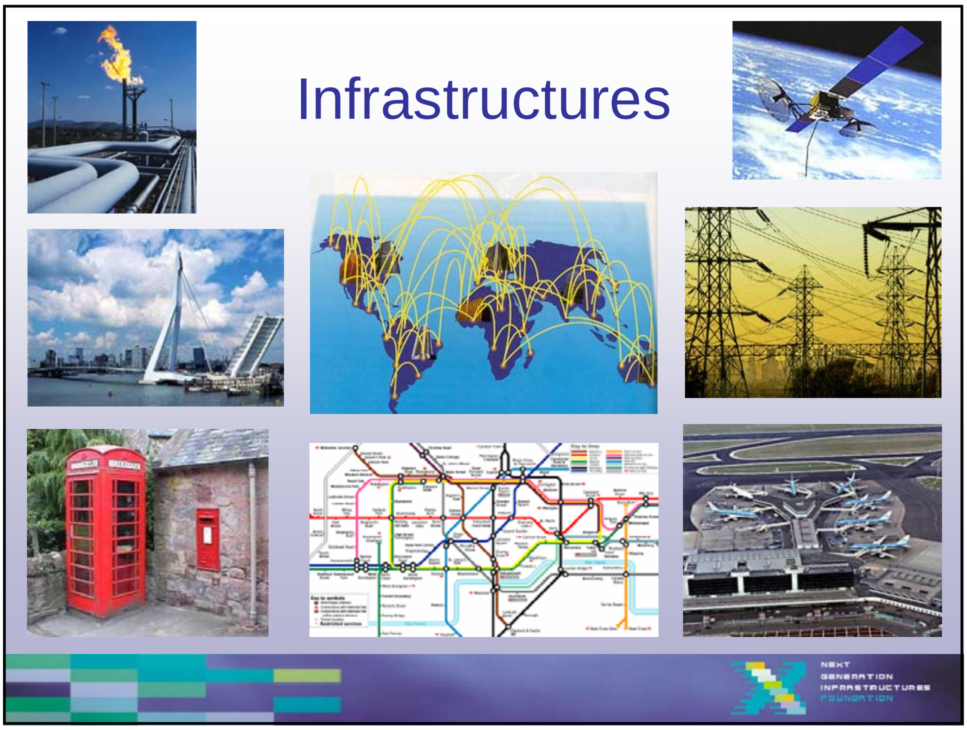

Critical Infrastructures at Risk
The need for innovation
Prof.dr.ir. Margot P.C. Weijnen
TU Delft - Dept. Technology, Policy and Management
Next Generation Infrastructures Foundation, scientific director
NEXT GENERATION INFRASTRUCTURES FOUNDATION


Infrastructures
NEXT GENERATION INFRASTRUCTURES FOUNDATION

Defining Infrastructure

Infrastructure provides energy and water, removes waste water and wastes, facilitates movement of people and goods, communication and information exchange, … financial transactions, health care, etc.

Infrastructure is the set of hard and soft structures that underpin economic and societal activities

Infrastructure systems are designed to satisfy specific social needs, but shape social change at a much broader and complex level – in other words, the unintended consequences of infrastructure may be much larger than the outcomes for which it was designed.

Defining Infrastructure

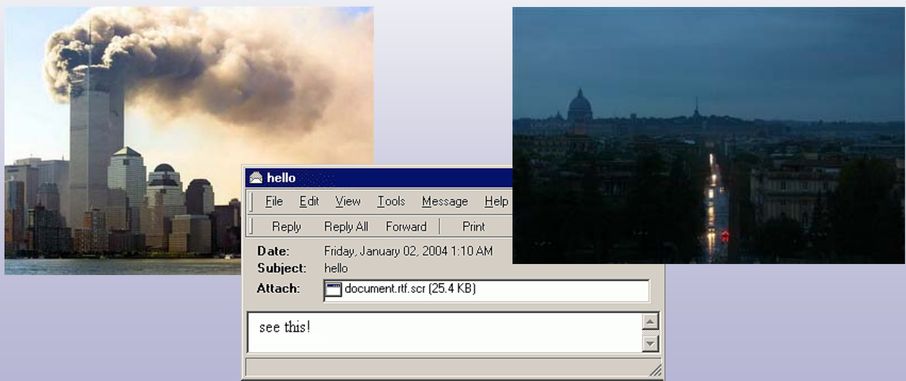
- Infrastructure systems provide essential services that constitute the basis for economic development and social well being:
  - *The US highway system is connected to almost everything else about life in the US today*
  - *Electric power provision radically changed our households*
  - *Information infrastructure has even greater power to shape future social and economic development – they have accelerated the internationalization of firms and markets and created a platform for the emergence of new infrastructures, e.g. financial transactions*
- Huge asymmetry between direct cost of service provision and social benefits
- Huge asymmetry between social cost and value of not provided service in case of infrastructure malfunctioning

Defining Infrastructure

- Distinct public interest goals involved
  - *universal access, affordability ….*
- Inherent network characteristics
  - *interdependence, access, market coverage, ….*
- Risk (or degree) of market failure
  - *competition alone will not ensure the most efficient allocation of resources, ….*

Vulnerability

terrorist attacks • computer viruses • blackouts

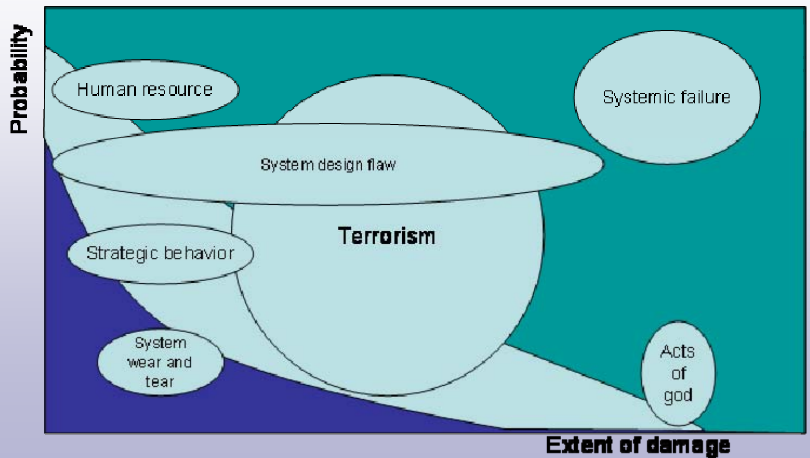


www.stephan-staehler.de / be.trendmicro-europe.com / about.reuters.com

Vulnerability

- Natural causes
- Wear and tear
- Human error
- Intentional damage
- Capacity overload

www.ethlife.ethz.ch / cyclone.atmos.uiuc.edu / genesis.sannet.gov



Costs of Service Interruption

• Road congestion & accidents	300 G€ annually, EU
• Cable disruptions	500 M$ US
• Computer hacks	1600 G$ annually, worldwide
• New York blackout	6 G$
• Netsky virus	35 G$ worldwide

NEXT GENERATION INFRASTRUCTURES FOUNDATION

… the need for innovation is evident …

NEXT GENERATION INFRASTRUCTURES FOUNDATION

Costs of service interruption

- Even “normal” service interruptions cost EU Member States 4% - 5% of GDP
- Abnormal service disruptions (terrorist attacks, natural disasters) are excluded from this estimate
- Current “innovations” mainly implemented in the area of security and justice

Therefore, there is an evident need for innovations that reduce normal service interruptions

Critical Infrastructure

- Infrastructure is “critical” when society and the economy depend on it for essential services
- Malfunctioning entails substantial penalties in terms of damage to the economy, public health and safety, the environment, et cetera
- All infrastructures are critical, but some are more critical than others:
  - Electricity infrastructure
  - Telecommunication and information infrastructure

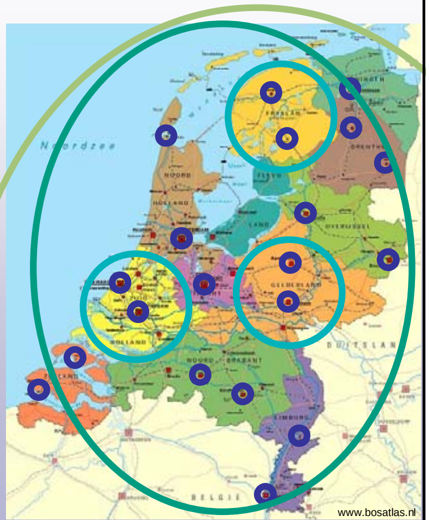
Designing Infrastructure?

Most infrastructures slowly evolved over time:

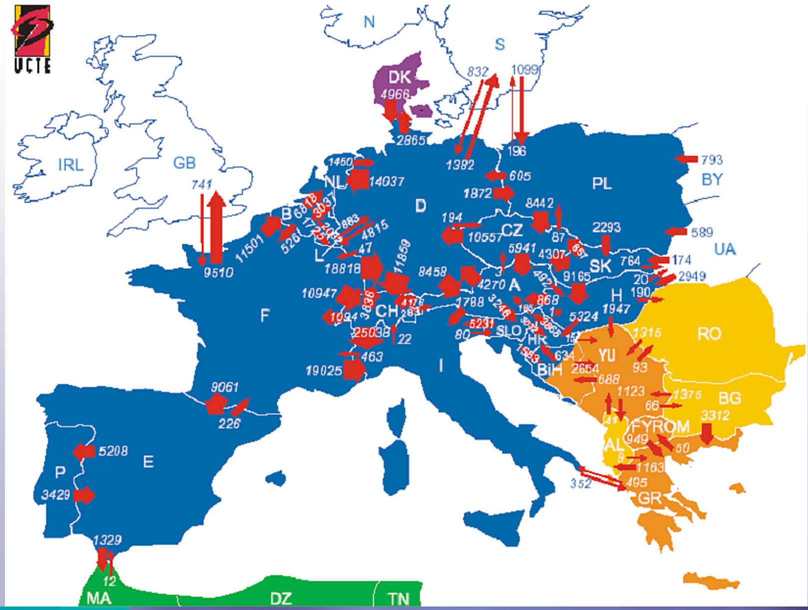
- Infrastructureless, in situ supply
- Dedicated carriers (on classical transport infrastructure)
- Dedicated local networks
- Local network interconnection and network expansion, with large scale centralized supply facilities
- Network intensification: increasing density of inter- and end-user connections, increasing throughput
- Improved reliability and quality
- Improved protection of public health and safety and the natural environment
- Penetration of ICT, enabling value added customer services

Electricity in NL: evolution

- 1880-1910: City
- 1910-1950: Province
- 1950-1980: Country
- 1980...: International Interconnectors



Physical electricity exchanges, 2002 (GWh)



Infrastructure design challenges

Dynamic complexity

Operational time scale:

can the system cope with incidents and disturbances?

Evolutionary time scale:

can the system cope with changing socio-economic conditions, technological innovation, changing public values and changing end-user demands?

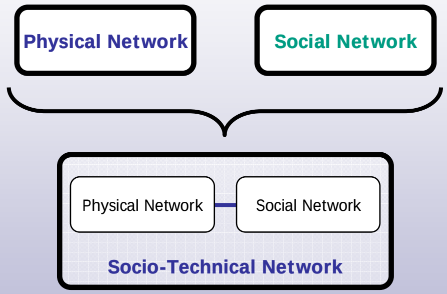
Infrastructure design challenges

- More than just the transport and distribution networks, the infrastructure includes the carriers, conversion and storage facilities <u>and</u> the governance, management and control systems needed to make the system meet its functional specifications and social objectives
- Infrastructures are complex networked systems - the reliability and quality of service are determined by the *<u>integrated system performance</u>*

Unraveling infrastructure complexity: the layered model

billing systems, help desk, information services, lease contracts	service provision	retailers, service providers, end-users, consumer bodies
information and control systems, permits, legislation, regulation, market structure	management & control	operators, TSO's, regulators, balancing market, power exchange, capacity auctions
materials, components, nodes, links, connectors, end-use devices, metering	physical assets	technology providers, contractors, plant owners, network owners

Unraveling infrastructure complexity: the socio-technical system model



Physical Networks

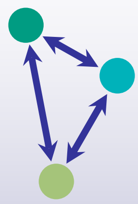
- Number of components / nodes
- Active / Adaptive nodes
- Agents, Nodes
- Network behaviour

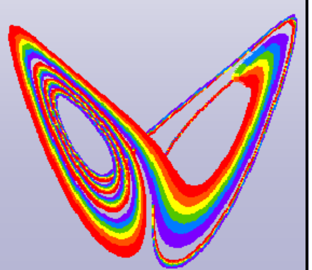
Number of Nodes

- Just estimate the number of...
  - electricity connections in a single street;
  - computers in your company.
- In the energy and communication networks this is the number of 'nodes'...
- ... of which there are millions...

Active Nodes

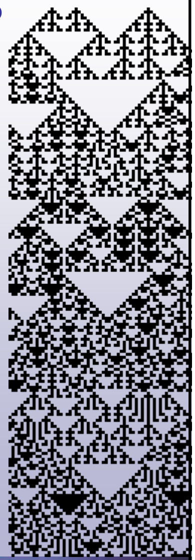
- Interaction
- Adaptivity
- Non-linearity
- Chaos?
  - deterministic
  - sensitive to disturbances





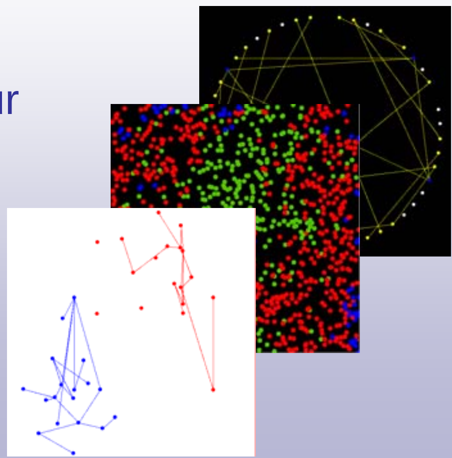
Actors, Agents, Nodes

- Simple form: Cellular Automata
  - elementary interaction
- All processes
  could be modelled using CA
  - But what are the rules?



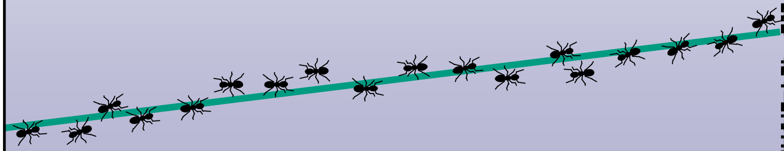
Agent Based Modelling

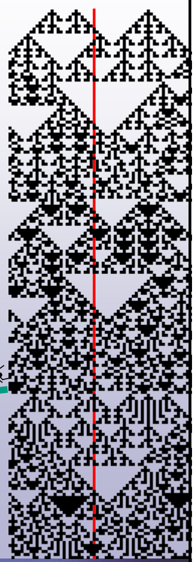
- Agent Behaviour
- Emergent Behaviour



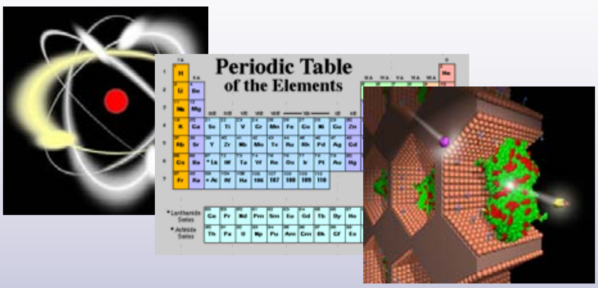
Emergent Behaviour

- Fixed Rules for Nodes
  - system behaviour
    - more difficult to predict
    - less difficult to predict





An Analogy: Levels

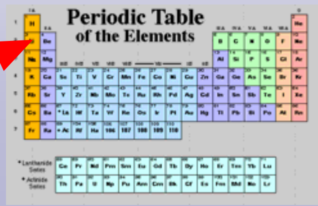


- Physics
  - basic rules
- Chemistry:
  - emergent behaviour of laws of **physics**
- Biology
  - emergent behaviour of laws of **chemistry**

www.sciencemuseum.org.uk / www.unm.edu / www.sc.doe.gov

Emergent Behaviour

- Modelled without modelling lower level
- System users:
  performance at top level counts

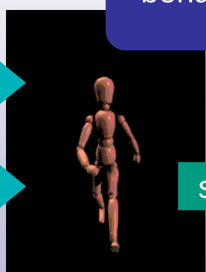


Social Network

- rules
- behavioral psychology
- learning

legislation

regulation



strategic behavior

"actor"

www.moonlightsys.com

Understanding actor behavior

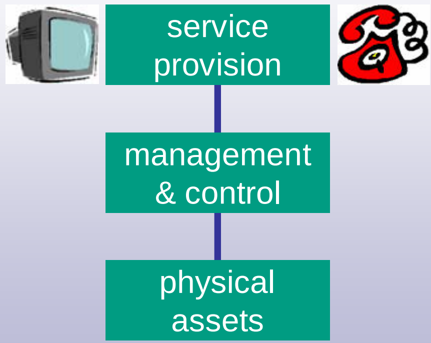
- Dynamic Actor Network Analysis
- Game Theory
- Simulation Gaming
- ...

www.gymnasion.tudelft.nl

Addressing network complexity

Physical network	**Social network**
Multi-agent: *functional and causal relationships*	Multi-actor: *informational and intentional relationships*
Multi-level	Multi-level
Multi-objective: *conflicting design criteria*	Multi-objective: *conflicting public values*
Dynamic: *interactive agents, adaptivity, non-linearities, new technology*	Dynamic: *learning and strategic actor behavior, changing public values*

Users: Service



Reliability and quality of service depend on the integrated system performance !

Innovating infrastructure

Network type → / System level ↓	Multi-actor social network	Complex physical network
service provision to end-user		
organisation & management		
physical assets		

… but how to predict the effect of (local) innovations on the integrated system performance ?

The first design challenge

- Many infrastructures develop slowly:
  - *long lead times for new projects*
  - *long life cycles*
- The demands upon the infrastructures change much faster!

Example: for gas supply, should Europe invest in pipelines to the East or in LNG facilities?

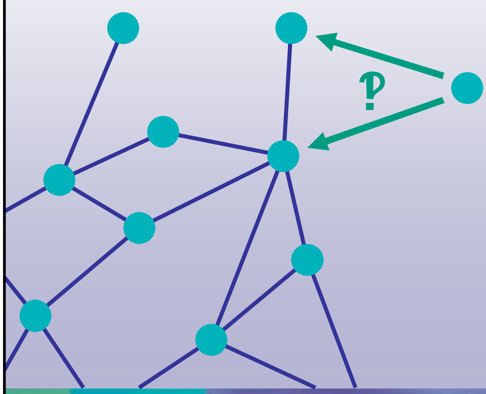
The second design challenge

Decentralized decision making in liberalized infrastructures:

- How to coordinate or steer the operational and management decisions of the many actors so that an adequate system response to disturbances is obtained?
- How to coordinate or steer the (investment) decisions of the many actors so that the long-term public interests are respected?
  - *availability*
  - *affordability*
  - *acceptabiliy*

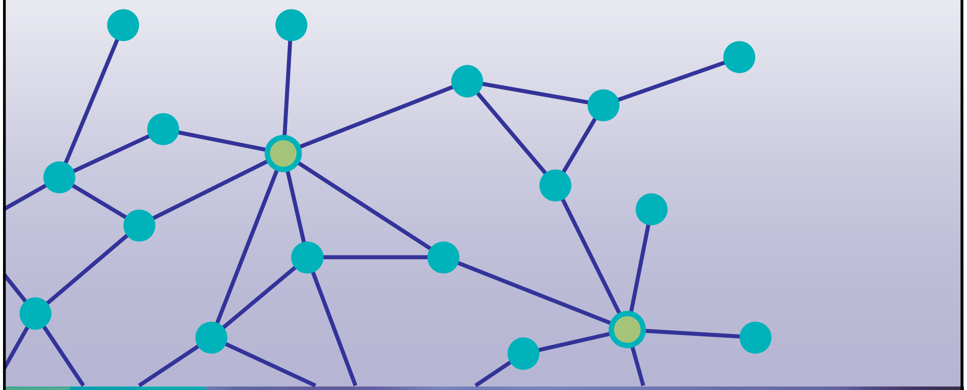
Physical Network Growth

- Not random, but preferenced



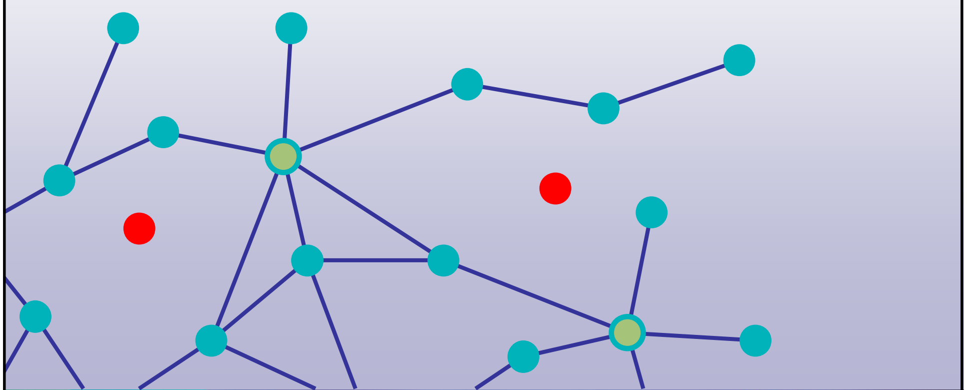
Robustness

Robust against random failures



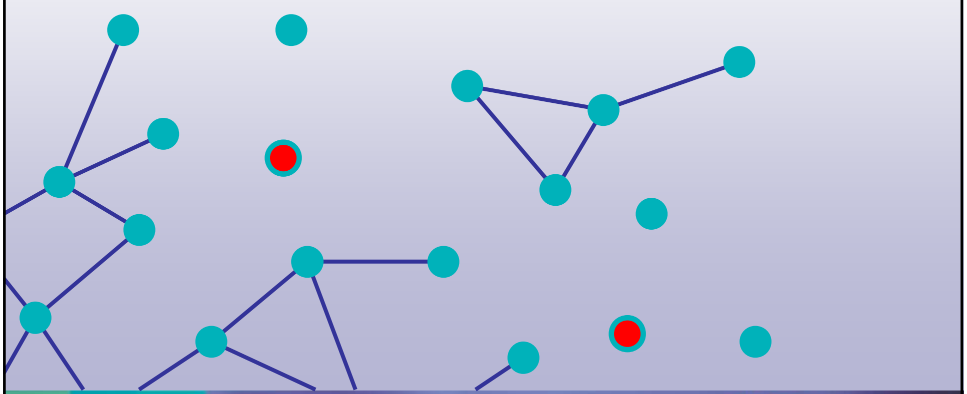
Robustness

Robust against random failures



Robustness

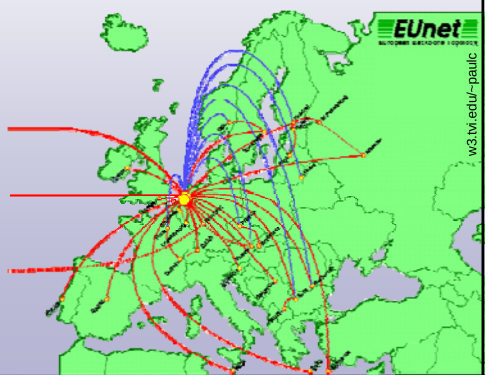
Vulnerable to targeted attacks



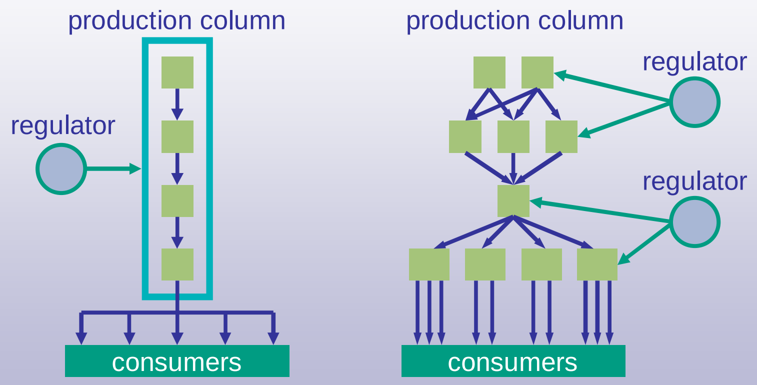
Vulnerability

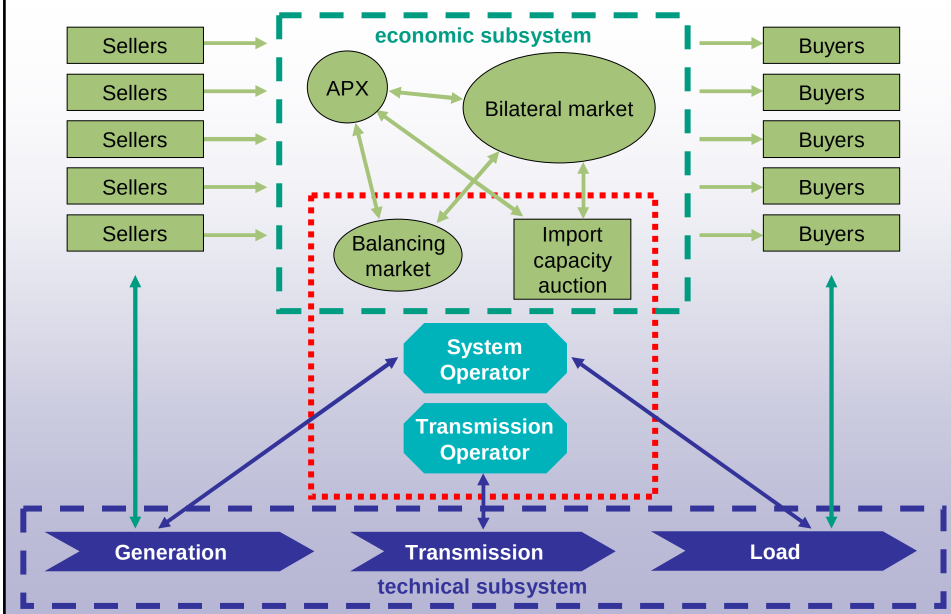
The Netherlands is a hub in many infrastructure bound markets:

- Internet
- Natural gas
- Schiphol airport
- Rotterdam harbor
  - oil products
  - petrochemicals
  - containers

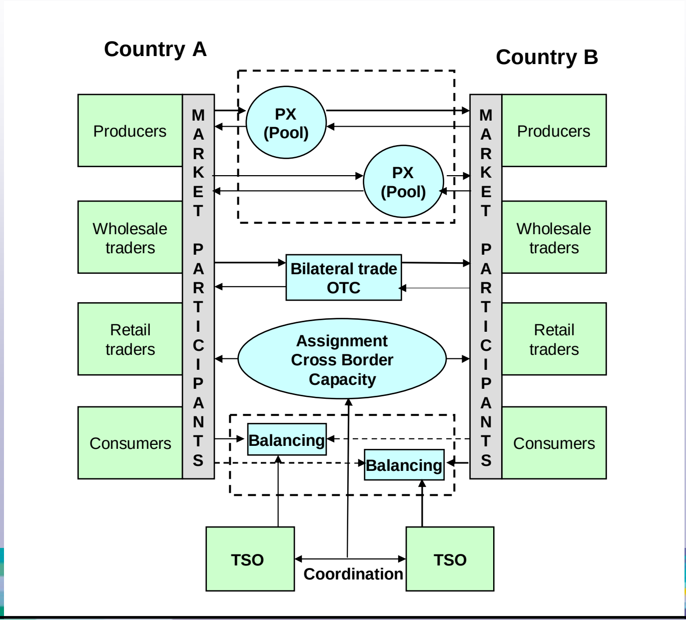


Social Network Growth

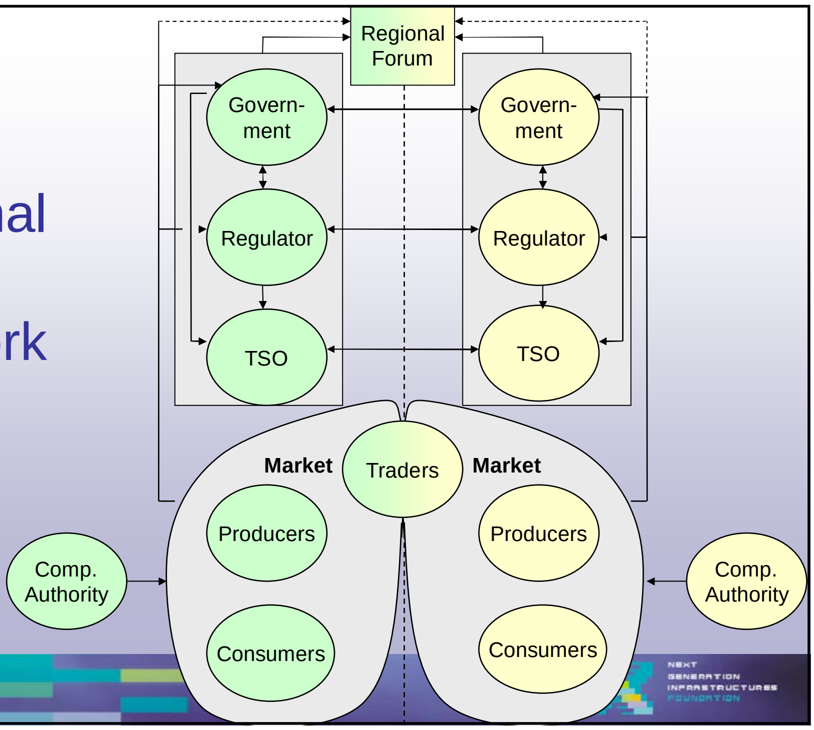




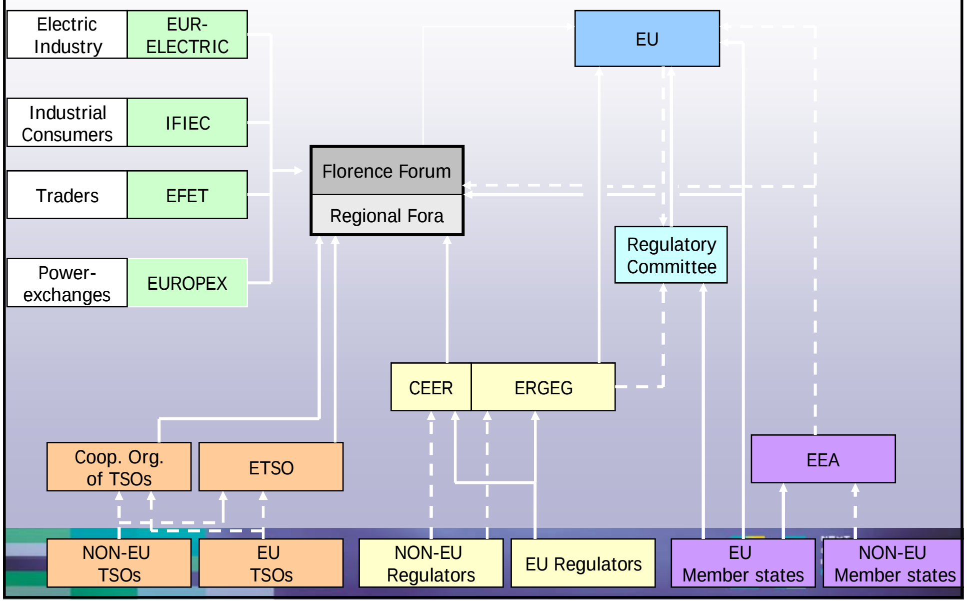
The economic subsystem, international



The multi-national actor network



The supra-national actor network...



Uncertainty

- New institutional setting: from monopoly to competition
  de- and re-regulation, liberalisation, privatisation, unbundling of infrastructure value chains, …
- Increasing complexity of the multi-actor network
  new players enter the playing field, many in new roles (traders, brokers, regulators)
- Internationalisation of infrastructure markets and firms
- Emergence of new markets and market places
  APX/AEX, NO_x and CO_2 emission trading, gas balancing market
- Transition from monopoly to market is turbulent and brings many uncertainties that hamper innovation
  regulatory uncertainty, political risks, uncertain returns, lack of market harmonisation, imperfect competition, standardisation, …

Ensuring Infrastructure Reliability

Short term:

- allocation of roles and responsibilities for risk management
- disturbance alert systems
- information/communication (infra)structures
- information exchange protocols
- crisis and emergency management capabilities

Ensuring Infrastructure Reliability

Short term:

Maintain high professional standards and strong sense of responsibility in the control rooms

Distributed autonomous control of the physical networks and distributed responsibility and response capabilities in the social networks are more likely to provide an adequate system response than centralized hierarchical control systems

Critical infrastructure: strategies for reliability

	anticipation	resilience
technical	•Infrastructure protection across next generation critical infrastructures •Increasing robustness and reliability	•Survivable information security •Self-healing infrastructure •Distributed and self-organizing control systems
organizational	•Risk control and management in infrastructure design •Apportioning responsibility in management of critical infrastructures	•Strengthening real-time management capabilities •Process improvement in incident management

•Strategies for networked reliability

•Identification of critical public infrastructures

Ensuring Infrastructure Reliability

Long term:

- policies, market and regulatory structures to stimulate investment in maintenance, capacity expansion and innovation
- new design methods, control systems and technologies to equip infrastructures with self-organizing and self-healing properties and ensure intrinsic adaptability to changing demands

Ensuring long term reliability of service

Example: securing generation adequacy in the electrical power market

- Declining reserve margins in Europe
- Many market imperfections:
  - *insufficient transparency*
  - *uncertainty regarding future supply & demand*
  - *large share of imports (23% of consumption)*
  - *regulatory uncertainty*
  - *risk aversion (both of producers and consumers)*
  - *insufficient development of long-term contracts*
- Will there be enough investment in power plants?

Risk asymmetry – producers' view

Compared to the socially optimal level of generation capacity, generators would rather err on the side of less capacity:

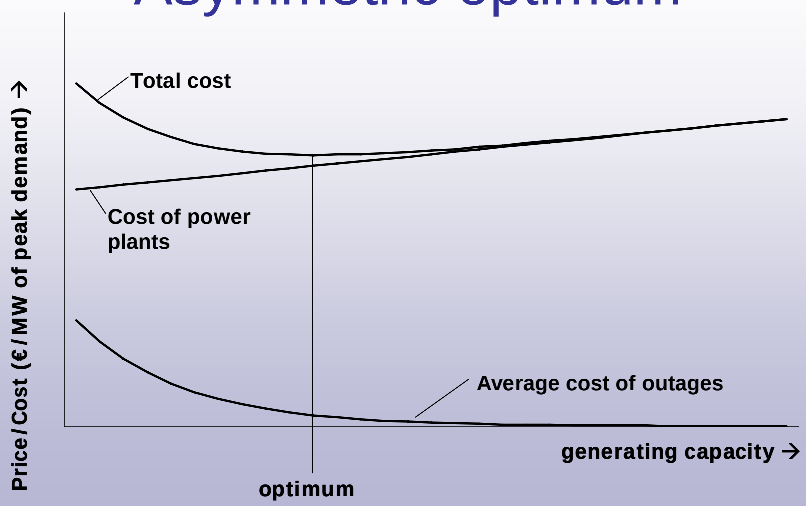
- reduced risk of unrecoverable investments
- generators' risk is limited to small loss of market share
- if competitors do same: higher chance of high prices → positive effect upon generator revenues!

Risk asymmetry – consumers' view

Compared to the social optimum, society would like to err on the side of overinvestment:

- cost of overinvestment small (e.g. 10% extra generation capacity → few % higher electricity cost)
- cost of underinvestment orders of magnitude higher
  - e.g. shortage in California < 2%
  - social cost of California crisis > 2 times the annual turnover of the electricity industry; 3.5% of GDP

Asymmetric optimum



Consequence: investment cycles?

Due to incomplete information and risk aversion:

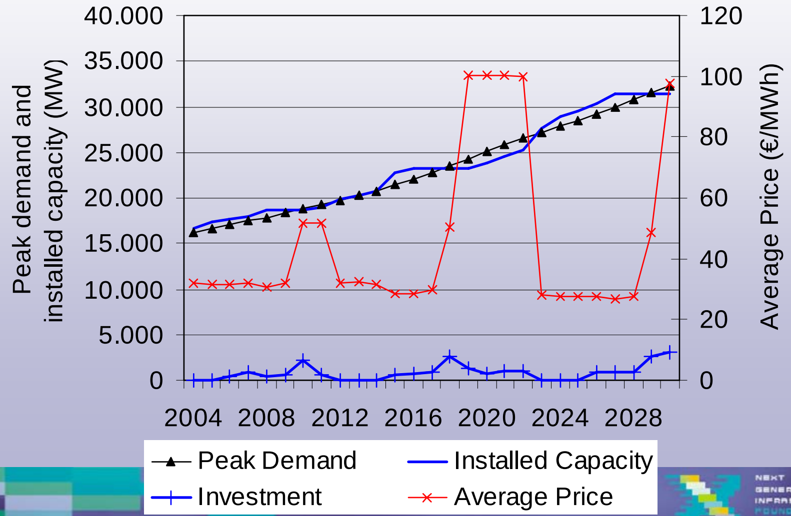
- investors base their decisions upon recent experience in the market
- delay investment until need is clear

→Demand projection based on the current phase of the business cycle

→Reaction to shortage only when prices rise and shortage is imminent

- long construction time of new capacity → arrives too late! → long price spike → overreaction by investors?

What could happen...



Ensuring long term reliability of service

Implement a form of capacity mechanism in the electrical power market to

- Stabilize investment in generation capacity
- Mitigate market power
- Provide price stabilization for consumers

Types of capacity mechanism

- capacity payments
- strategic reserve (NL)
- operating reserves pricing
- capacity requirements (ICAP, USA)
- reliability contracts
  - system operator or supply companies buy call options from generators
- capacity subscriptions

Policy dilemmas

- No proven, effective capacity mechanism for decentralized markets with strong trade with other markets (like most European markets!)
- Problem appears likely, but is not certain

→Intervene now or wait until the problem is clear (but then it may be too late)?

→Should individual countries implement a capacity mechanism, or wait for an international solution?

Could the current market imperfections (oligopoly) turn out to be a blessing in disguise?

What do we learn from the previous example?

Infrastructure design is inherently "wicked"

The design of electricity infrastructure is a multi-dimensional (institutional, economic, technology) design problem, unlike the 'tame' or 'benign' problems that engineers and economists are used to cope with:

- Reductionist approach - divide problems into discrete pieces
- System functions can be expressed in discrete, objective terms
- Optimum designs exist and can be discovered
- Uncertainty can be handled by constructing bigger and better models
- The future context can be predicted (neo-classic economics)

However, infrastructure design poses 'wicked' problems

Infrastructure design is inherently "wicked"

- There is no definitive formulation of a wicked problem
- Wicked problems have no stopping rules
- Solutions to wicked problems are not true or false, but good or bad
- There is no immediate and no ultimate test of a solution
- Every wicked problem is essentially unique

Wicked problems require a new approach to design

Infrastructure design is inherently "wicked"

Wicked problems require a new approach to design:

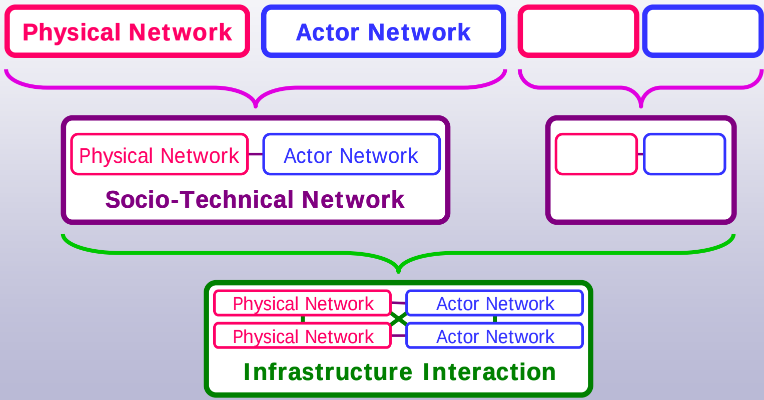
- Future vision driven, not relying on incremental innovation: *scenarios - back-casting - simulation*
- Holistic design processes: *interdisciplinary context and common design language*
- Systematic examination of potential unintended consequences
- Satisficing, precaution, and minimizing regret

which accomodates for

- Public inputs
- Integrated design teams
- Adaptable systems

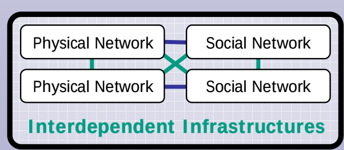
… infrastructure reality is even more complex …

The next level of complexity: interdependent infrastructures



Interdependent Infrastructures

- Physical Convergence
  - *multi-functionality*
- Organisational Convergence
  - *multi-utilities*
- Market Convergence
  - *in substitution*
  - *in complements*
- Spatial Convergence



Reliability of critical infrastructure

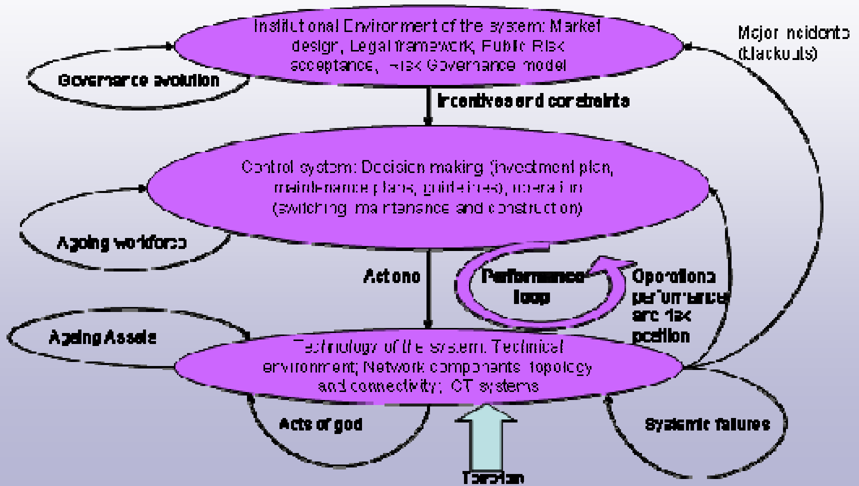
Requires a balanced mix of innovations in:

- Institutional design (policy, market, regulation)
- Physical assets/network structure
- Incentive structure for steering actor behavior

that should ensure adaptivity to changing socioeconomic conditions and changing user demands, and

that should not impede the emergence of alternative infrastructures or infrastructure alternatives

Reliability of critical infrastructure



… steering innovation through market forces and network regulation …

Innovation in liberalized utility sectors

- Focus on flexibility/variety of choice between alternative infrastructures and infrastructure alternatives:
  - POT vs. cable vs. glass vs. wireless
  - Local grids vs. national grid
  - Decentralized (and renewable) electricity supply
- Focus on efficiency (what about future reliability?)
  - Declining reserve margins
  - Better utilization of available capacity, e.g. through time-of-use pricing
- Distributed system coordination and planning
- Demand driven innovation - market pull:
  - Service on demand
  - Service quality differentiation

Dominant innovation: penetration of ICT in all utility sectors

- Physical assets – intelligent infrastructure
  - Deeply distributed autonomous intelligence in the networks: self-adaptive capabilities, QoS routing (self-organising, self-healing network properties)
  - Autonomous intelligence in carriers (cars, aircraft, trains)
- Intelligent management and control
  - More intelligent capacity management (Traffic Information Systems, tariff differentiation by time-of-use and user group, better information sharing between infrastructure operators, such as in ATM, etc.)
  - Market operation through the Internet (e.g. APX)
- Service provision – smart services
  - Personalised services, service-on-demand, multi-utility services, consolidated billing, etc.

NEXT GENERATION INFRASTRUCTURES FOUNDATION

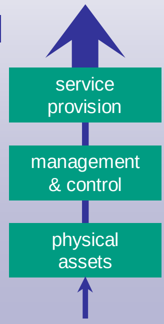
Barriers to innovation

- Imperfect competition
- Regulatory uncertainty
- Poor standardization
- Poor physical interconnection
- Poor market harmonization
- Political risks, uncertain returns, long payback times

NEXT GENERATION INFRASTRUCTURES FOUNDATION

Conclusions
Dealing with new innovation dynamics

- Network growth steered by market forces
- Change: technology push to market pull
- Emphasis on service innovation
- Technology selection:
  determined by market / social network



Conclusions
The need for innovation

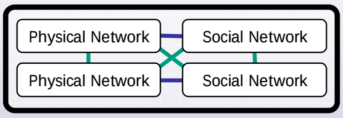
".. to ensure future economic growth, the EU needs a comprehensive and holistic strategy to spur on public and private investment in expansion and innovation of its network utilities …."

".. closer cooperation between the European Commission, national competition authorities and national regulatory authorities"

Reducing uncertainty and improving competition

Conclusions

Understanding and steering infrastructure innovation



- Dealing with complexities
  - physical network
  - social network
- Understanding of the integrated socio-technical system
- Dealing with uncertainties and risks

And therefore requires a multi-disciplinary, cross-sectoral **knowledge infrastructure,** such as the

Next Generation Infrastructures knowledge initiative

www.nginfra.nl

Thank you for your attention.
Questions?