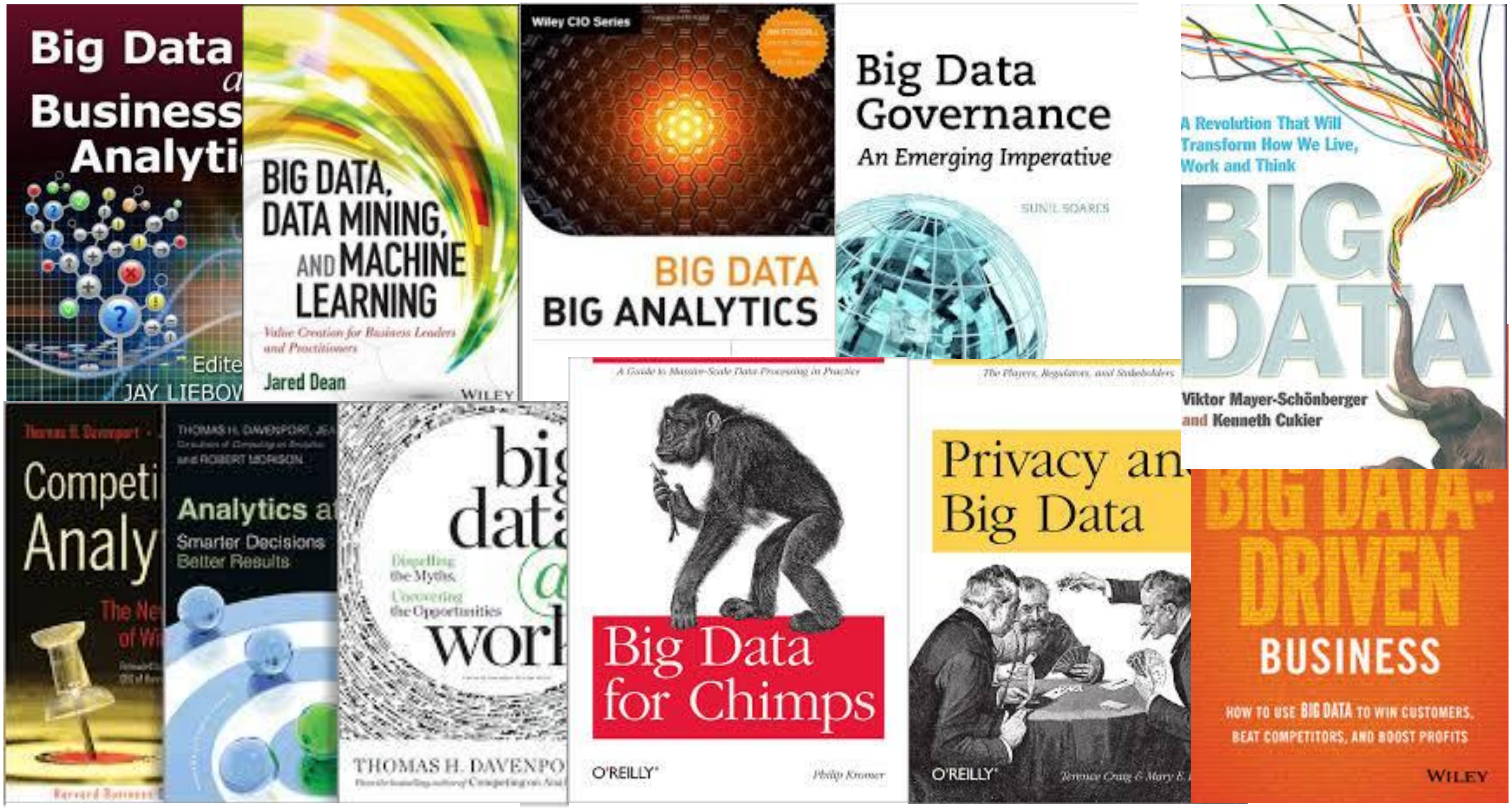
And it’s not just Rail

- Management itself is changing
- Based on processing power
- And IT Business solutions



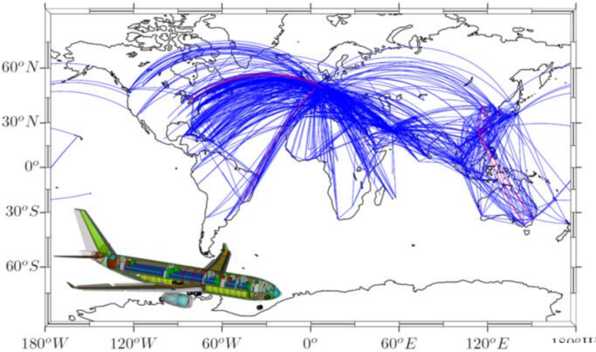
http://www.lostingoogle.me/survive-digital-darwinism-evolve-or-die/

It's here to stay…

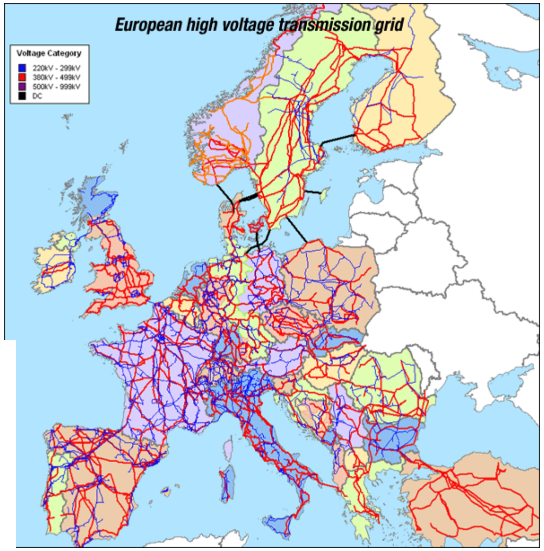


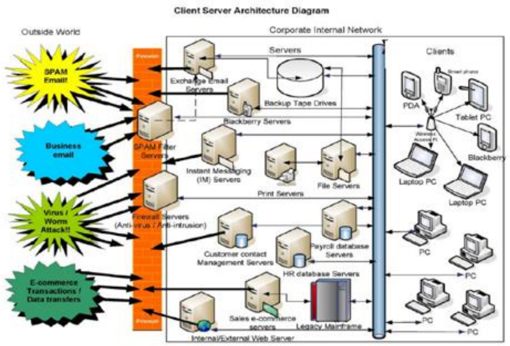
COMPLEX

Complex Systems

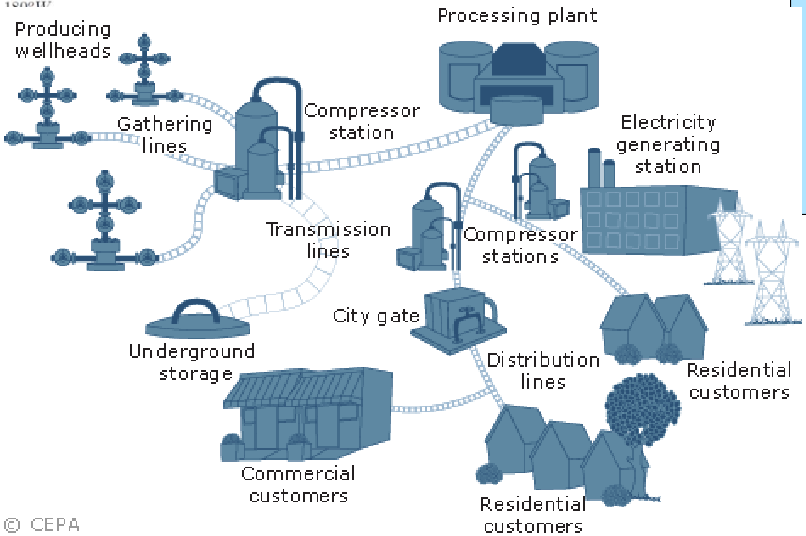


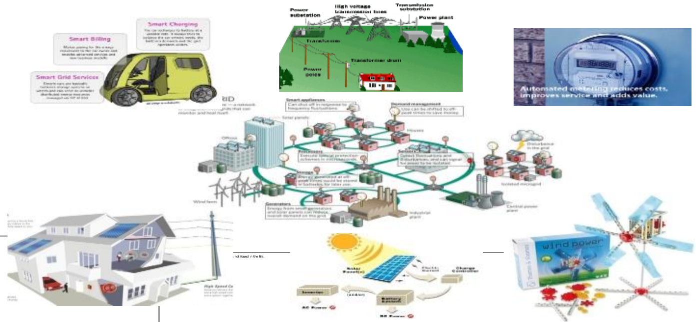
Complex Systems

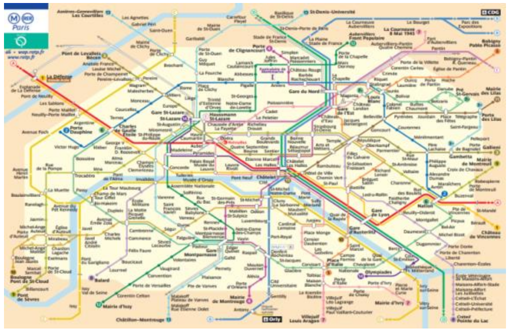




Microsoft submission to Federal Rules Committee

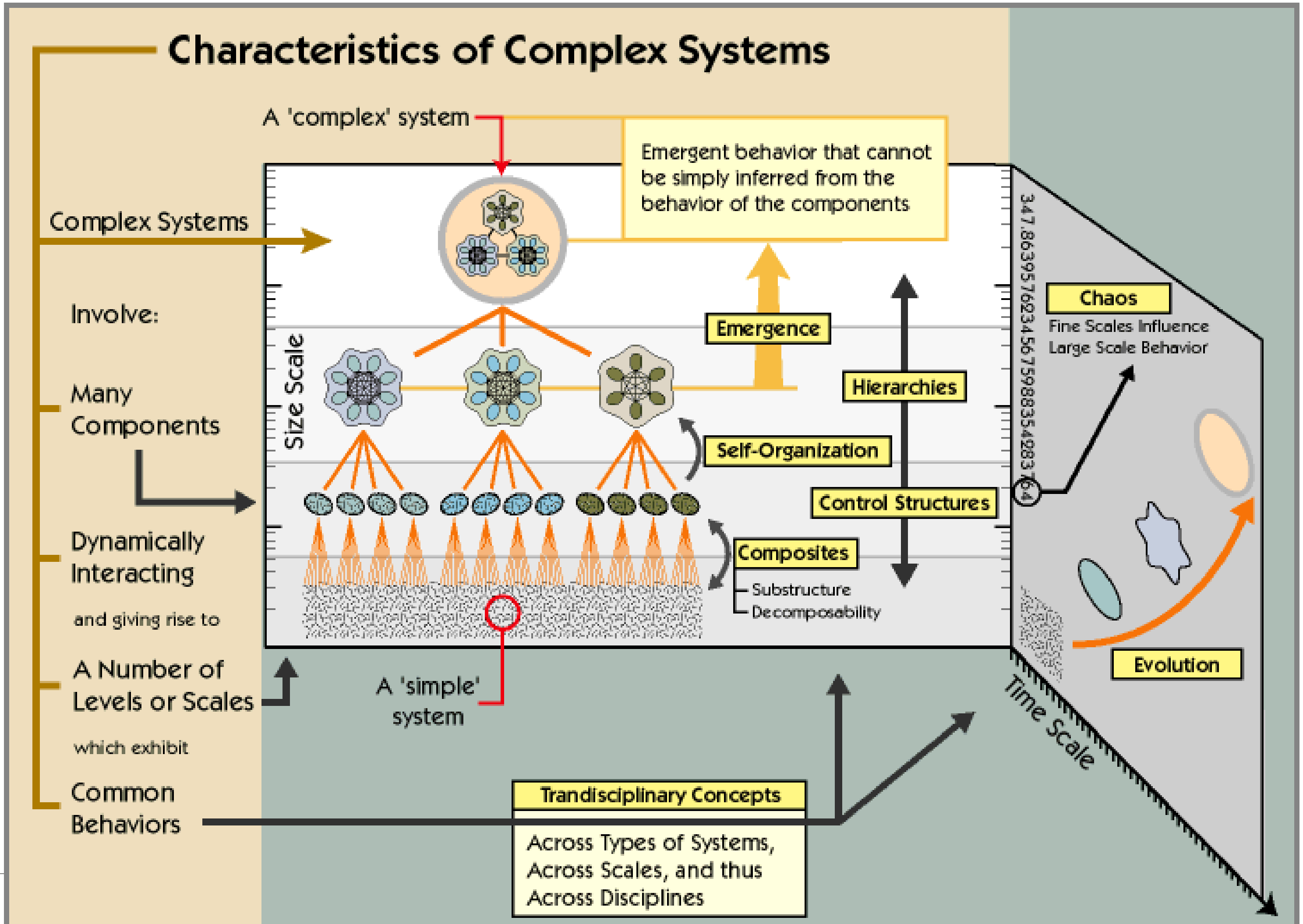






Characteristics of complex systems

[New England Complex Systems Institute, 2005]



Characteristics of complex systems

- Network of many interacting components
- Components of heterogeneous type
- Hierarchy of subsystems
- Interactions across multiple scales of space and/or time

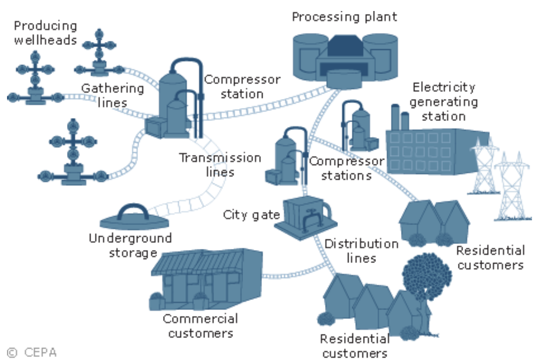
Dependences (uni-directional) and interdependences (bi-directional)

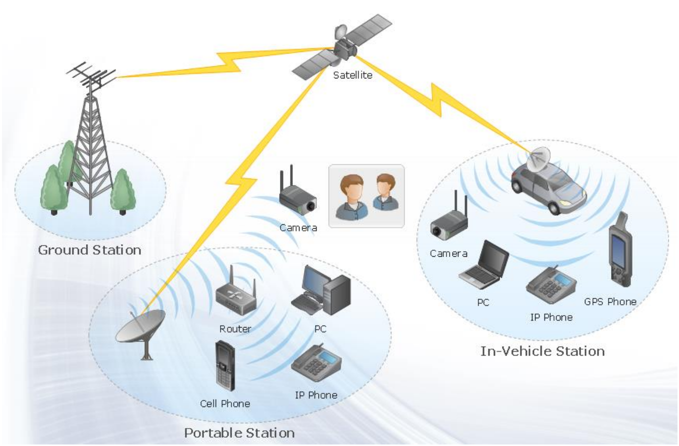
Complexity

- Structural complexity
  - Heterogeneity
  - Scale and dimensionality
  - Dependences and interdependences
- Dynamic complexity
  - Emergent behavior
  - Adaptive learning
  - Evolution and growth mechanisms
  - Cascading

Structural complexity

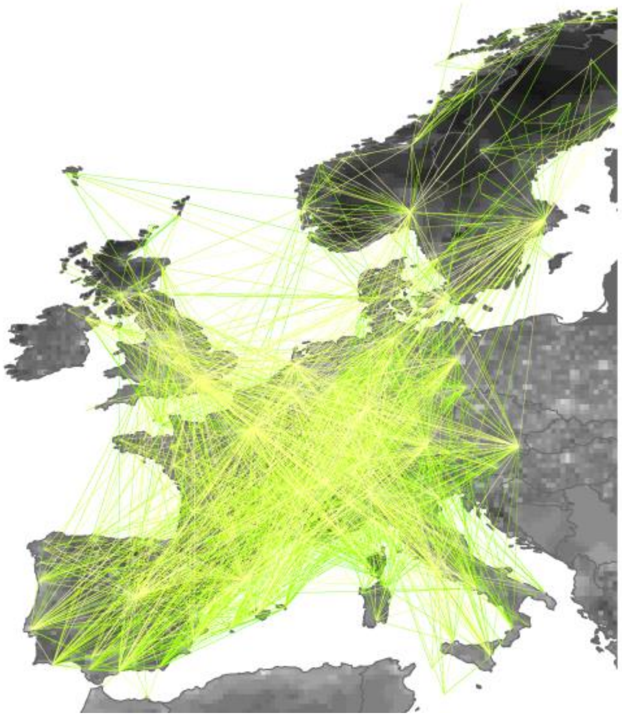
- ***Heterogeneity*** of components across different technological domains due to increased integration among systems.
  - ❖ Physical hard components (compressors, transmission ines, …)
  - ❖ Soft components (SCADA, information and telecommunication systems)
  - ❖ Human and organizational components





Structural complexity

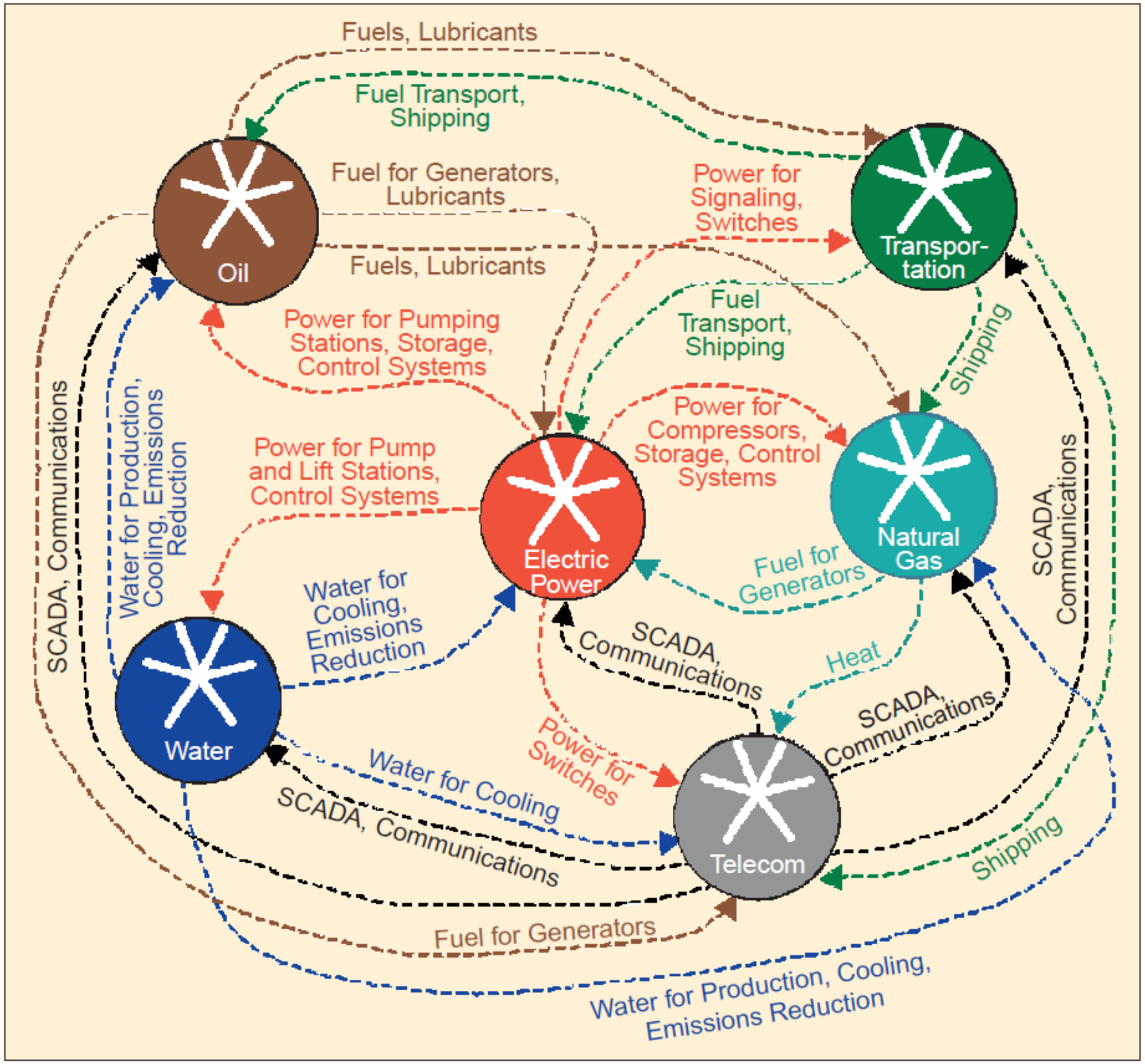
- ***Scale and dimensionality*** of connectivity through a large number of components highly interconnected by ***dependences and interdependences*** distributed over a large geographic extent.



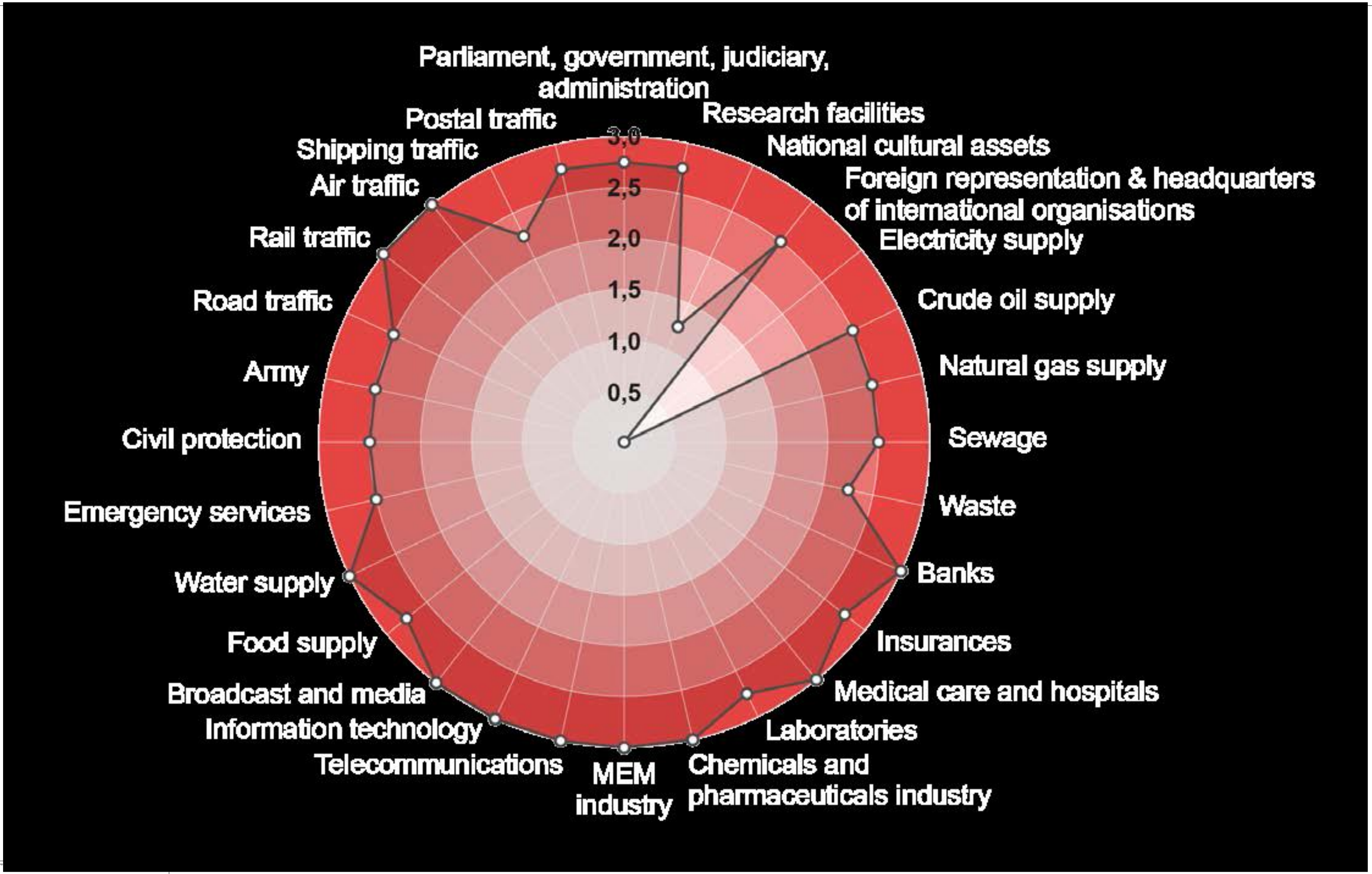
Structural complexity

Example of infrastructures **interdependencies** [Rinaldi et al. 2001]

(systems of systems)



Structural complexity



Dynamic complexity

Emergent behavior refers to actions of a system as a whole that are not simple combinations of the actions of the individual constituents of the system. It emerges in response to changes in the environmental and operational conditions of parts of the system.

Examples:

- *Internet*: social bookmarking leads to an emergent effect in which information resources are reorganized according to users priorities.
- *Electric power grids*: local failures can evolve into unexpected cascade failure patterns with transnational, cross-industry effects.
- *Smart grids*: large amount of information exchanged within technologies at a period of high electricity demand can lead to a vulnerable condition of the system.
- *Road transportation congestion*: slow movement of the traffic.

43

Dynamic complexity

Emergent behavior: Traffic

Global system property that emerges: **slow movement of the traffic**

It **arises from** the cumulative effects of the actions and interactions of all individual vehicles. The global effects depend on the general activities of sufficiently many of them, within the context of that highway.

It is **not due to** specific actions of individual vehicles → no individual vehicle plays a critical role.
If some subset of the vehicles acted differently in their local actions (within certain boundaries), the global effect of slow-moving traffic would be unchanged.

The RISKS of complex systems

FAILURES

Failures

Loss of revenues

Unplanned shut-down,
D.C. Cook NPP

Fatalities and contaminations

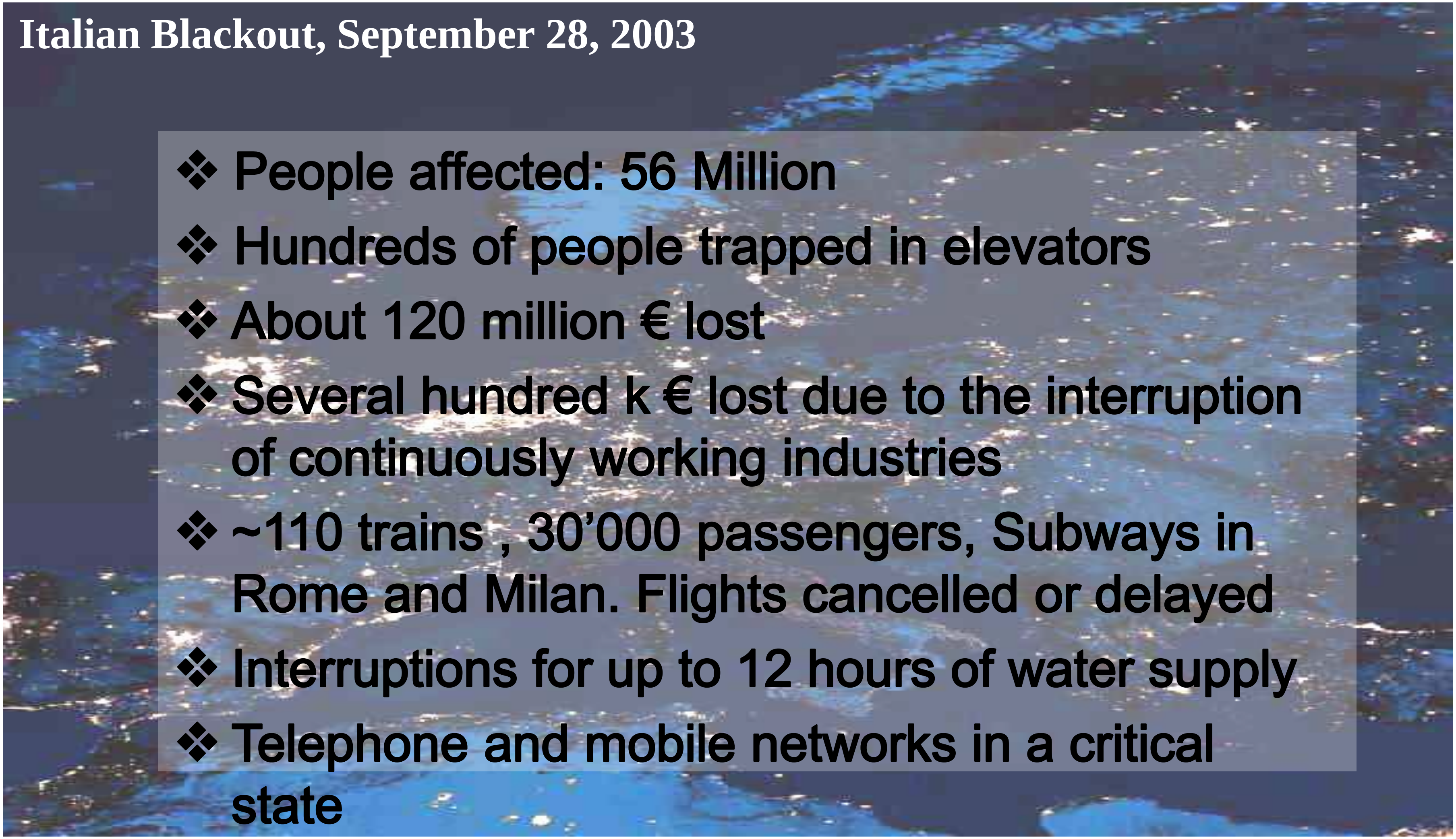
Oil rig explosion in 2010,
Gulf of Mexico

Failures

Crisis, service/business interruption, asset loss…

Failures: Italian Blackout, September 28, 2003

Relevance of the problem: large consequence

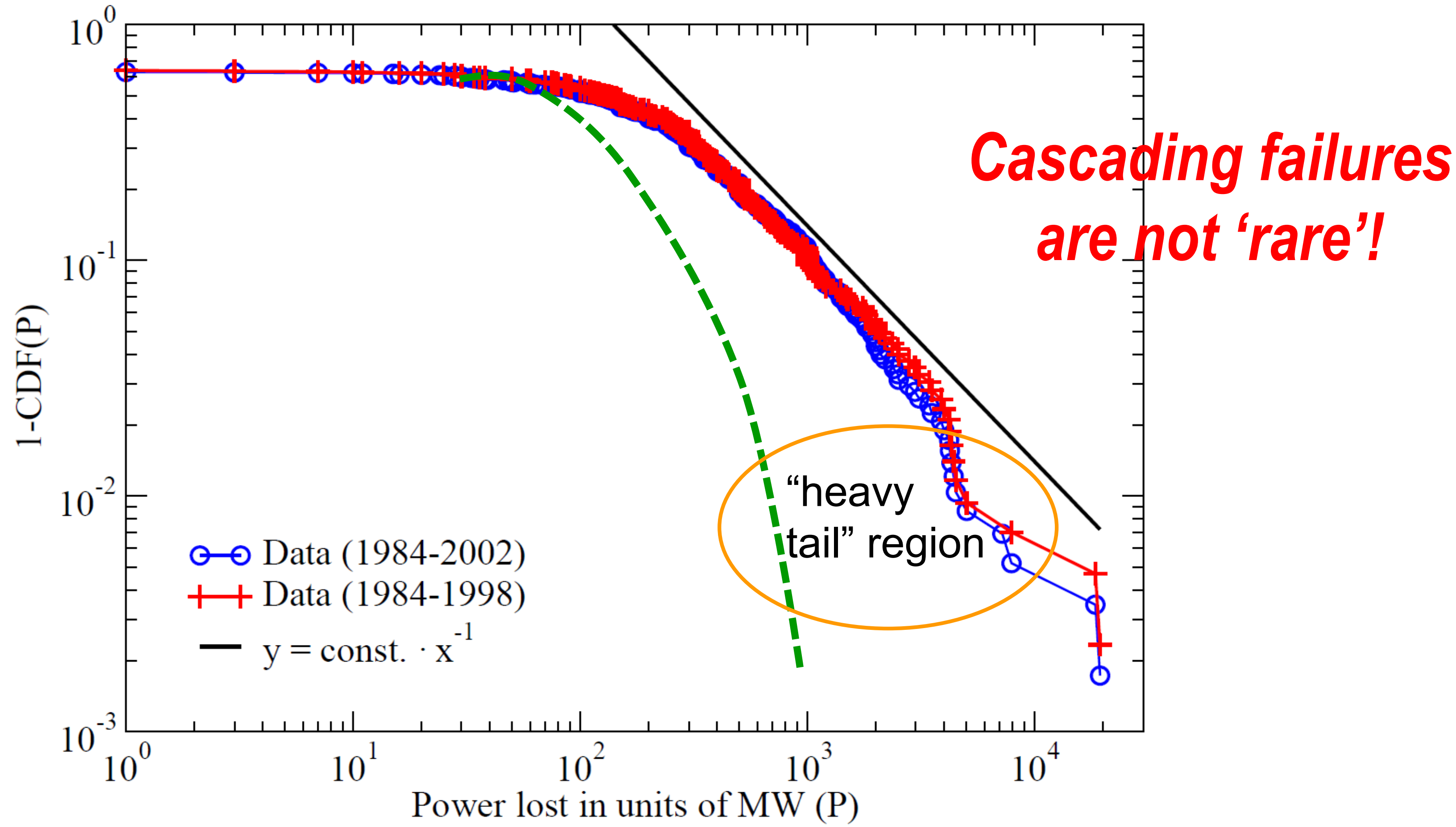


Italian Blackout, September 28, 2003

- People affected: 56 Million
- Hundreds of people trapped in elevators
- About 120 million € lost
- Several hundred k € lost due to the interruption of continuously working industries
- ~110 trains , 30’000 passengers, Subways in Rome and Milan. Flights cancelled or delayed
- Interruptions for up to 12 hours of water supply
- Telephone and mobile networks in a critical state

… and baby boom …

Relevance of the problem: non-negligible probability



(Weron et al., 2006)

Failures: Relevance of the problem

Cascading failures

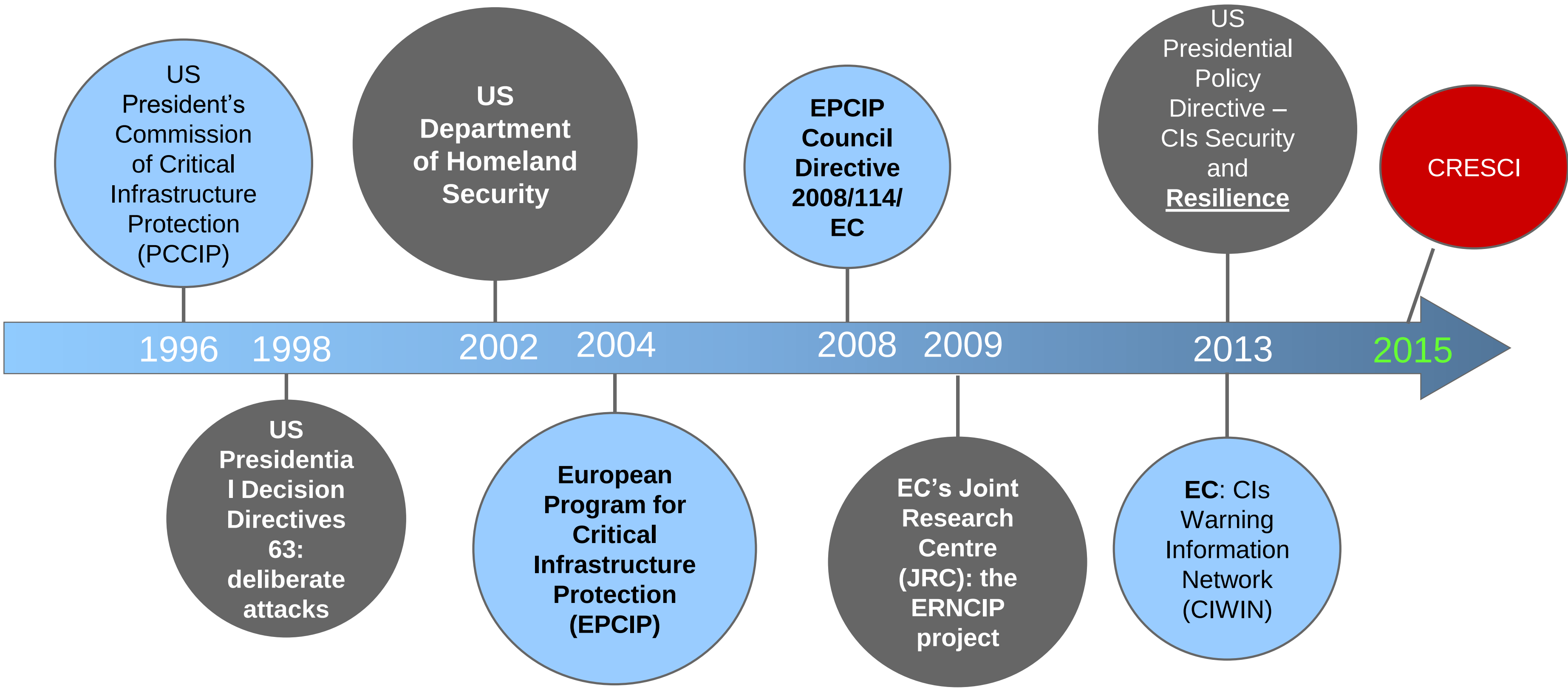
Large consequence

Non-negligible probability

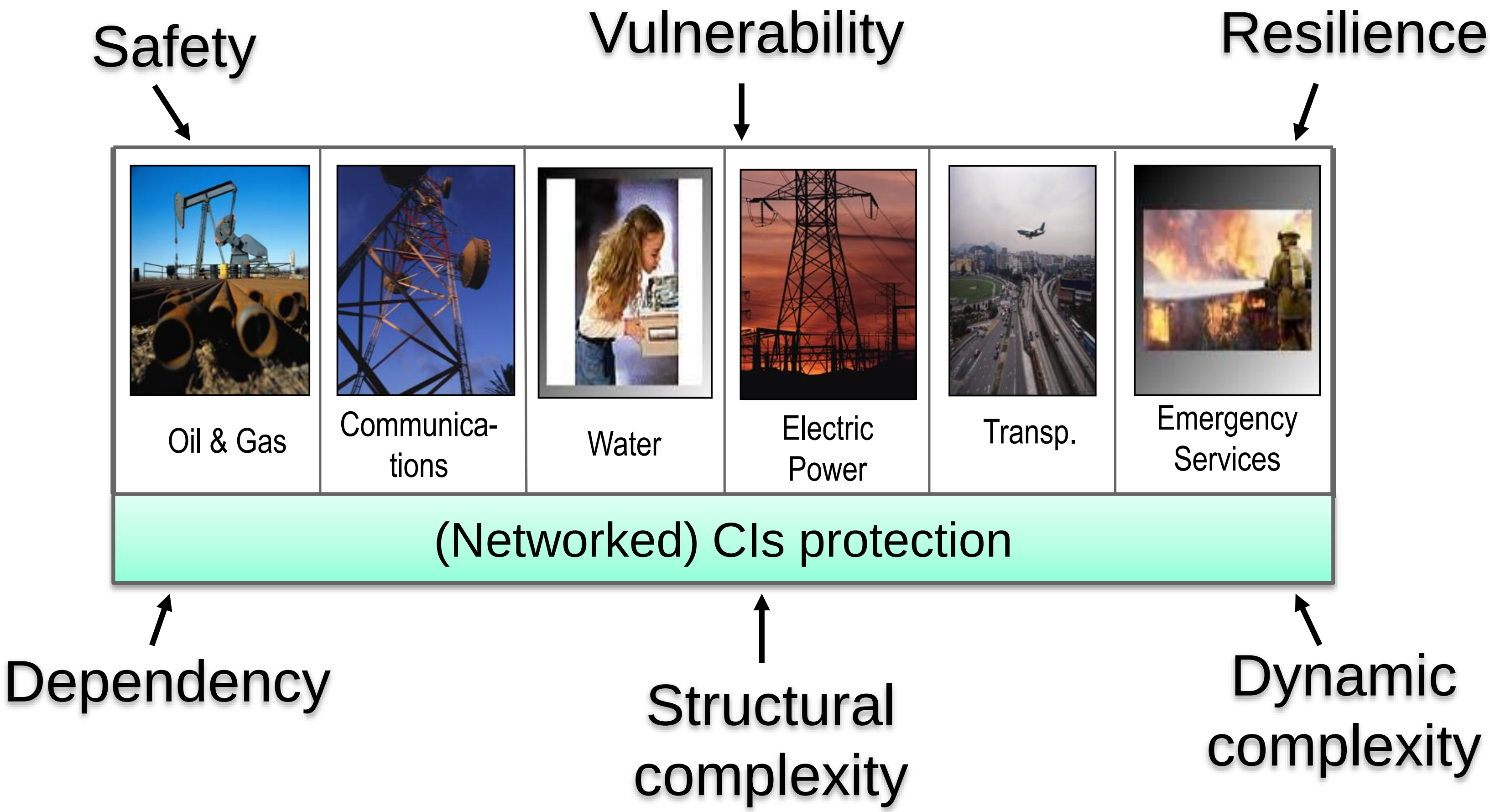
Critical infrastructure protection and resilience (CIPR)

Failures: Relevance of the problem

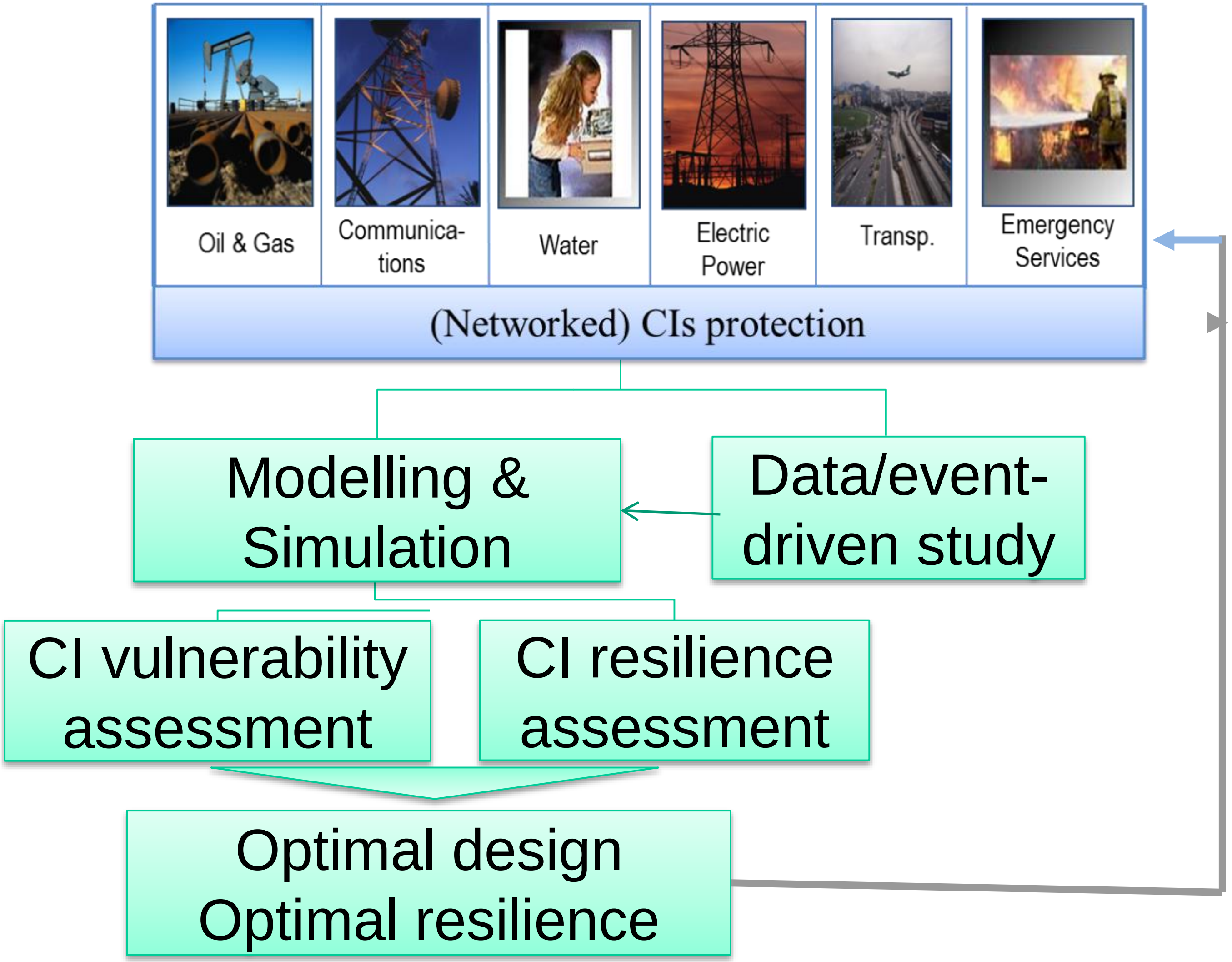
Critical infrastructure protection (CIP) - U.S. & E.U.



Protection and resilience of critical infrastructures: scientific and technical issues

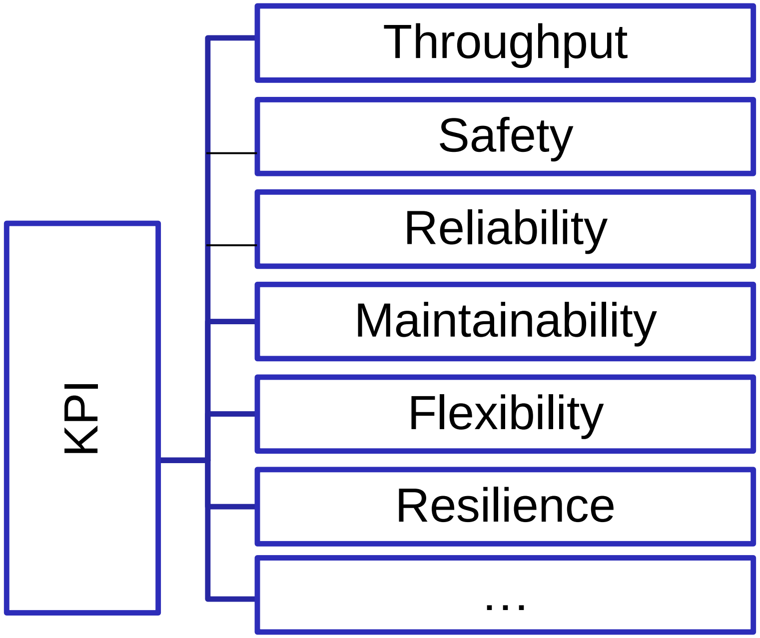


Protection and resilience of critical infrastructures: ways to go



Complex systems KPIs

- Key Performance Indicators (KPI): A key performance indicator (KPI) is a business metric used to evaluate factors that are crucial to the success of an organization.

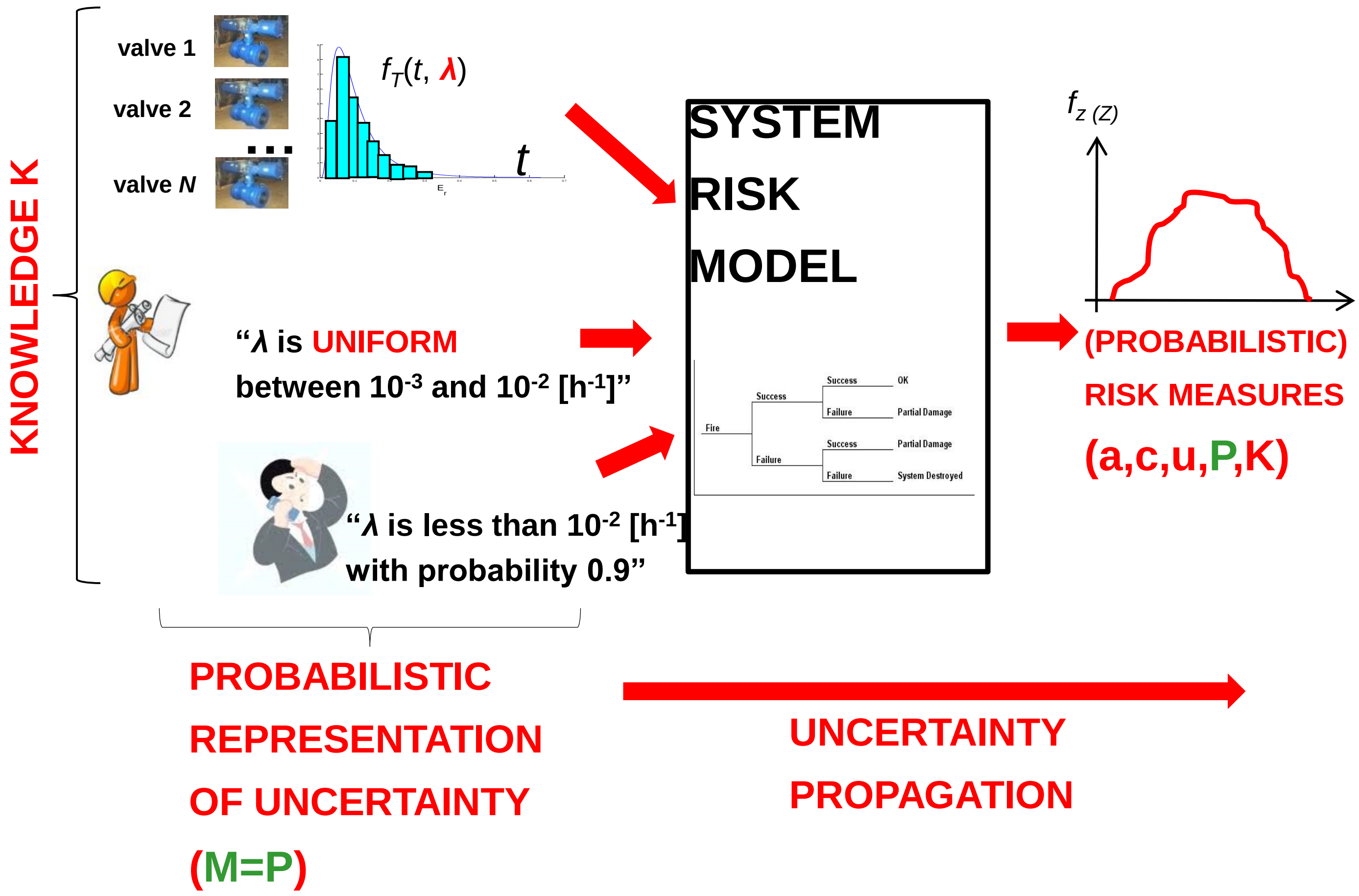


57

SAFETY

KPIs– Safety and Hazards

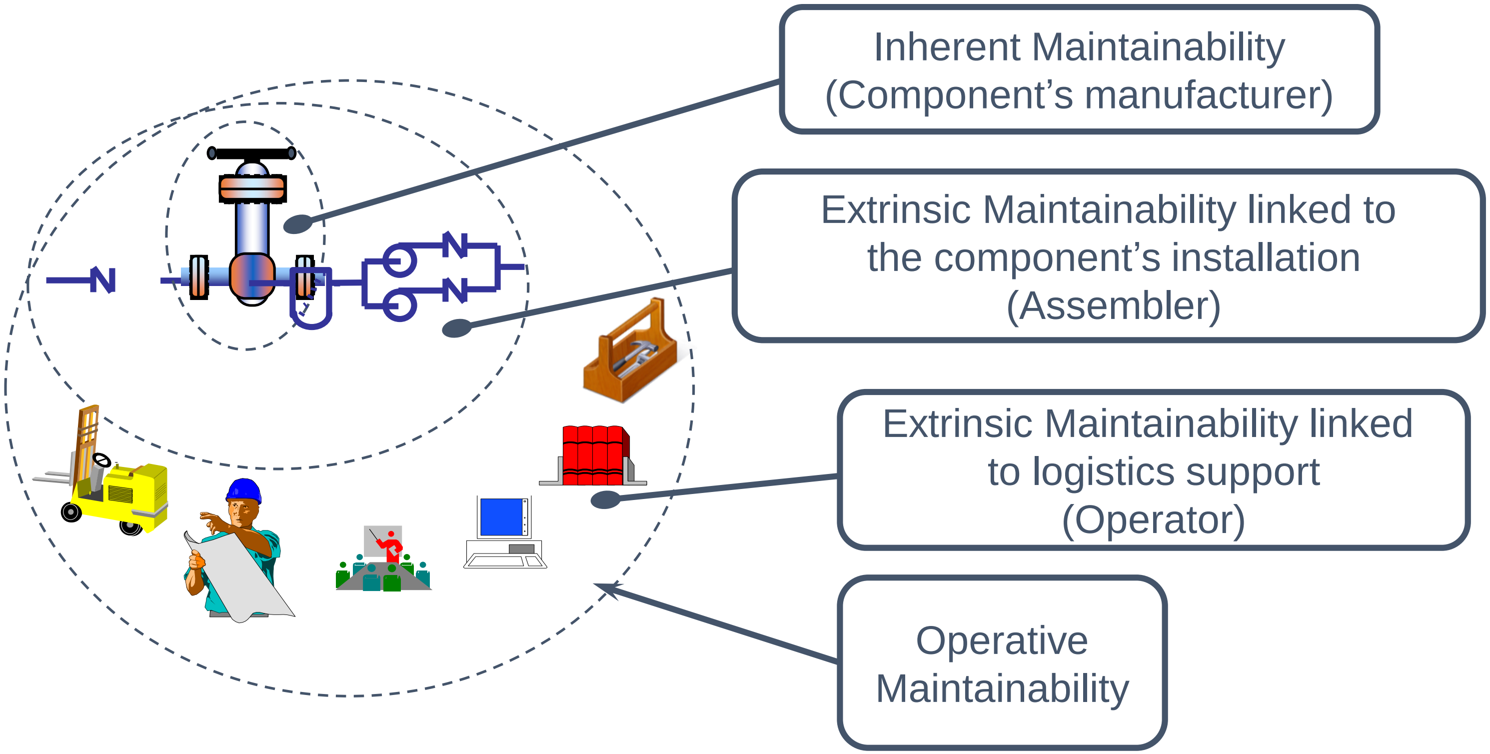
KPIs– Safety and Probabilistic risk assessment



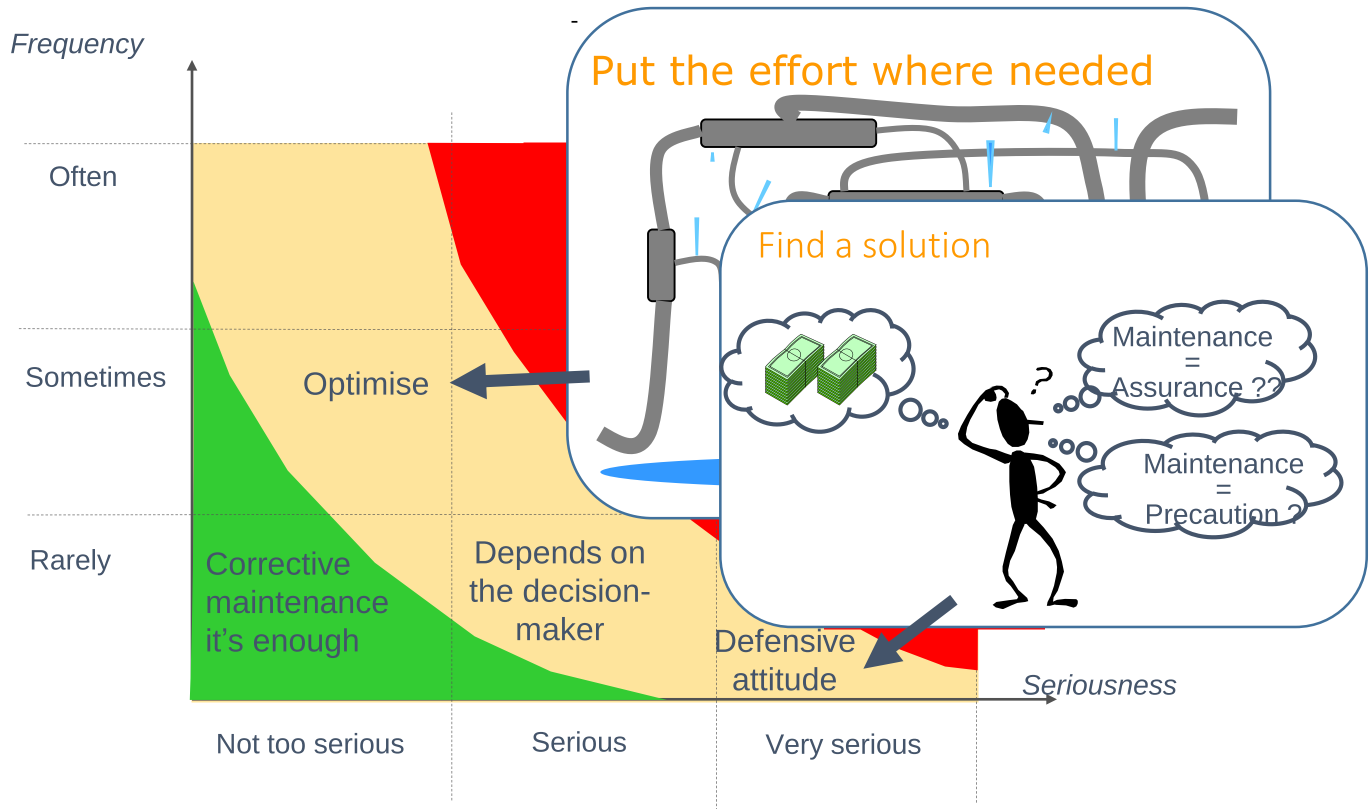
62

MAINTAINABILITY

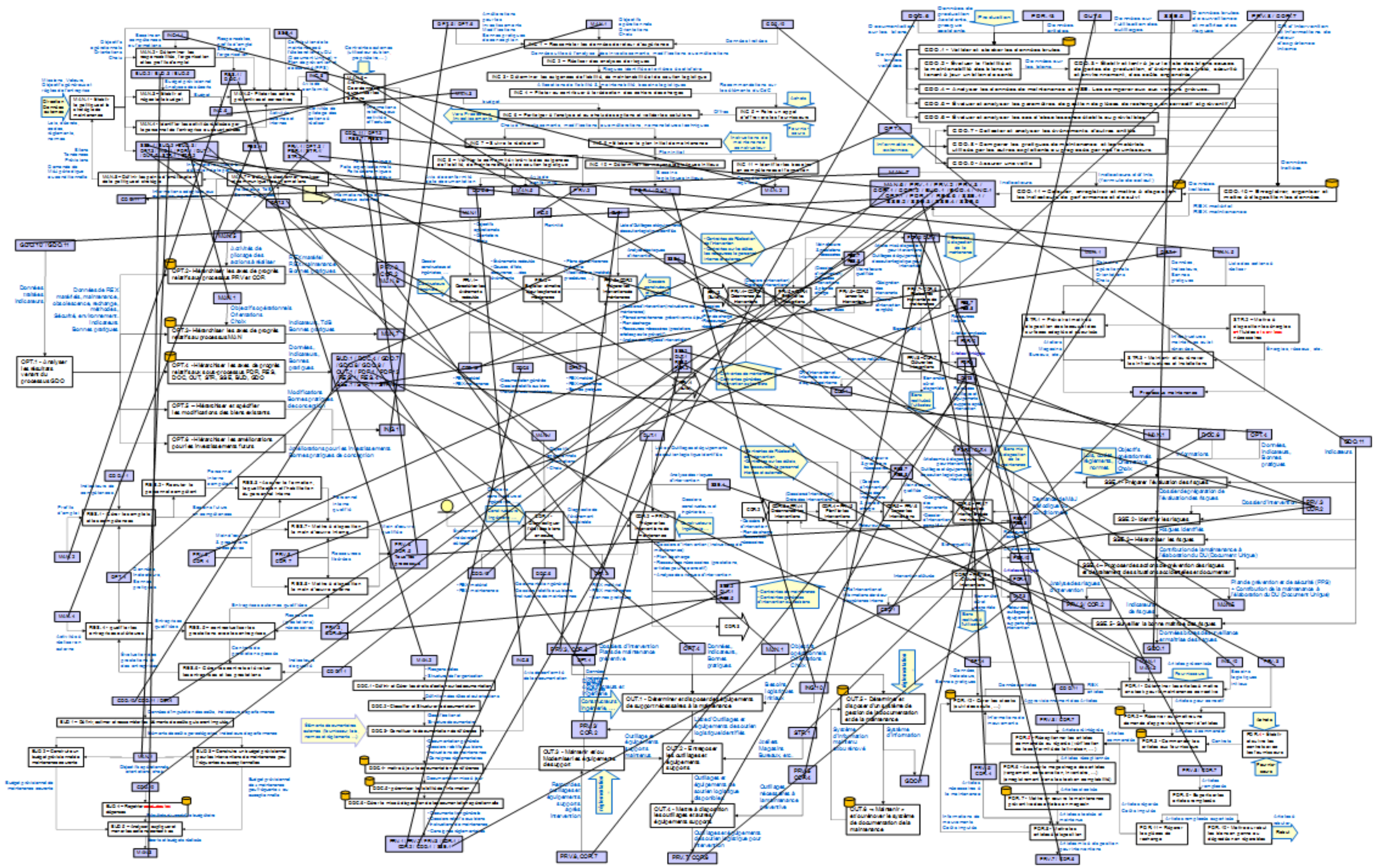
KPIs– Maintainability and Maintenance



KPIs– Maintainability, Maintenance and Safety

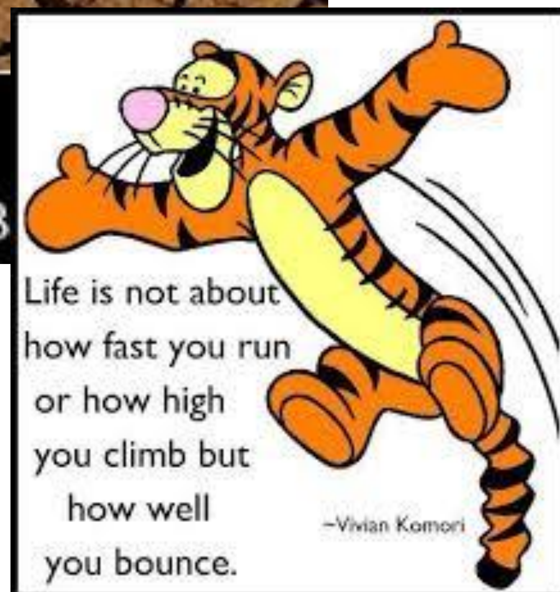


2. Maintenance management process



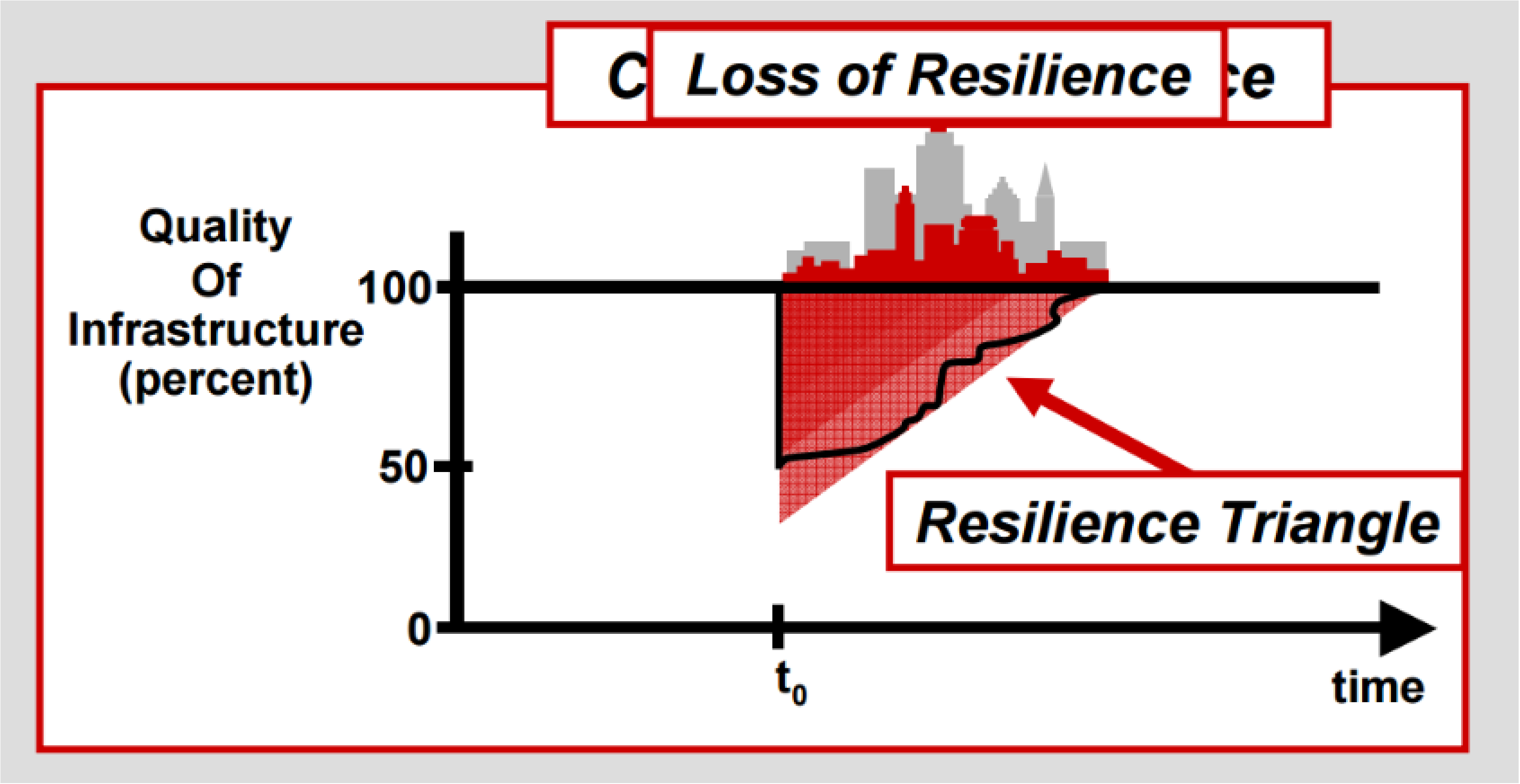
- RESILIENCE


Resilience
The Courage to Come B


Life is not about how fast you run or how high you climb but how well you bounce.
~Vivian Komori


She stood in the storm and when the wind did not blow her away, she adjusted her sails
- Elizabeth Edwards


RESILIENCE
The capacity to prepare for disruptions, recover from shocks and stresses, and adapt and grow from a disruptive experience.
#RebuildBETTER


C
Loss of Resilience
ce
Quality
Of
Infrastructure
(percent)
100
50
0
Resilience Triangle
t_0
time

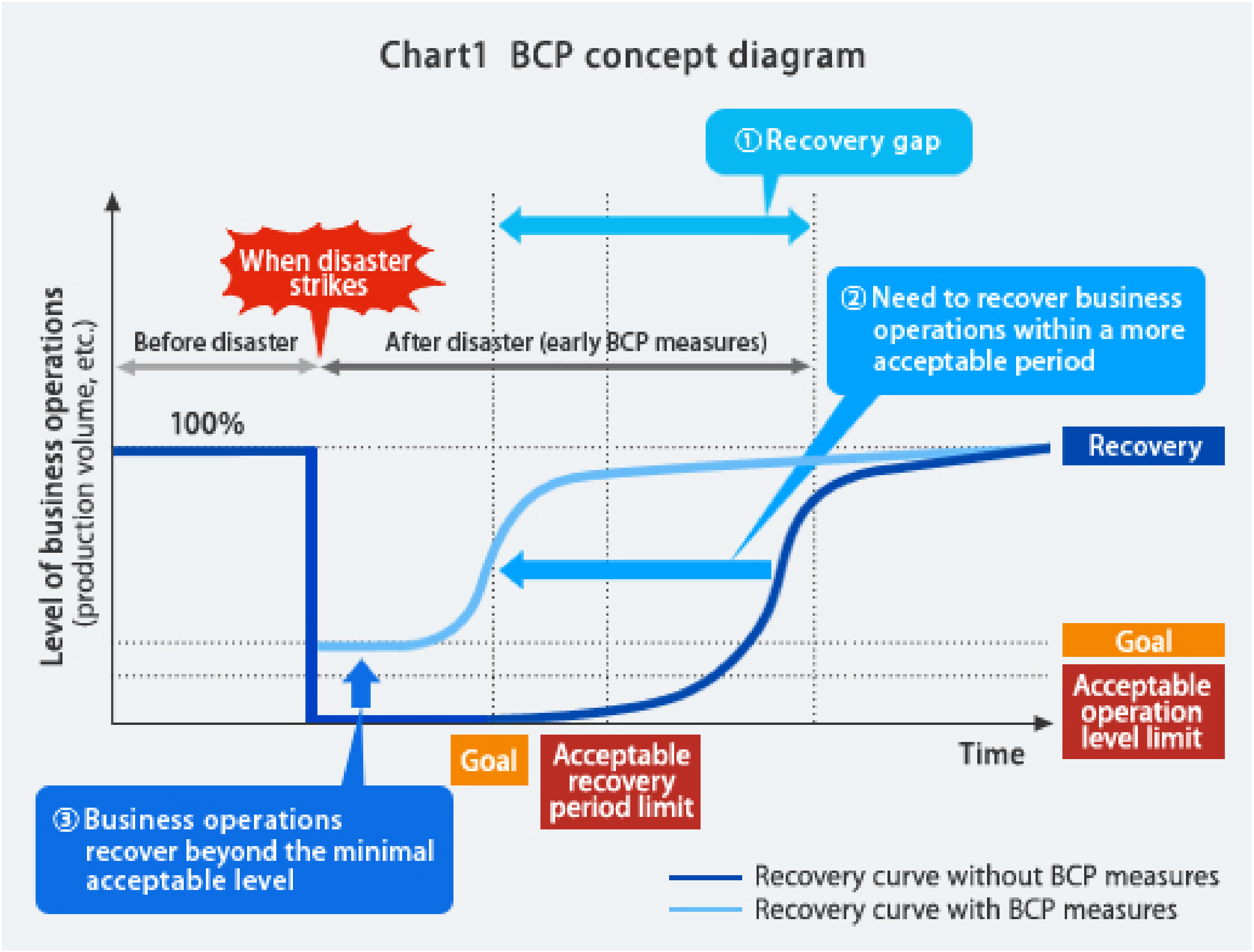
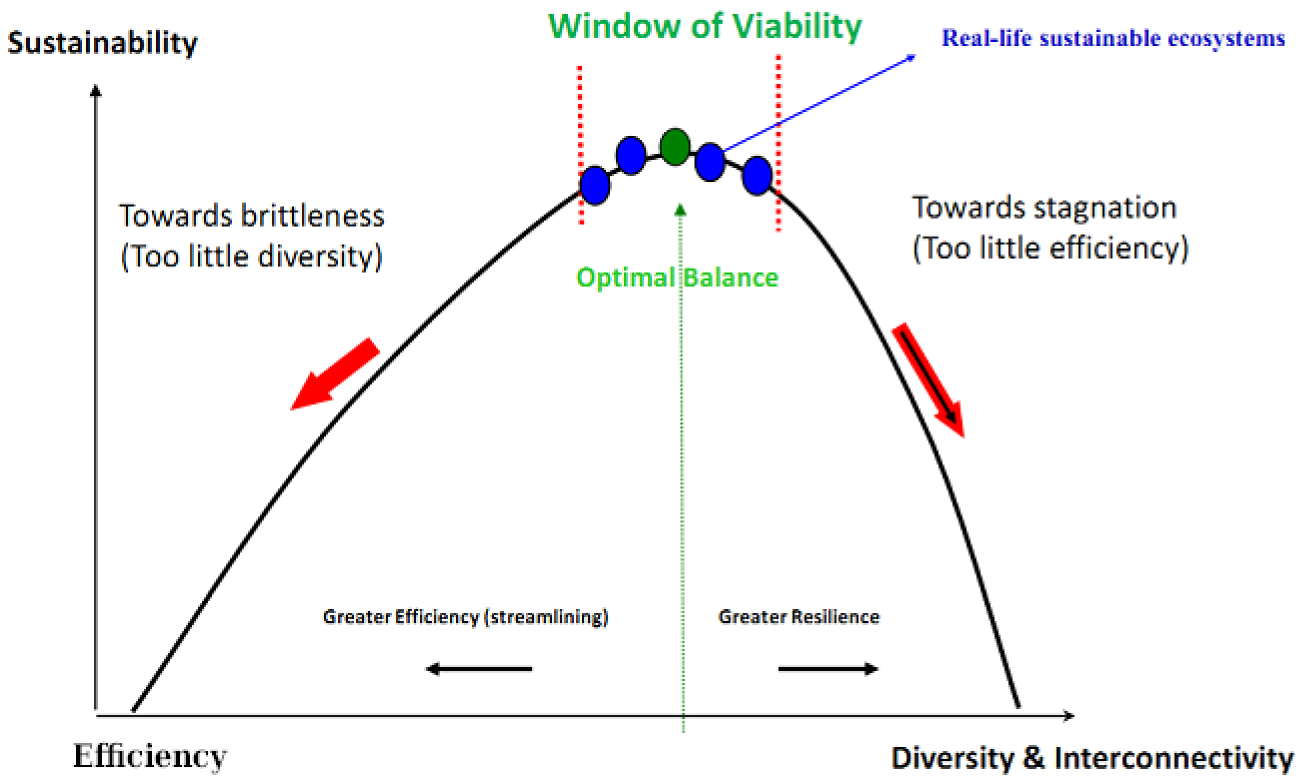
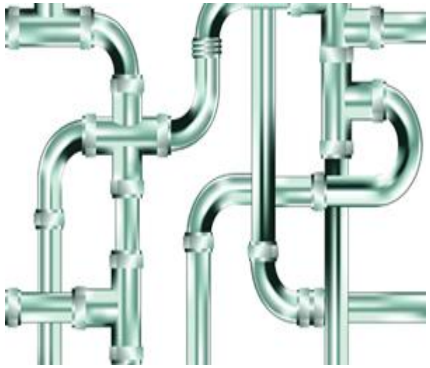
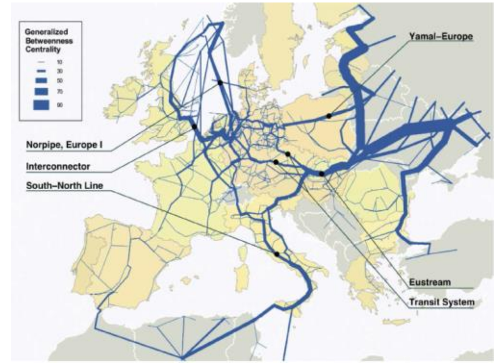
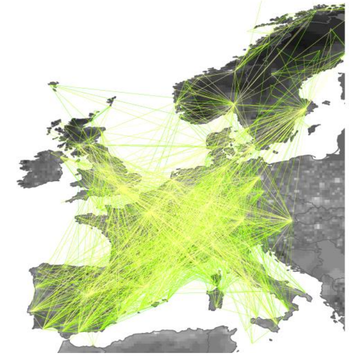


Chart1 BCP concept diagram
①Recovery gap
When disaster strikes
Before disaster
After disaster (early BCP measures)
②Need to recover business operations within a more acceptable period
Level of business operations (production volume, etc.)
100%
Recovery
Goal
Acceptable operation level limit
Time
Goal
Acceptable recovery period limit
③Business operations recover beyond the minimal acceptable level
Recovery curve without BCP measures
Recovery curve with BCP measures


Window of Viability
Real-life sustainable ecosystems
Sustainability
Towards brittleness
(Too little diversity)
Optimal Balance
Towards stagnation
(Too little efficiency)
Greater Efficiency (streamlining)
Greater Resilience
Efficiency
Diversity & Interconnectivity

Systems: desired characteristics



- Systems have to be:
  - **Efficient** (max performance)
  - **Resilient** (adsorptive, adaptive and recovery capacity)

A

Φ

Too much efficiency:

No reserve capacity

No backup

Too much resilience:

Too many alarms, controls and strategies of recovery that it is difficult to decide what to do

Perspective: Information Theory

- **Efficiency (A) = presence of order** (in the sense of diversity processes)
- It is the capacity of the system of exercising directed power to maintain its integrity over time.
- Contributing factors: streamlining, large size and high capacity

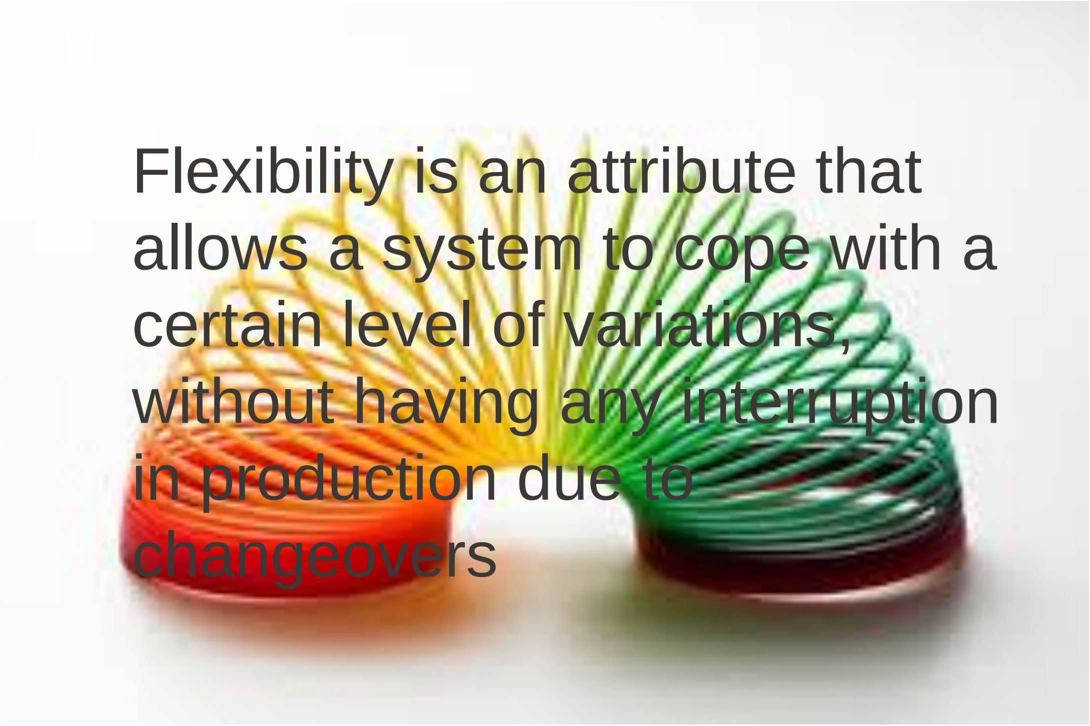
- **Resilience (Φ) = absence of order** (in the sense of diversity processes)
- It represents the reserve that allows the system to persist
- Contributing factors: flexibility, diversity, small size and dense connectivity

Absence of order ~ Conditional entropy

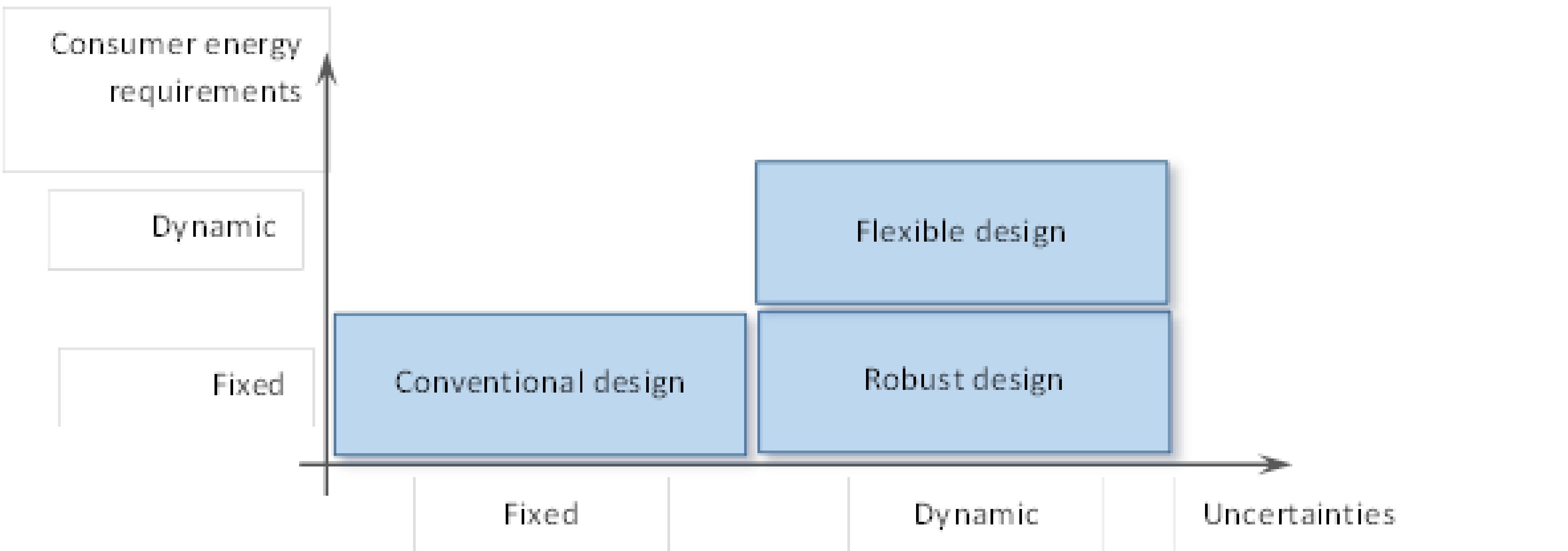
→ Information Theory (IT)

Already applied to the ecology field
[Ulanowicz et al. 2009]

- FLEXIBILITY



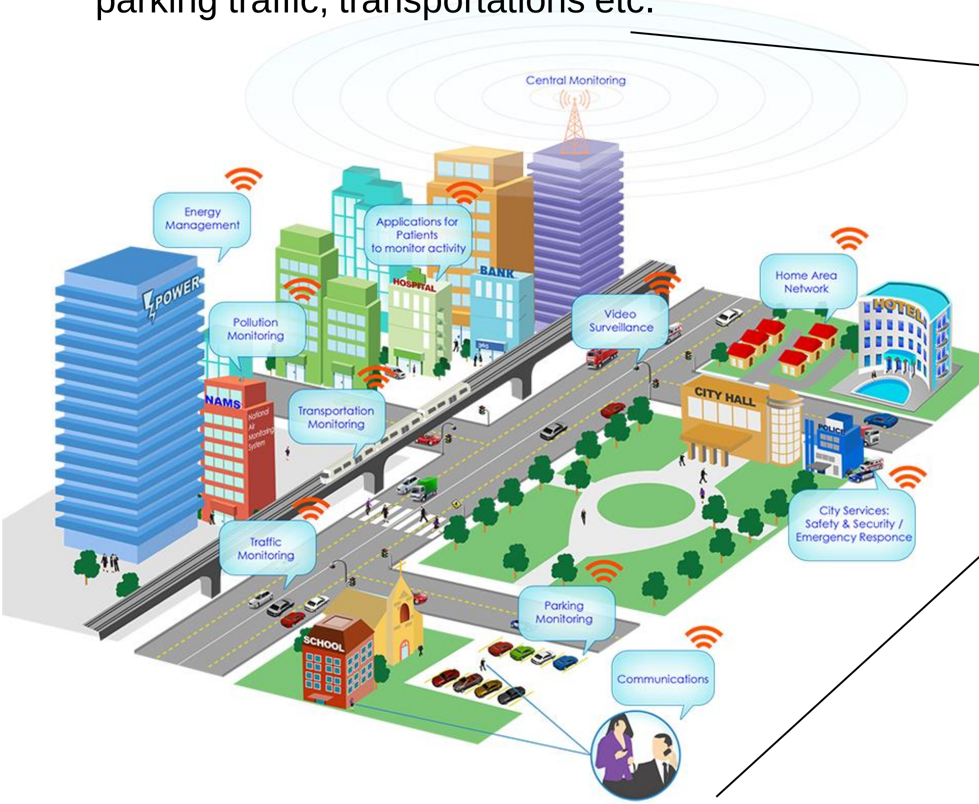
Flexibility is an attribute that allows a system to cope with a certain level of variations, without having any interruption in production due to changeovers


Consumer energy requirements
Dynamic
Fixed
Flexible design
Conventional design
Robust design
Fixed
Dynamic
Uncertainties

THROUGHPUT/SAFETY/ RELIABILITY/MAINTENANABILITY/RESILIENCE/FLEXIBILITY

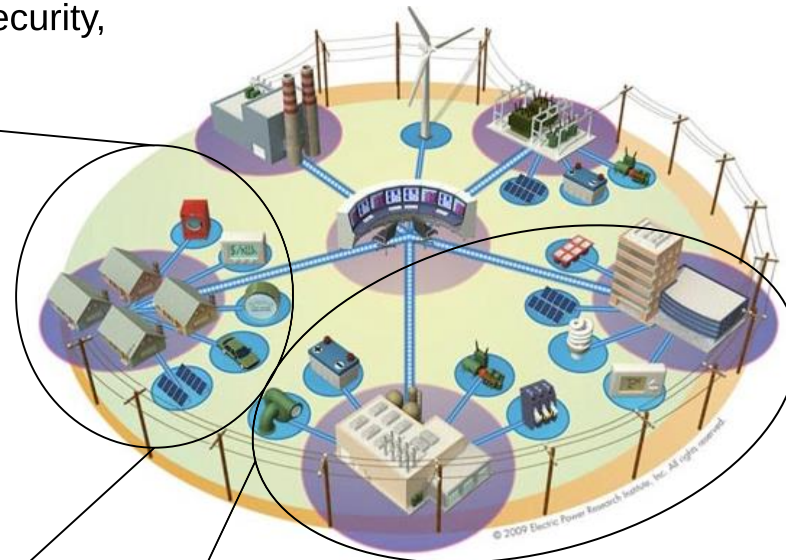
Smart grids, Smart Cities and Eco-Industrial Parks

Application of Internet of Things concept in Smart Cities to tackle urban challenges – pollution, energy efficiency, security, parking traffic, transportations etc.

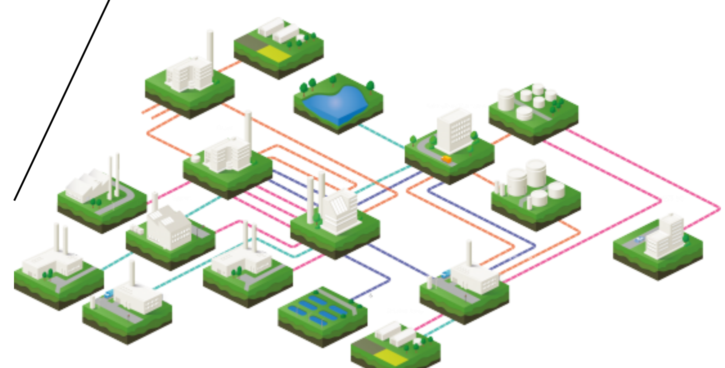


Source: IOT Phillippines INC.

Internet of Things in Smart Grids



Eco-Industrial Parks



Source: Kalundborg Symbiosis

Complex systems: the Dual Analysis

- **Complex systems: structure + dynamics**

•Direct Problem

Aggregation Challenge

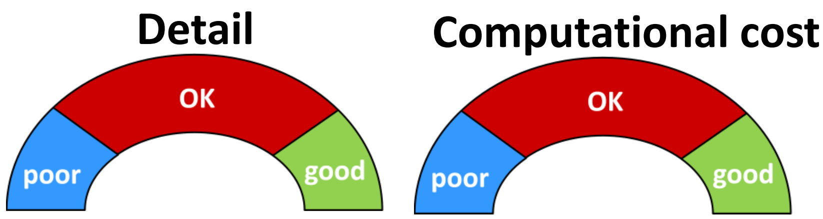
KPIs

Inverse Problem

Disaggregation Challenge

System elements important for the KPIs

- **Complex systems modeling: topological, flow, phenomenological, logic**



Complex system analysis

System analysis:

- hazards and threats identification
- physical and logical structure identification
- **dependencies and interdependences** identification and modeling
- dynamic analysis (cascading failures)

Quantification of system KPIs

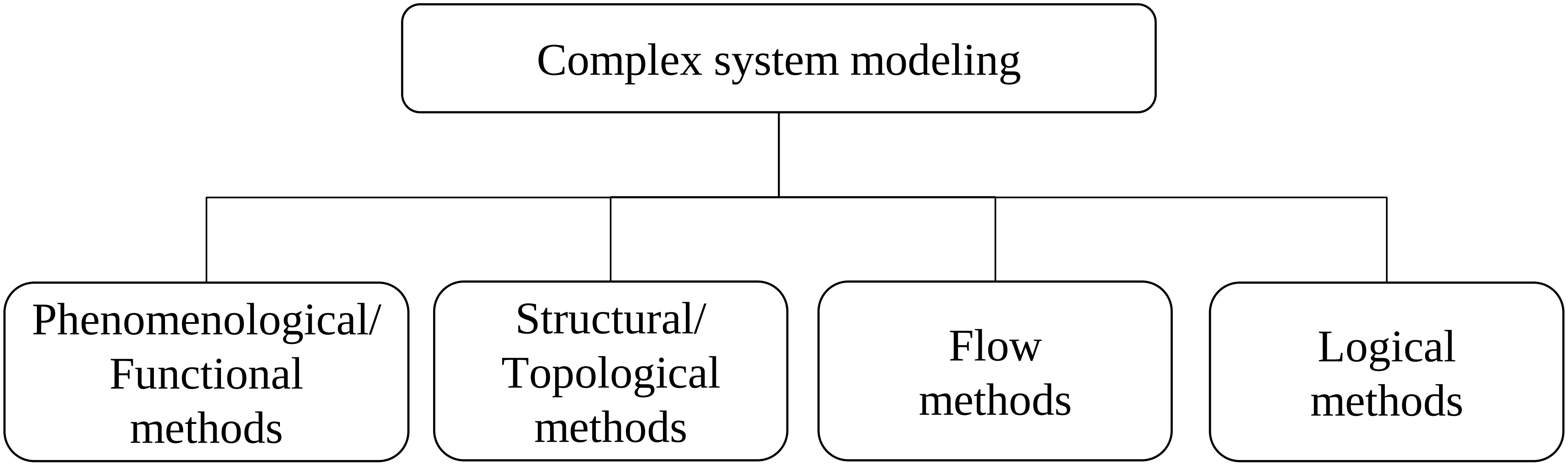
Identification of critical elements

Application for system improvements (optimization):

- design
- operation
- interdiction/protection

W. Kroger and E. Zio, *"Vulnerable Systems"*, Springer, 2011

Complex system modeling



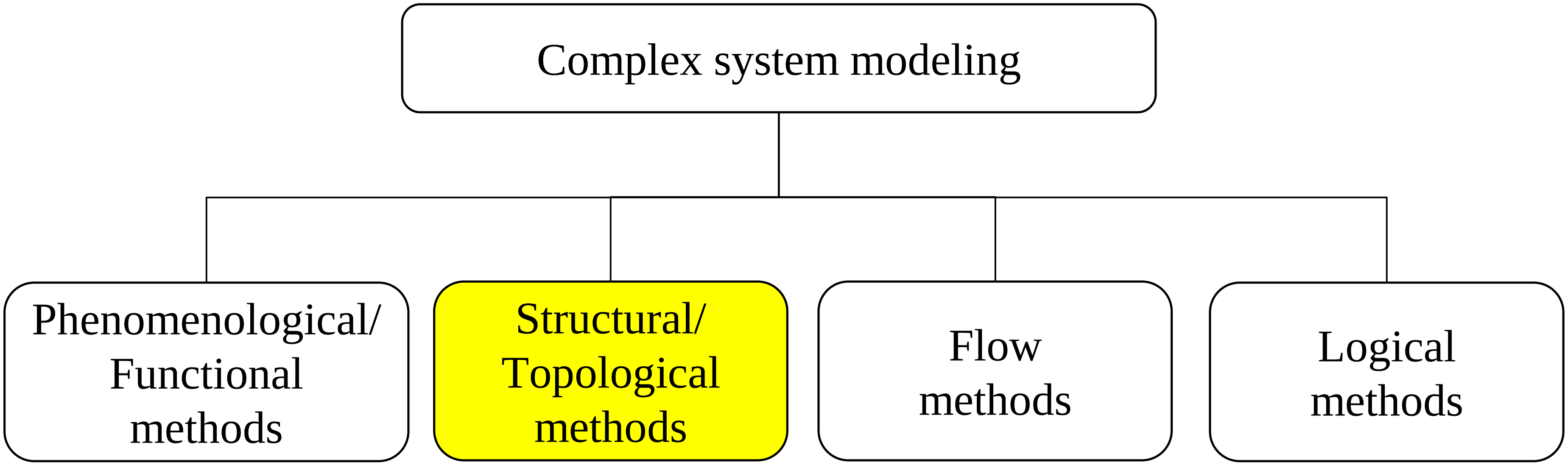
e.g., Agent Based Modeling and Simulation, System Dynamic Model, Economic-Based Approaches, …

e.g., Topology-based approaches

e.g., Flow-based approaches (maximum flow model, …)

e.g., Risk Analysis (fault/event trees, …), Probabilistic Modeling (Markov Chains, Bayesian network, …)

Complex system modeling



e.g., Agent Based Modeling and Simulation, System Dynamic Model, Economic-Based Approaches, …

e.g., Topology-based approaches

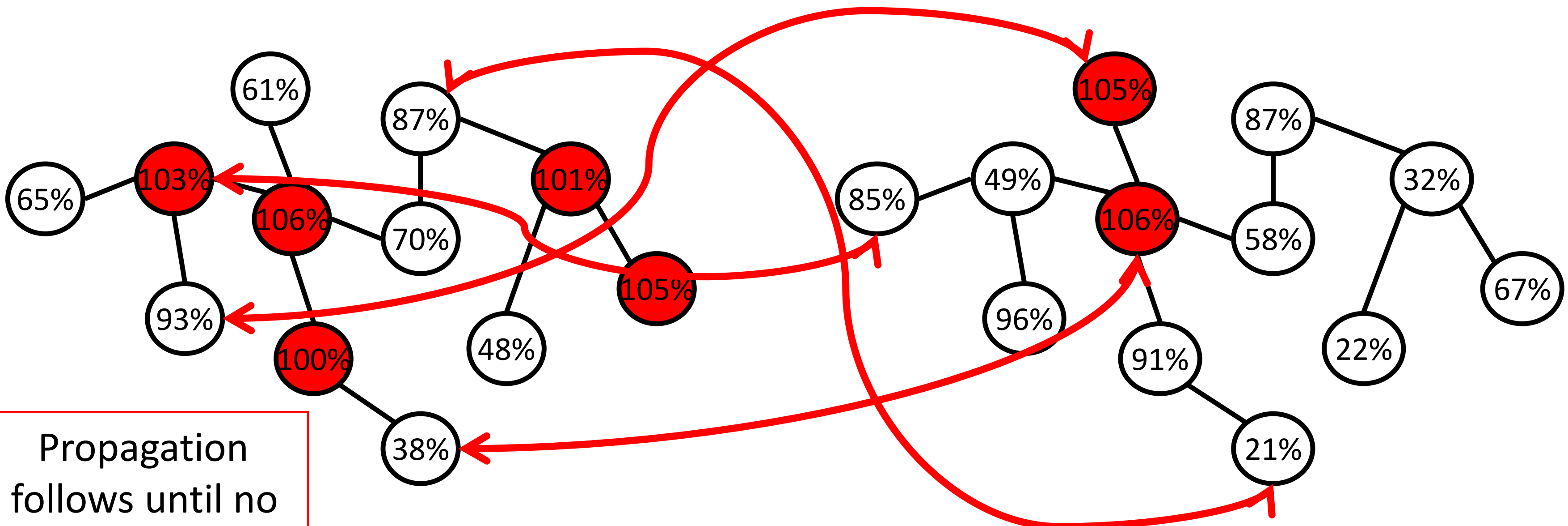
e.g., Flow-based approaches (maximum flow model, …)

e.g., Risk Analysis (fault/event trees, …), Probabilistic Modeling (Markov Chains, Bayesian network, …)

Structural topological methods: modeling cascading failures

Spreading rules:

- fixed load (5%) transferred after a failure to neighboring nodes
- fixed load, *l*, (10%) transferred after a failure to interdependent nodes

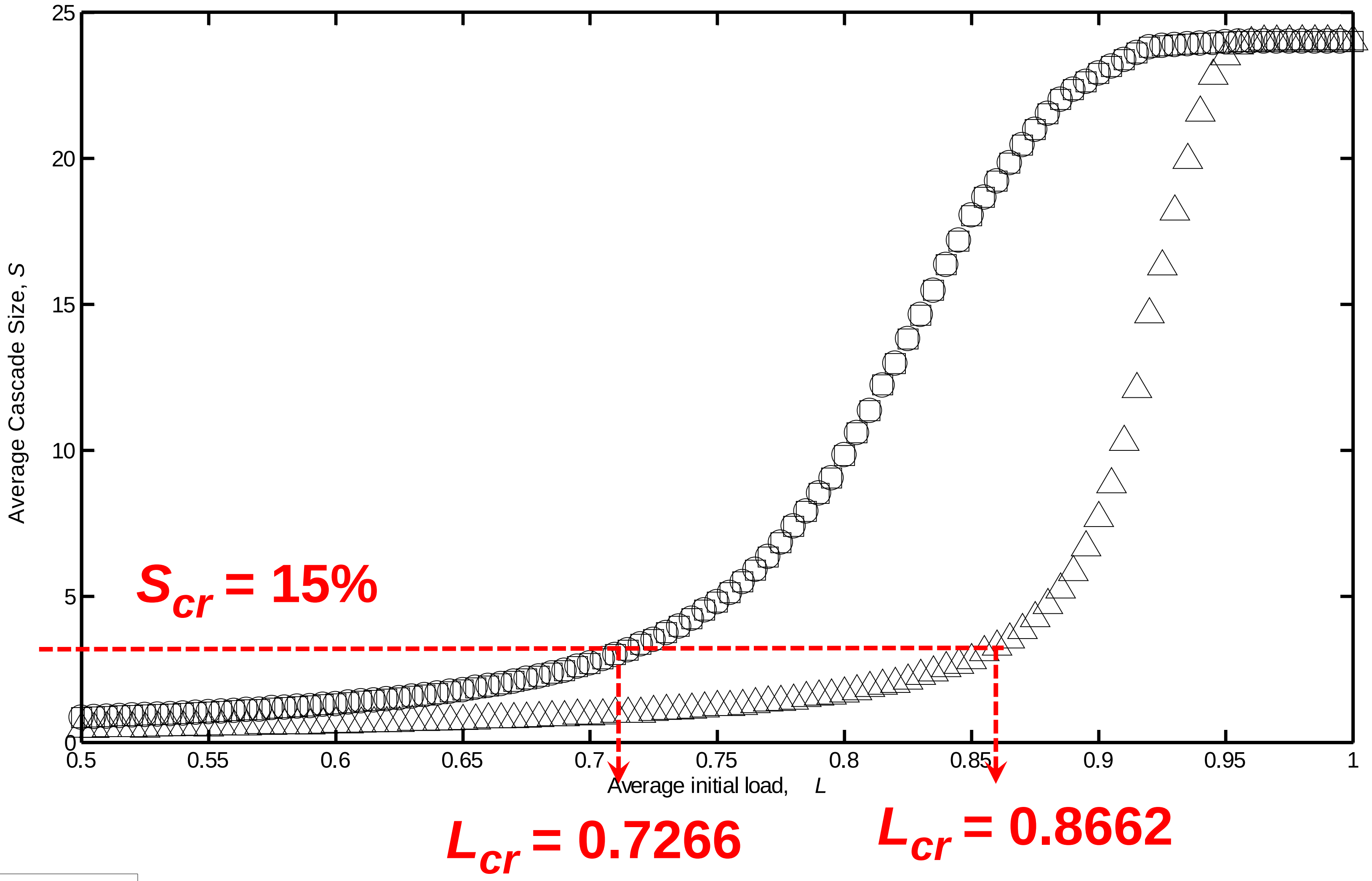


Propagation follows until no more working component can fail

100% = component relative limit capacity

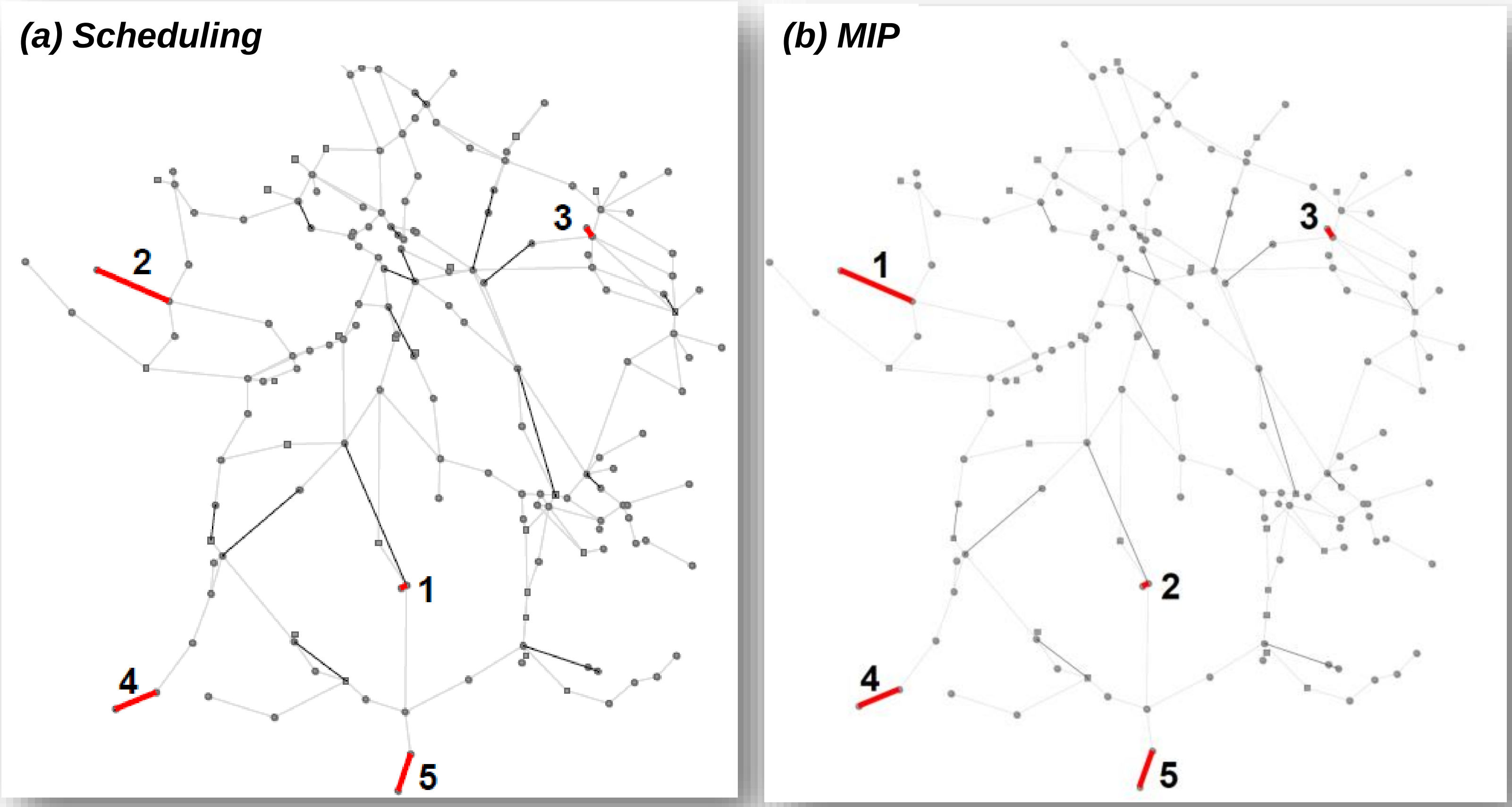
Initiating event: uniform disturbance (10%)

Modeling the complexity of Critical Infrastructures



E. Zio and G. Sansavini, "*Modeling Interdependent Network Systems for Identifying Cascade-Safe Operating Margins*", IEEE Transactions on Reliability, 60(1), pp. 94-101, March 2011

Optimal restoration for system resilience Application to the FPTN400



Technical result: similar restoration plans by heuristic scheduling algorithm & MIP

Complex system modeling

Complex system modeling

- **Phenomenological/ Functional methods**

  e.g., Agent Based Modeling and Simulation, System Dynamic Model, Economic-Based Approaches, …

- **Structural/ Topological methods**

  e.g., Topology-based approaches

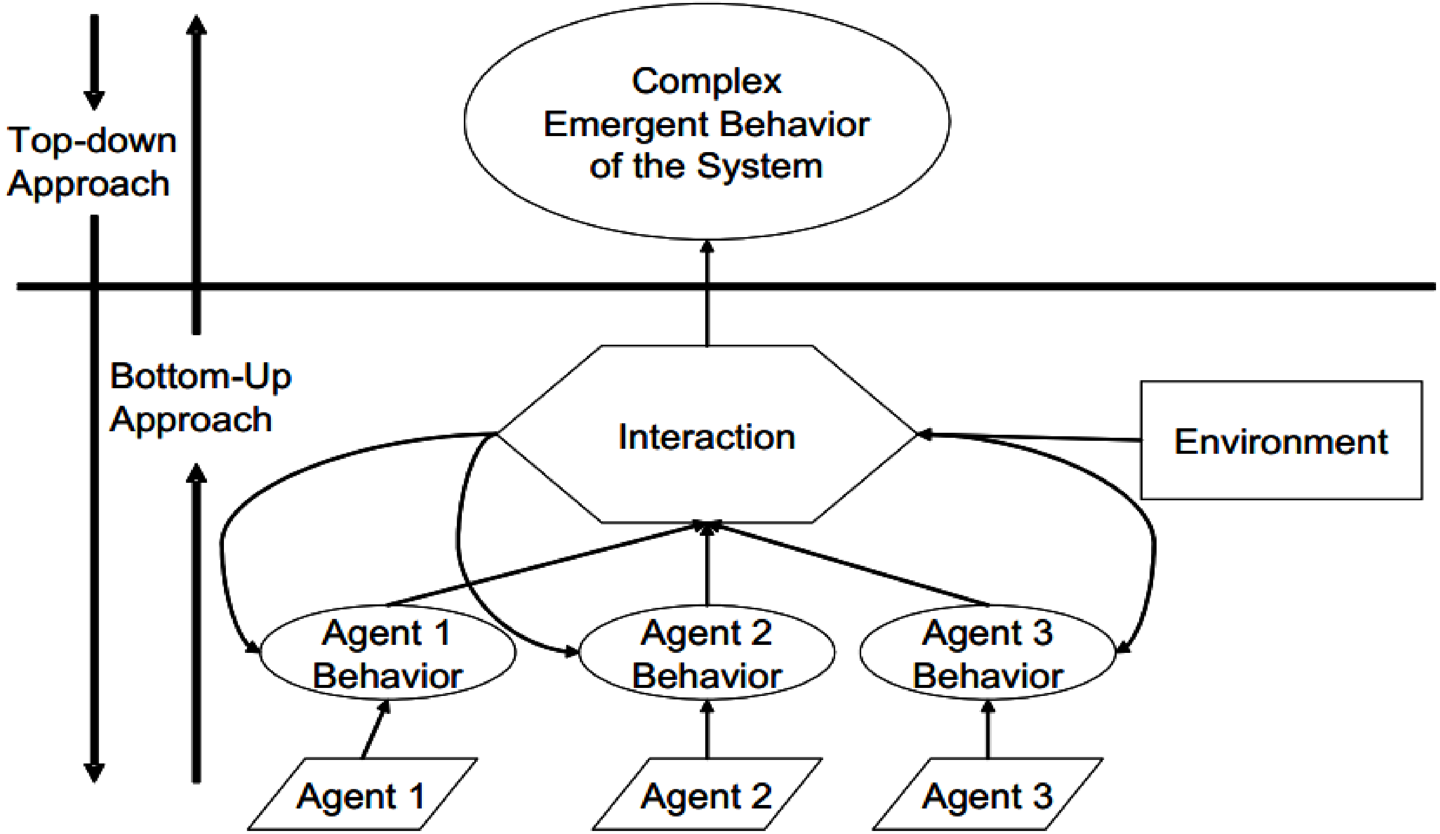
- **Flow methods**

  e.g., Flow-based approaches (maximum flow model, …)

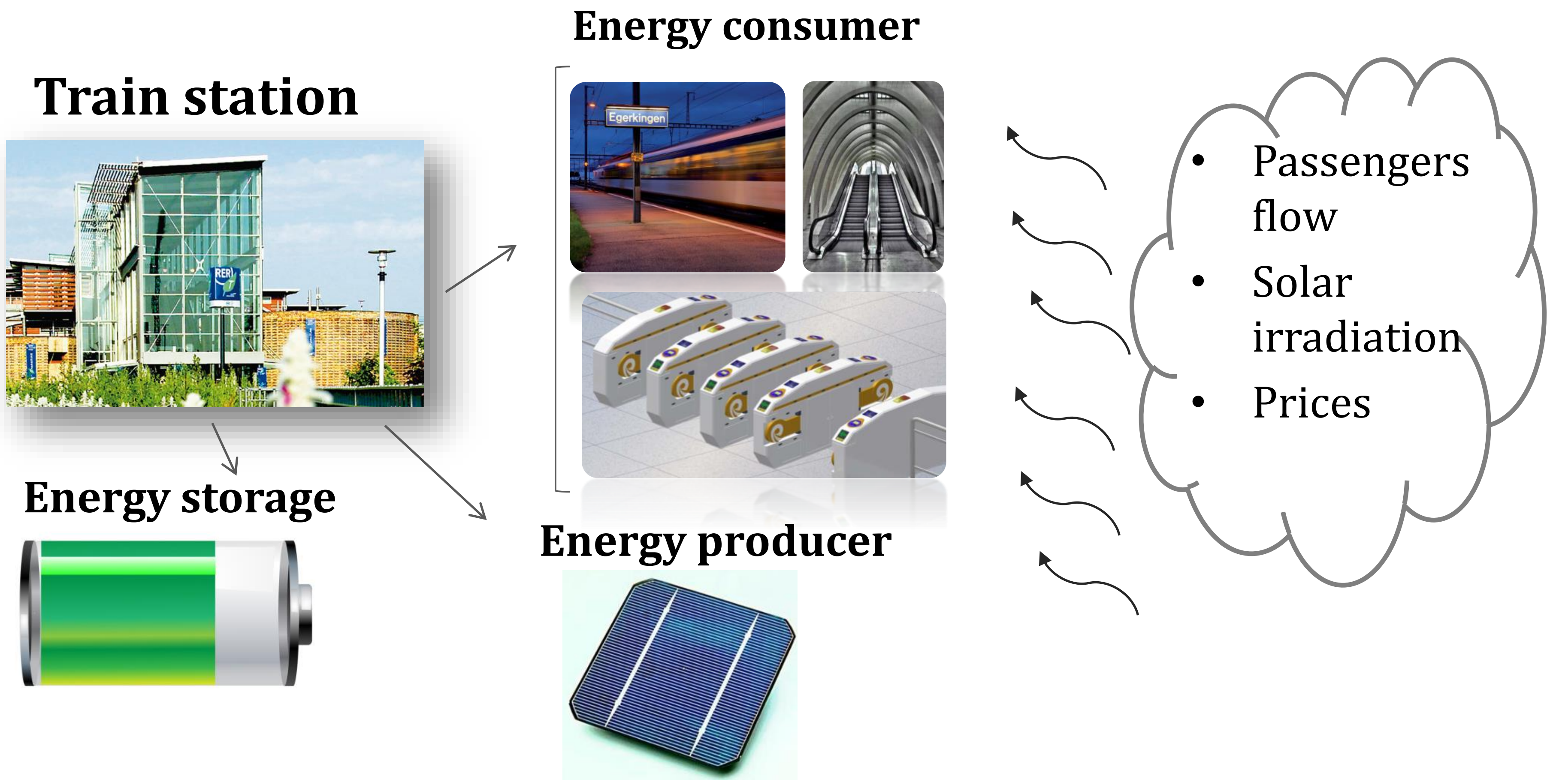
- **Logical methods**

  e.g., Risk Analysis (fault/event trees, …), Probabilistic Modeling (Markov Chains, Bayesian network, …)

Agent-Based Modeling of Complex Systems



Microgrid Agent-Based Modeling and Optimization under Uncertainty



(Kuznetsova et al, 2014)

Microgrid Agent-Based Modeling and Optimization under Uncertainty

Modelling

❖ Agent-based modeling (ABM)

- Representation of microgrid actors (systems) as agents
- Dynamic interactions between agents and the environment
- Multi-layered agen[…] for forecasting, opt[…]

E

E

Train station

Energy storage

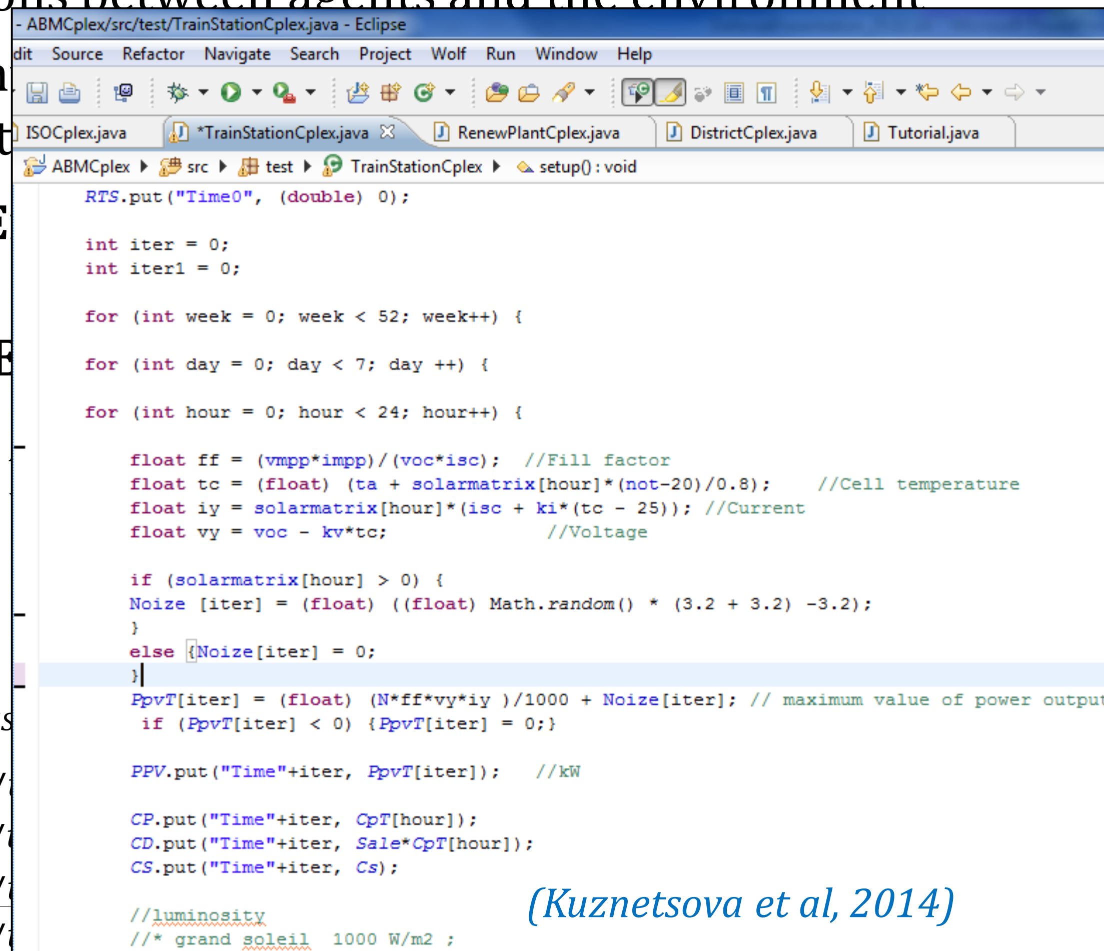
$$R_t^{TS} = R_{t-1}^{TS} + \delta_t^{TS,ch} \cdot R^{TS,stor} - \delta_t^{TS,dis} \cdot R^{TS}$$

$$\delta_t^{TS,ch} + \delta_t^{TS,dis} \leq 1 \quad \forall$$

$$0 \leq \delta_t^{TS,ch} \leq 1 \quad \forall$$

$$0 \leq \delta_t^{TS,dis} \leq 1 \quad \forall$$

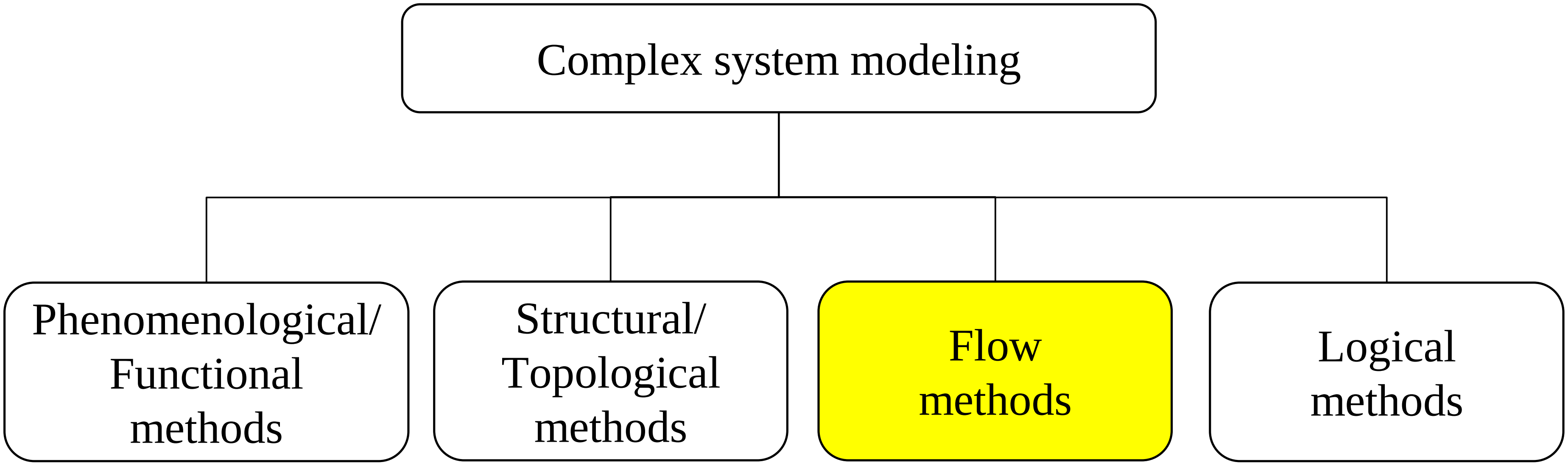
$$0 \leq R_t^{TS} \leq R^{TS,max} \quad \forall$$



(Kuznetsova et al, 2014)

ta

Complex system modeling



e.g., Agent Based Modeling and Simulation, System Dynamic Model, Economic-Based Approaches, …

e.g., Topology-based approaches

e.g., Flow-based approaches (maximum flow model, …)

e.g., Risk Analysis (fault/event trees, …), Probabilistic Modeling (Markov Chains, Bayesian network, …)

Case study: Gas-Power interconnected infrastructures

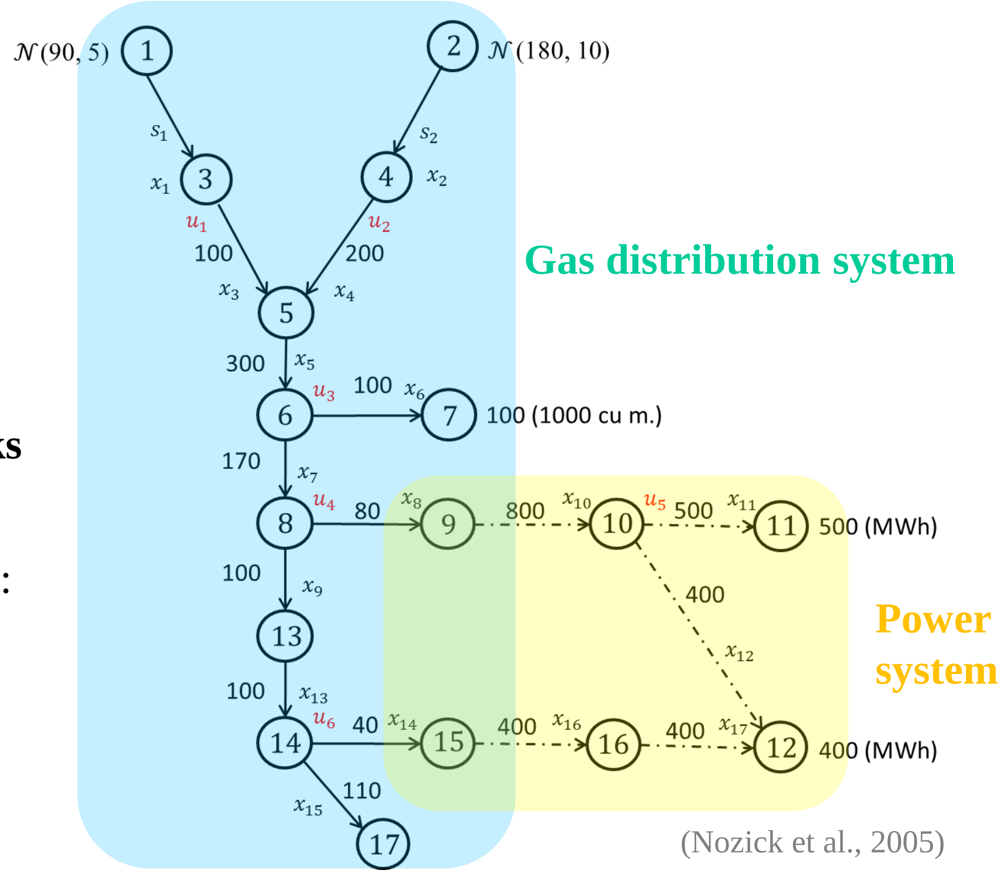
- With the **dynamics of system states**:
  (on the buffers and the links)

$$x^+ = Ax + Bu + s$$
$$y = Cx + Du$$

- Taking into consideration the **constraints/capacities of nodes and links**

- The **outputs of system** are states of users:

$$y = [x_6, x_{15}, x_{11}, x_{12}, x_{17}]$$
$$\rightarrow D_{D_1}, D_{D_2}, D_{L_1}, D_{L_2}$$



(Nozick et al., 2005)

- Solve the **optimization problem** in order to ensure the users demands:

$$J = min(\omega_{D_1}|x_6 - D_{D_1}| + \omega_{D_2}|x_{15} - D_{D_2}| + \omega_{L_1}|x_{11} - D_{L_2}| + \omega_{L_2}|x_{12} + x_{17} - D_{L_2}|),$$

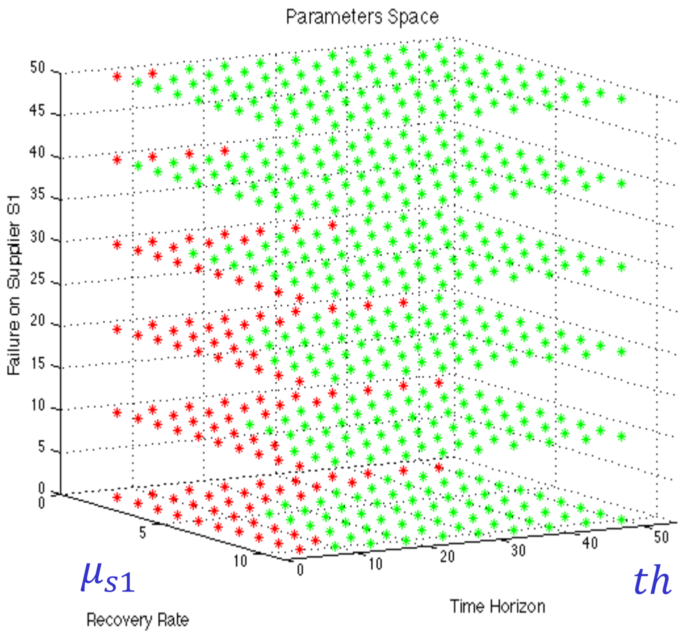
where $\omega_{D_1}, \omega_{D_2}, \omega_{L_1}, \omega_{L_2}$ are the weighting parameters of the users.

Case study: Gas-Power interconnected infrastructures

Resilience region

Parameter space $F \times \mu_{s1} \times th$

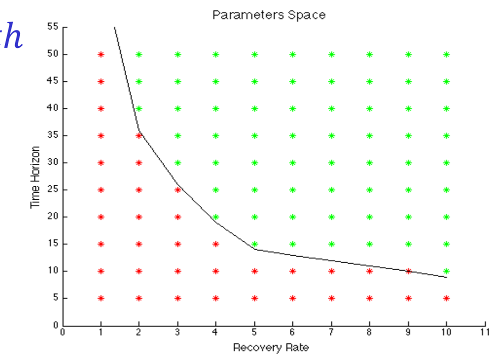
F



μ_{s1} th

$F = 0$

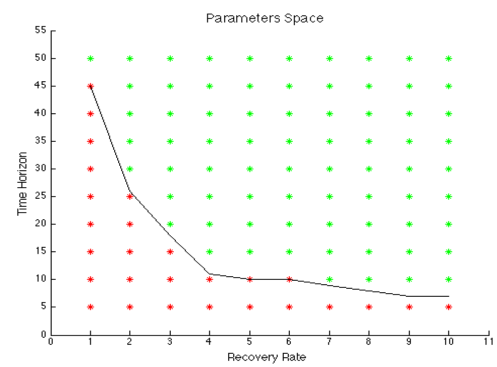
th



μ_{s1}

$F = 20$

th

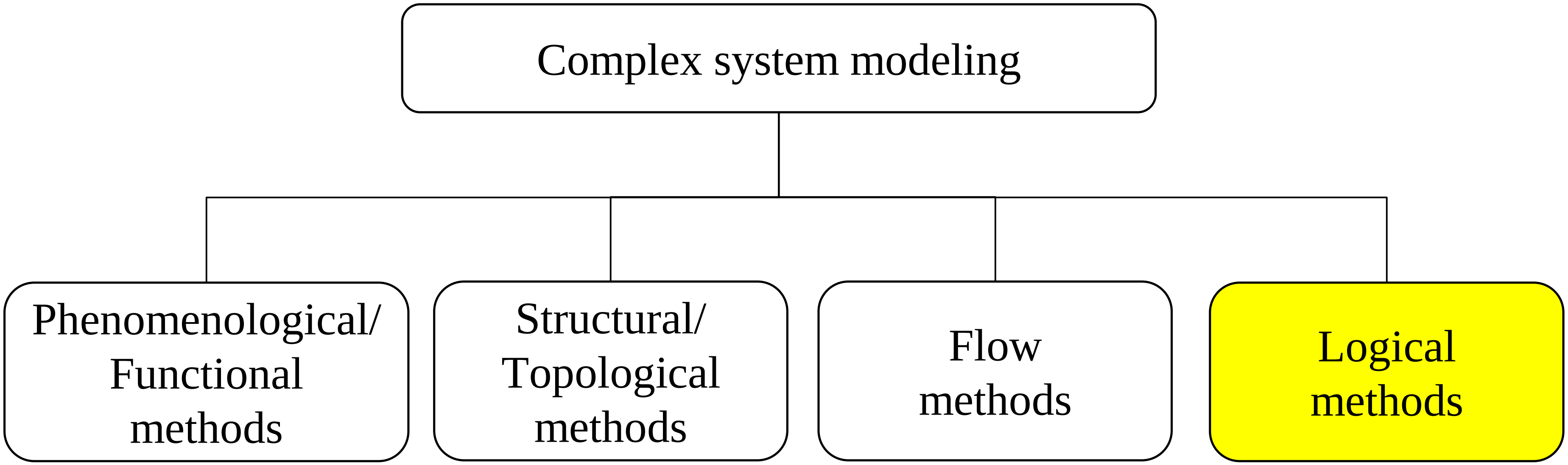


μ_{s1}

*: Resilience region

*: Non-resilience region

Complex system modeling



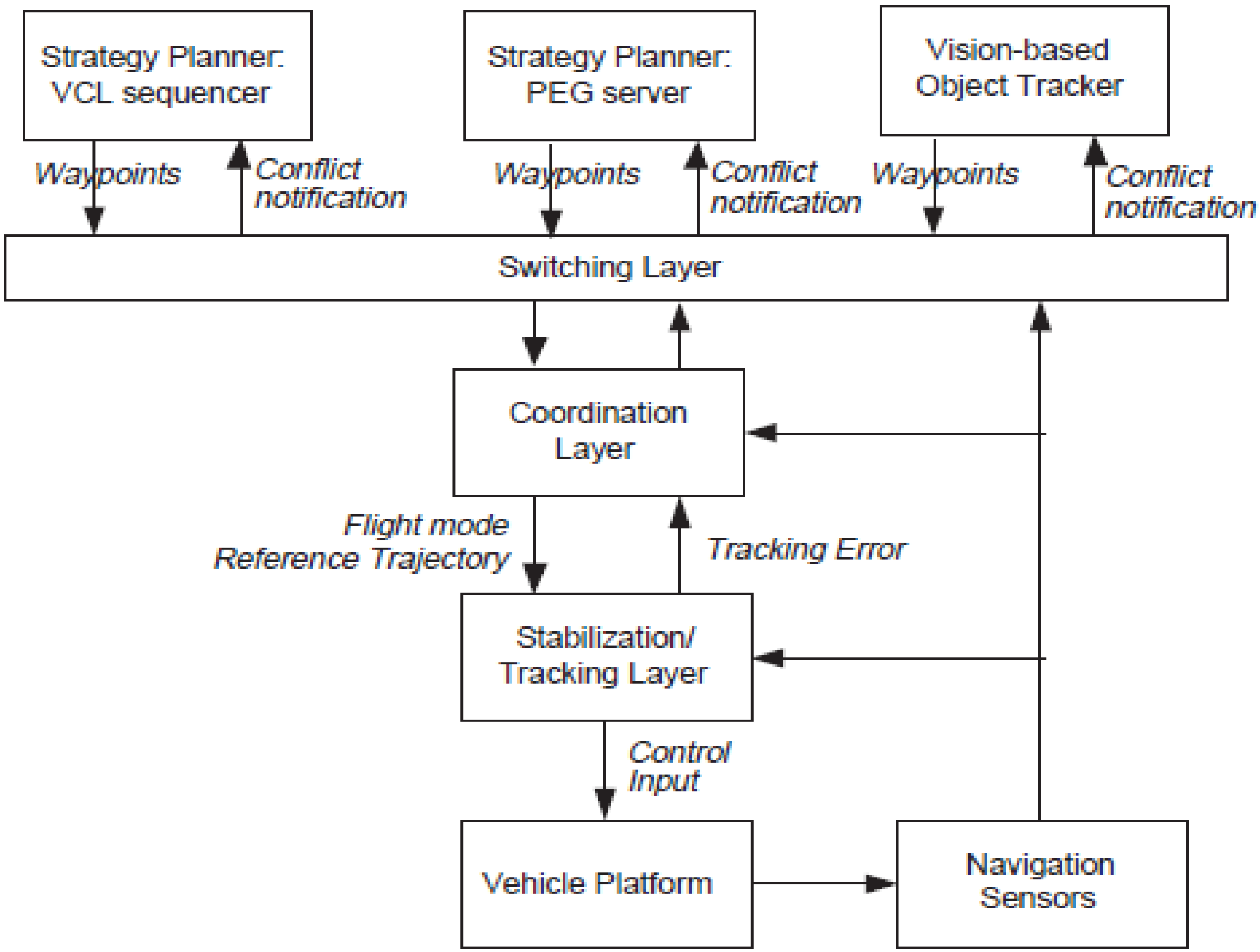
e.g., Agent Based Modeling and Simulation, System Dynamic Model, Economic-Based Approaches, …

e.g., Topology-based approaches

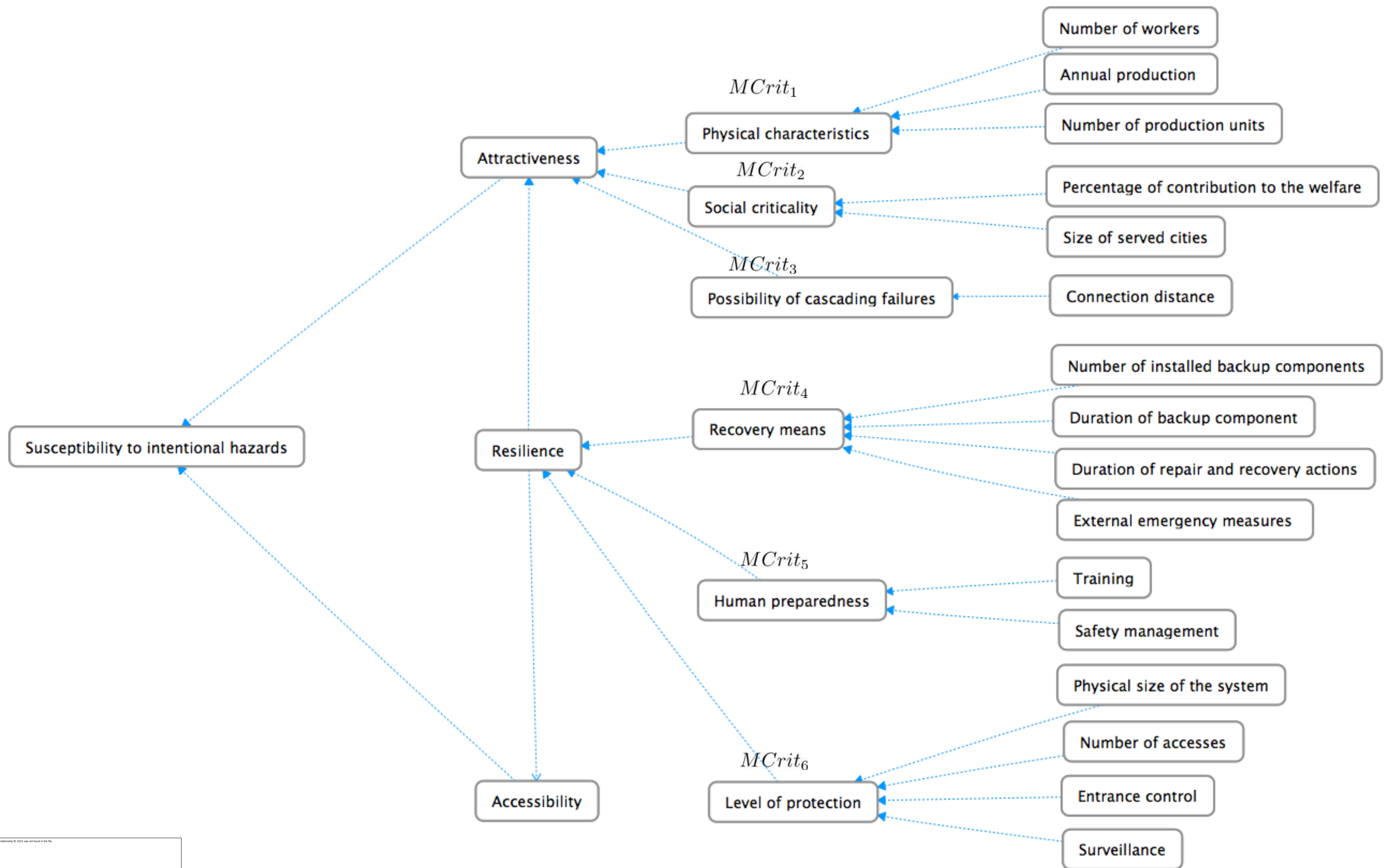
e.g., Flow-based approaches (maximum flow model, …)

e.g., Risk Analysis (fault/event trees, …), Probabilistic Modeling (Markov Chains, Bayesian network, …)

Complex system hierarchical modeling



Complex system hierarchical modeling



Conclusions

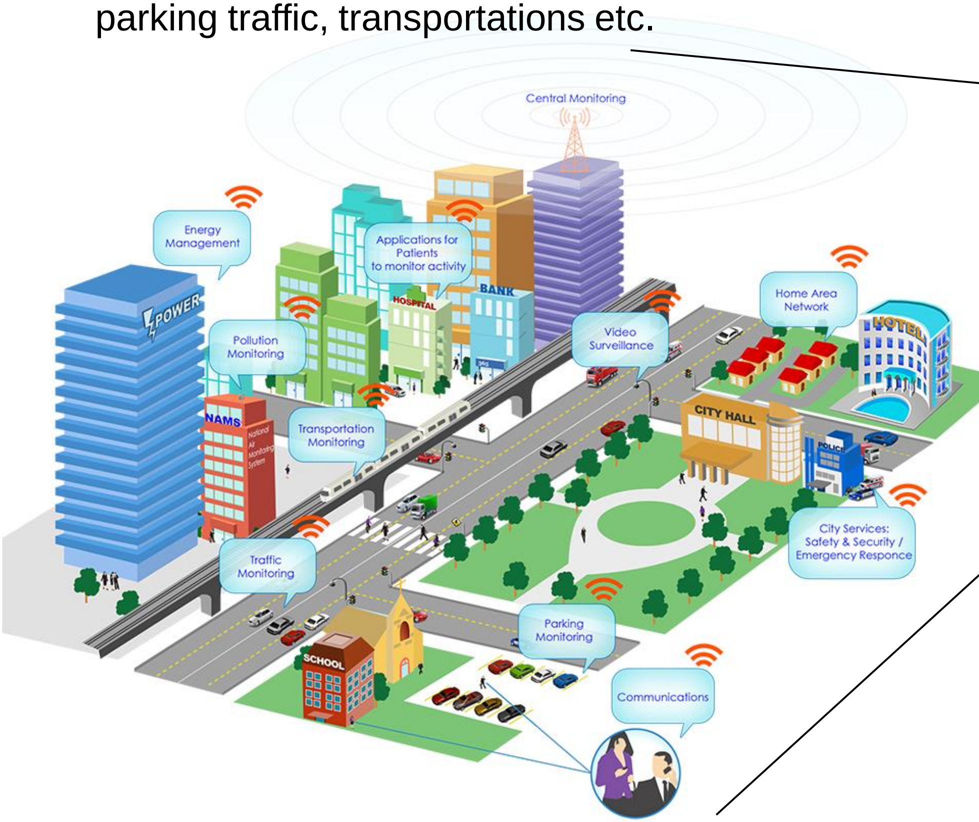
Advice…

« Modern information systems will support effective dynamic and timely safety management activity across a rail network. The future rail safety manager will review and analyze real time safety information data in a safety control center acting on alarms with urgent response in the field. Systems will also support rapid tactical analysis of similar combinations of weaknesses in safety defenses in rapidly and intelligently filtering aggregated risk, asset and safety control data to quickl target a broader response. Such systems will also support robust analysis of investment options to strengthen the safety control framework where necessary rapdily developing robust investment caes based on clear analysis of the balance between cost, performance and safety, to support timely management decisions. »

European Safety and Reliability Conference (ESREL) Keynote lecture, 27 September 2016
George Bearfield
Director of System Safety
Rail Safety and Standards Board

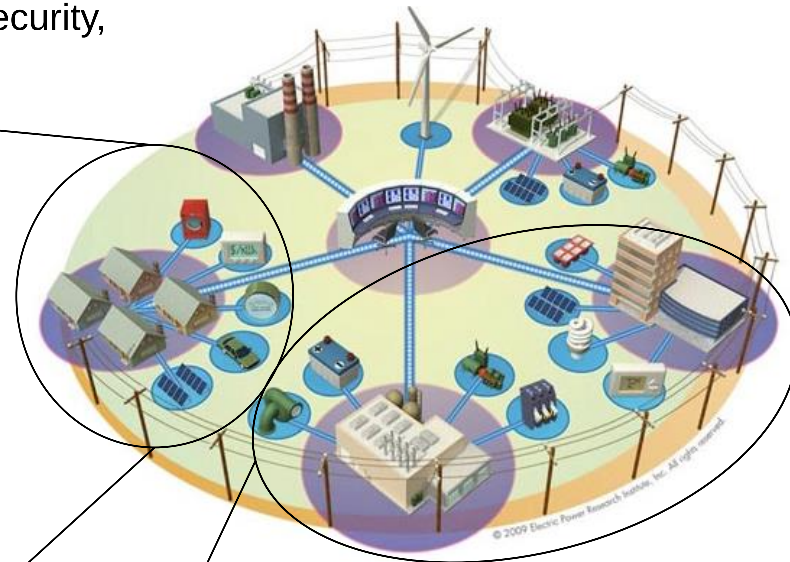
Smart grids, Smart Cities and Eco-Industrial Parks

Application of Internet of Things concept in Smart Cities to tackle urban challenges – pollution, energy efficiency, security, parking traffic, transportations etc.

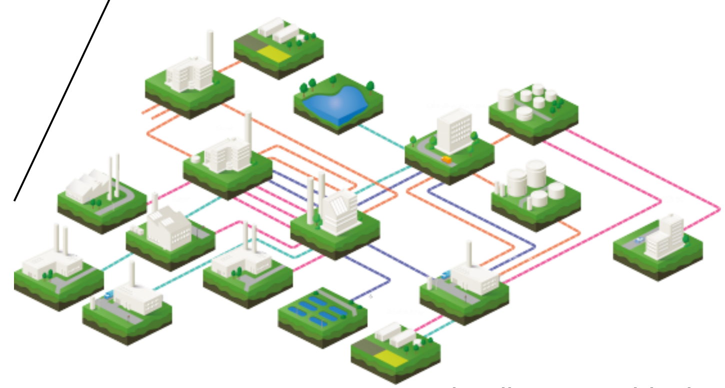


Source: IOT Phillippines INC.

Internet of Things in Smart Grids



Eco-Industrial Parks



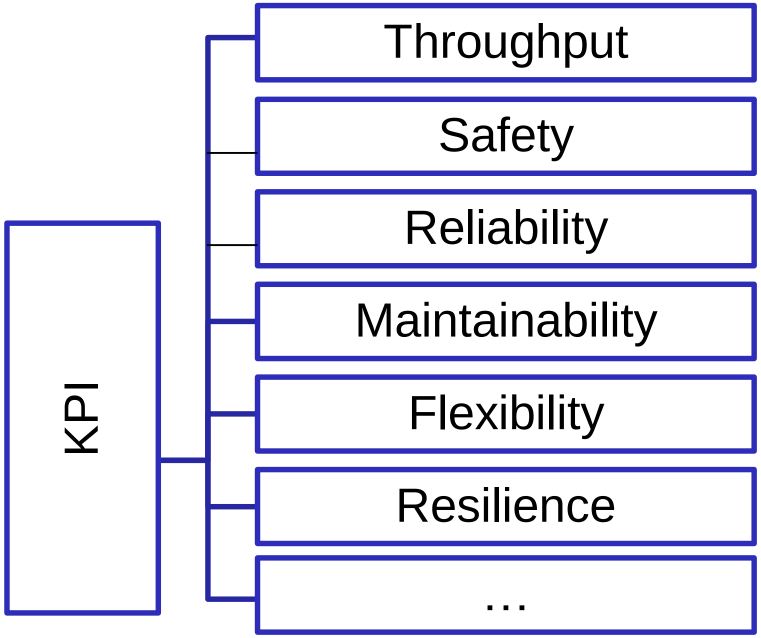
Source: Kalundborg Symbiosis

Smart…and complex!

Structural complexity: heterogeneity, dimensionality, connectivity

Dynamic complexity : emergent behavior

Uncertainty: aleatory, epistemic, perfect storms, black swans

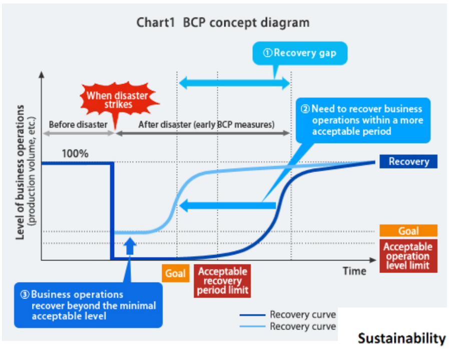


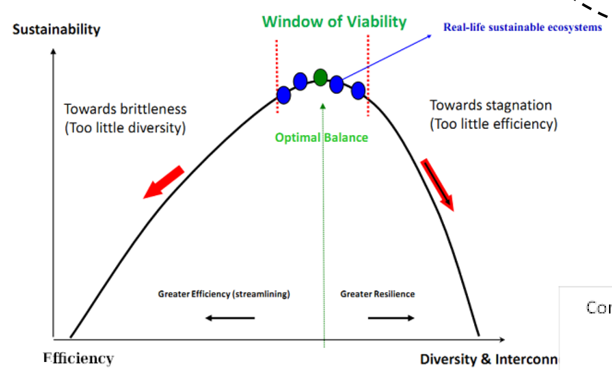
Safety/Reliability/Maintainability/ Resilience/Flexibility

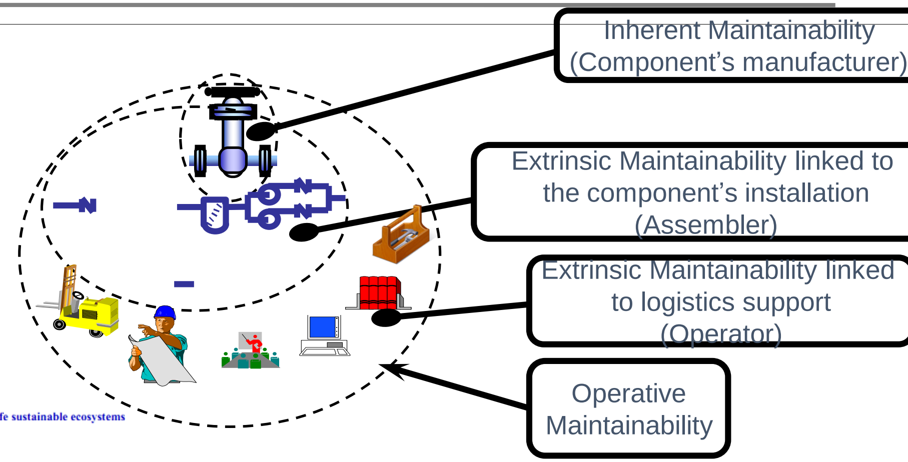
« There is a concern that beyond a certain point, « smartness » that involves a large number of connections may also create more vulnerabilities that benefits justify, The problem is to find an optimum that balances the benefits of connectivity and the risk of cyber attacks. »

European Safety and Reliability Conference (ESREL) Keynote lecture, 29 September 2016
Elisabeth Pate-Cormell
Professor of Management Science and Engineering, Stanford University

Safety/Reliability/Maintainability/Resilience/Flexibility

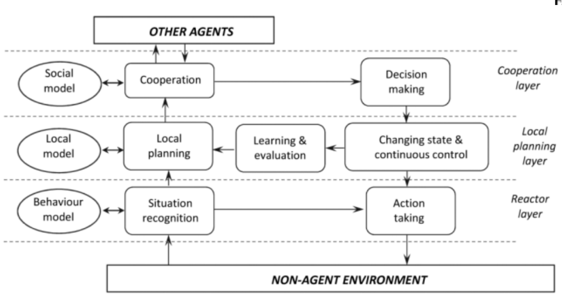


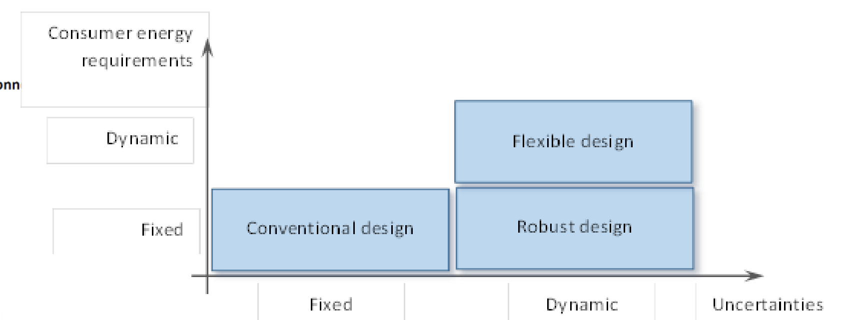




Modelling

(with uncertainty)





Optimization

(under uncertainty)

Complex System Modeling and Analysis

System analysis:

- hazards and threats identification
- physical and logical structure identification
- dependencies and interdependences identification and modeling
- failure/resilience dynamics analysis (cascades)

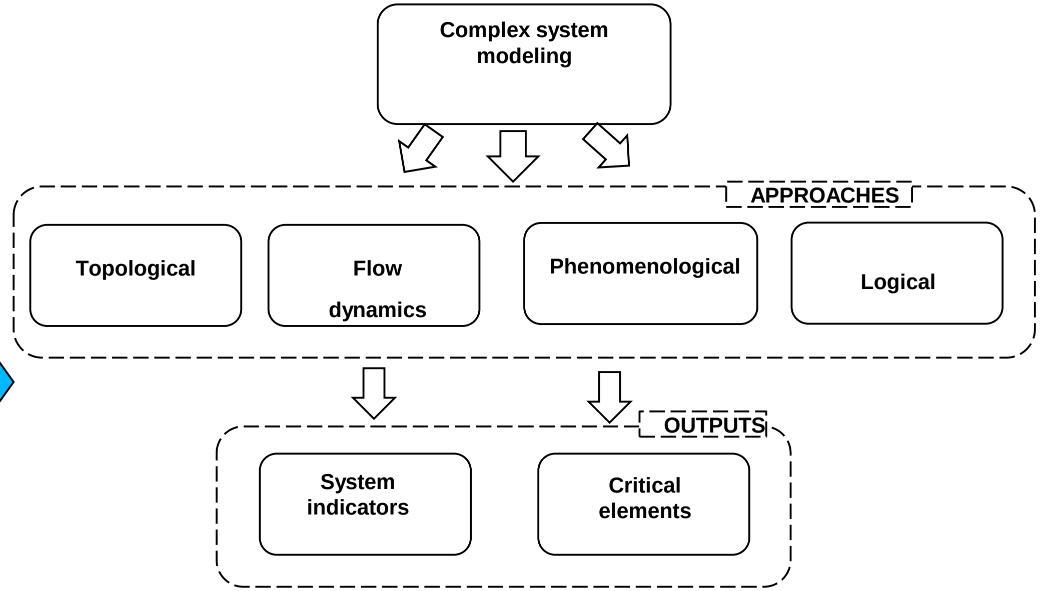
Quantification of KPIs

Identification

Identification of critical elements

Application for system improvements:

- design
- operation
- interdiction/protection



Systems of systems

W. Kroger and E. Zio, *"Vulnerable Systems"*, Springer, 2011

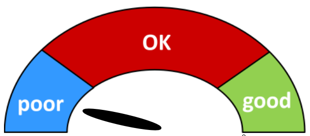
Complex system modeling

Structural Complexity + Dynamic Complexity

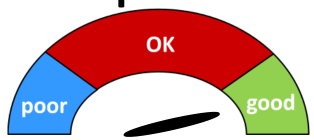
Modeling, Simulation, Optimization and Computational Challenges

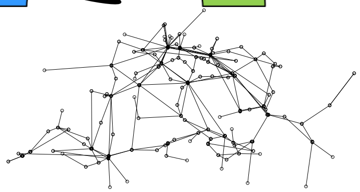
Topological

Detail



Computational cost

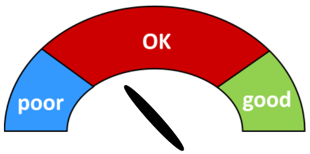




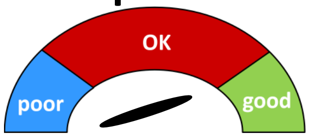
Phenomenological

$$\begin{cases} \dot{x}_i = -\mu_i\left(x_i - \sum_{i\in I_i}\alpha_{ji}x_j\right) + w_i;\ if\ x_i \le \sigma_i, i,j \in 1,\dots,N_s;\ i \ne j, \\ \dot{x}_i = \lambda_i(1-x_i)\ ; \qquad if\ x_i > \sigma_i, i,j \in 1,\dots,N_s;\ i \ne j, \end{cases}$$

Detail



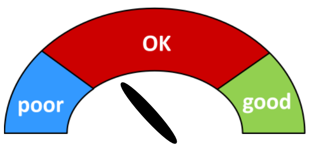
Computational cost



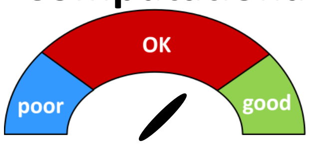
Uncertainty

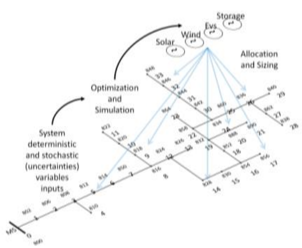
Logic

Detail



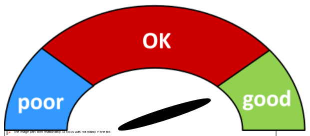
Computational cost



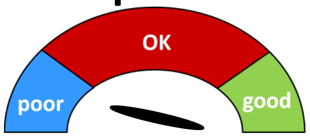


Flow dynamics

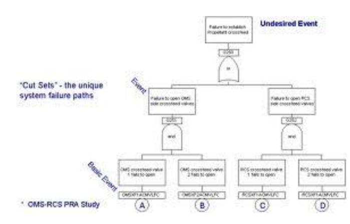
Detail



Computational cost

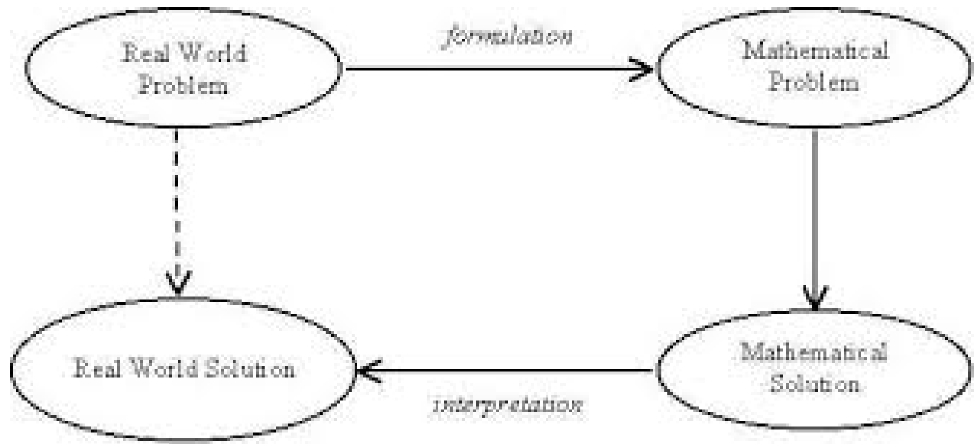


Integrated Approach

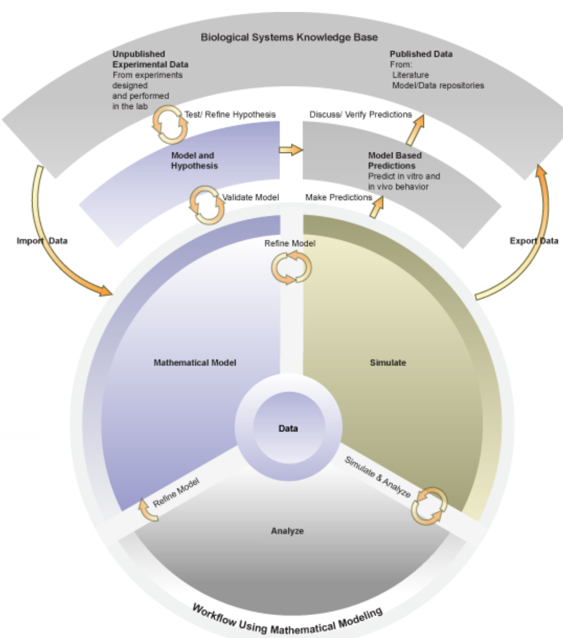


The Big KID

Big Knowledge(ID)



$$
\begin{aligned}
v_q &= -r_s i_q + \frac{\omega_r}{\omega_b}\Psi_d + \frac{p}{\omega_b}\Psi_q, \\
v_d &= -r_s i_d - \frac{\omega_r}{\omega_b}\Psi_q + \frac{p}{\omega_b}\Psi_d, \\
v_o &= -r_s i_o + \frac{p}{\omega_b}\Psi_o, & p\theta_r &= \omega_r, \\
0 &= r_{aq} i_{aq} + \frac{p}{\omega_b}\Psi_{aq}, & p\theta_e &= \omega_e, \\
v_f &= r_f i_f + \frac{p}{\omega_b}\Psi_f, & \delta &= \theta_r - \theta_e, \qquad (1) \\
0 &= r_{ad} i_{ad} + \frac{p}{\omega_b}\Psi_{ad}, & \omega_m &= \frac{2}{p}\,\omega_r, \\
T_e &= \frac{3}{2}\,\frac{P}{2}\,\frac{1}{\omega_b}(\Psi_d i_q - \Psi_q i_d), \\
p\omega_r &= \frac{P}{2J}\,(T_a - T_e),
\end{aligned}
$$



Big (K)Information(D)

Big (KI)Data

1110101001010001011100100101011000010101001

1101110111011101010010100010111001001010110

0001010100111011101110111010100101000101110

0100101011000010101001110111011101110101001

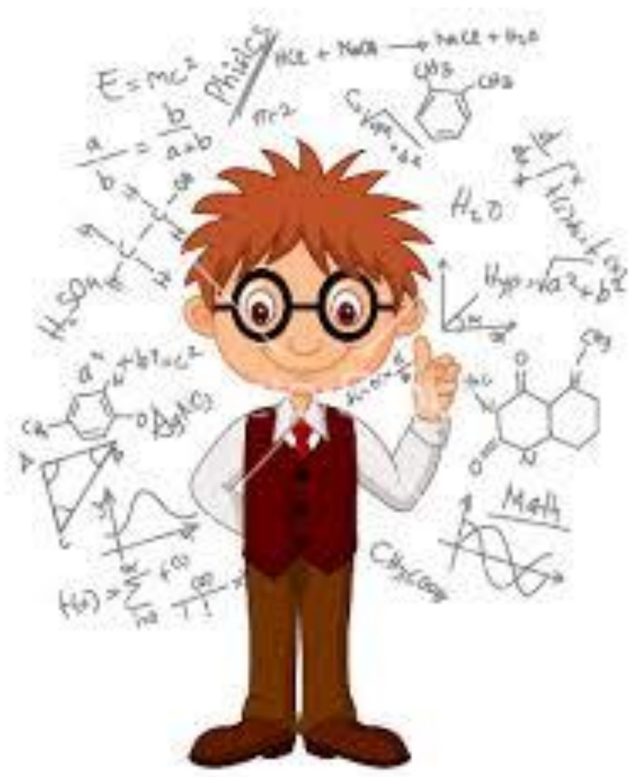
0100010111001001010110000101110101001010001

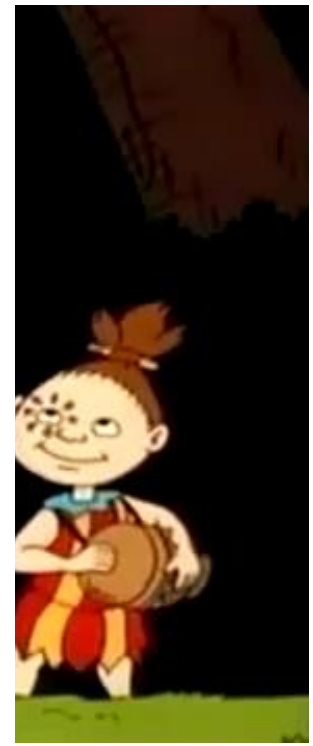
0111001001010110000101010011101110111011101

0100101000101110010010101100001010100111011

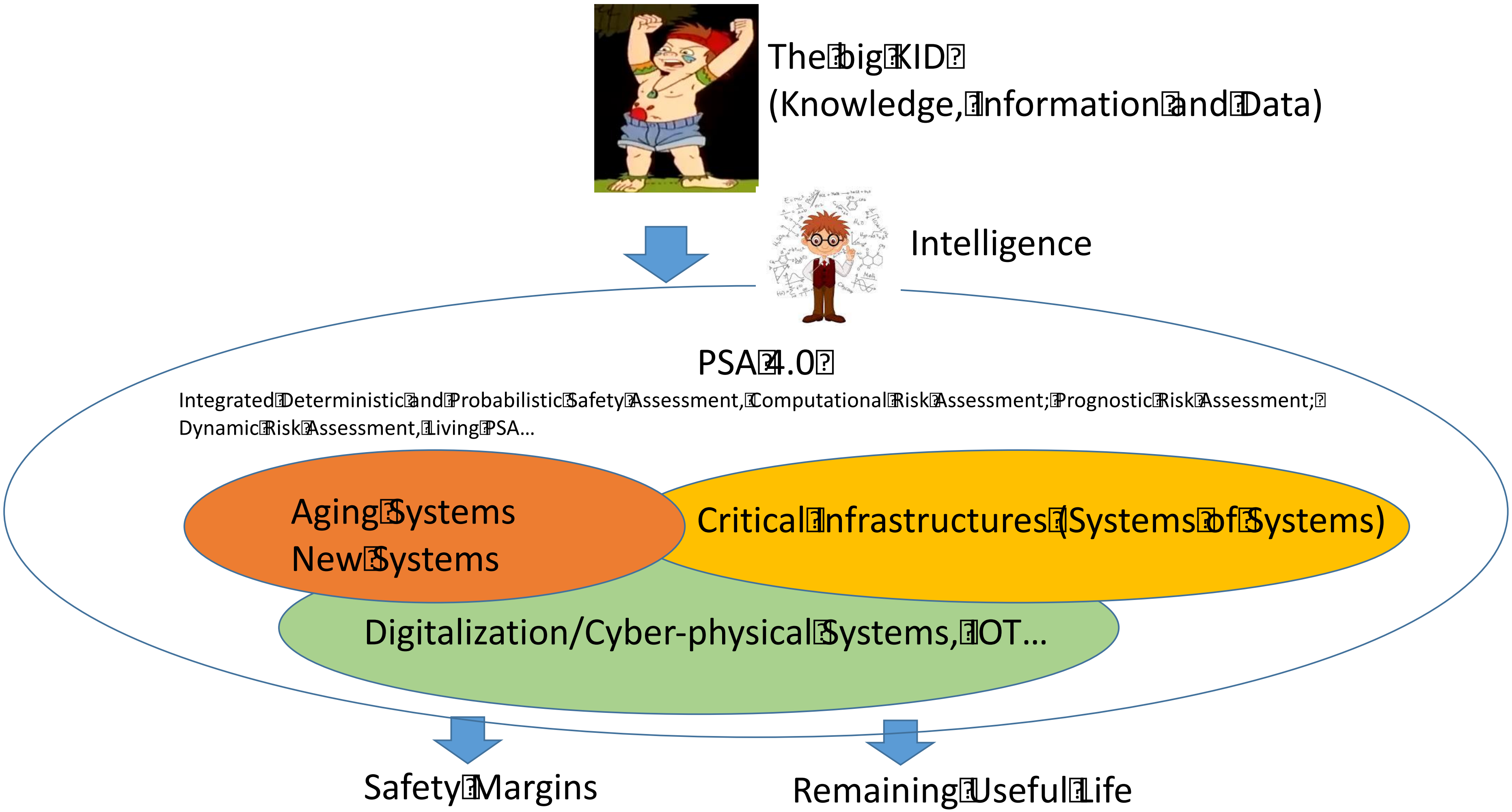
1011101110101001010001011100100101011000010

Can the Big KID become SMART for modern risk assessment?



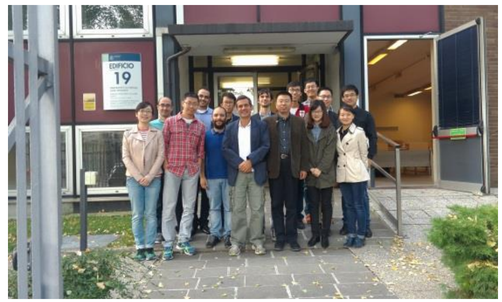


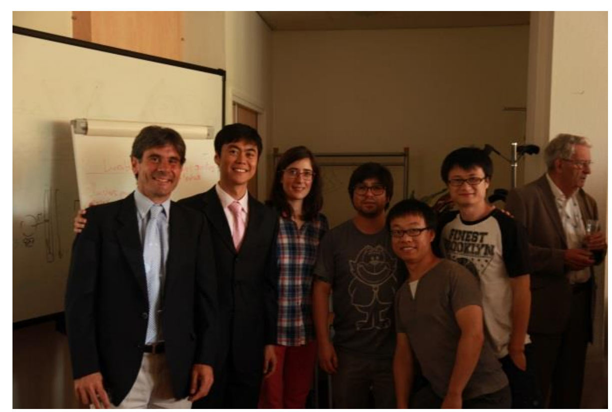
Complex system modern safety management



Thanks…

…for your outstanding contributions





Thanks…

…for your attention