NGI101x - 1.3B - Getting to know the jargon II

In this animation we will demonstrate why infrastructures have become so complex. We will also shortly introduce various ways and techniques to get more grip on this complexity and some notions what this means in terms of governance.

There are many changes. First of all we witness rapid technological progress. When it comes to energy: wind turbines and solar panels are well known and already main sources for the supply of electricity in countries like Spain, Germany and Denmark, to name a few in Europe. However, we also see many other types of technological innovations in the field of renewable energy sources; some more, some less promising. Examples are wave energy harvesting, power kites for high altitude wind energy harvesting, electricity production through photosynthesis, and nanotechnology for energy storage. We also see big ideas like using the Sahara for large scale electricity production through concentrated solar power plants.

To complicate matters further, technological progress in one domain typically co-evolves with technological innovation in other domains.

For example, the need to reduce traffic congestion and CO_2 emissions requires the large scale adoption of electric vehicles, or other types of clean vehicles, and the use of ICT for smarter usage of road capacity, for example to facilitate dynamic road pricing, automated modes of transport and more intelligent traffic management.

IT infrastructure is not only crucial for the next generation of transport infrastructures. We can see an ever increasing penetration of IT and telecommunication infrastructures into all aspects of society. Everything becomes connected to the internet including infrastructures. This creates opportunities in all infrastructure sectors to use available infrastructure capacity smarter, and to develop tailor-made services for different user groups, even personalized services. At the same time, the use of ICT in all infrastructures generates heaps of data on the state of the infrastructure and on user behavior. These data can potentially be used by infrastructure operators, service providers, municipal, national and supranational authorities to understand and shape the evolution of infrastructure systems.

This also shows that infrastructures become more and more interdependent. Transport infrastructure depends on energy: transport fuels as well as electricity. Electricity infrastructure depends on ICT infrastructures and vice-versa. This interdependency is a double edged sword: ICT enables better performance of critical infrastructures but also brings new risks and vulnerabilities, as ICT itself is a critical infrastructure.

All these technological changes take place in the context of grand societal challenges such as an increasing world population, increasing urbanization, depleting fossil fuel and fresh water resources, rapidly increasing demands for personal mobility and freight transport, climate change, cyber security threats and fundamental privacy issues.

These issues are increasingly complicated in view of the increasing number of players involved. At the dawn of infrastructure development, the situation was simple: we were dealing with local or regional systems, run by a single entity, whether a private or a public monopoly. This entity was in charge of the service provision for a specific region. But nowadays there are many, many more players, with diverging interests, some operating at the local level, others at national and supranational levels. Some of these players are public entities, others are semi-public or private entities. On the one side, mergers and acquisitions have resulted in large scale multinational infrastructure companies. On the other side, user co-operatives are emerging which have more bargaining power than single users on the pricing of infrastructure services, and some of which even aspire to seizing back control of infrastructure provision.

New technologies are also opening the way towards bottom-up, user-driven infrastructure development. This phenomenon, known as inverse infrastructures, relies on decentralized technologies for infrastructure services, which are linked in local networks, at the initiative of the individual producers and users, in a self-organized way, and relying on decentralized control. The internet is often seen as an example of an inverse infrastructure. Other examples are local WiFi networks and microgrids for electricity services in a local neighborhood. Such developments require users to align their interests and adopt new modes of organization.

All these actors have their own and often diverging interests. Governments want reliable and affordable infrastructures; private companies look for profit; some consumers want high quality, while others may give priority to lower prices.

To summarize: Infrastructures systems and services for transport of people and goods, for energy and water provision and for information sharing and communication form the very backbone of our society. This backbone, however, is a complex system of interconnected and interdependent infrastructure systems, which are complex systems in themselves. Traditional mechanisms of top-down control have largely been abandoned, as they cannot work in complex systems. All infrastructure systems face common challenges: the scarcity of capital and natural resources forces us to make better use of available infrastructure capacity and to reduced negative impacts on the natural environment. Around the world, billions of people still do not have access to reliable drinking water, to electricity services, to all weather roads or other basic infrastructure services. In those parts of the world where legacy infrastructure systems are lacking, there is the potential to leapfrog to the latest technologies, such as in Africa, which leapfrogged towards mobile telecommunication and information infrastructures, skipping the copper wired fixed telephone infrastructure. In other parts of the world, users impose higher quality demands on legacy infrastructure systems and even require individualized service. Regardless how different the challenges for different world regions may seem at first sight, in all cases we will have to struggle with the complexity of infrastructure systems: the diversity of actors and interests involved and the diversity of potential technological solutions. In complex systems, the notion of optimality is useless. Many solutions can be adequate, and adequacy is context dependent.

It is a daunting tor even impossible task to design and steer infrastructure innovation. How then do we make sure that we move into the right direction?

Imagine: you have to make a decision about huge new investments in roads, CO_2 reduction or a new energy network. How will the future look like? What is your time horizon? Which technologies are most promising? Will all buildings become energy neutral? How do you make sure that the infrastructure meets new safety standards? How do you ensure its affordability both in the short and in the long run? What do you know about future performance requirements, given demographic change and changing economic conditions? Which data do you need?

You will probably find yourself at a roundabout with many competing options and trying to find a comprehensive solution. Which direction to take? What are the red and green signals?

The key question here is how to understand, model, and perhaps most importantly, how to nudge the processes of technological change and systems integration into the desired direction.

We will provide you with some modeling and simulation tools to help you in this process and to get to grips with the complexity of infrastructure systems. For example, the technique of Agent-based simulation can help you to gain insight into complex interaction patterns in networks of users and other stakeholders. You could use this to explore the outcomes of various CO_2 reduction policies or different market designs in the evolution of electricity infrastructure. The availability of Big and open data makes these tools more worthwhile to consider. Simulation gaming is also a valuable method to gain deeper insight in the interactions between decision makers in the system, for example to explore path dependencies that may emerge from today's investment decisions. Exploratory modeling of different scenarios is yet another useful technique.

If we think about the future we first have to think about the performance criteria that must be achieved. In our field we often use the 4 A's: accessibility, affordability, availability and acceptability.

This includes issues like sustainability, resilience, robustness, low prices, or access to infrastructures in rural areas. But also concerns about terrorist attacks demonstrating the vulnerability of infrastructures and ethical notions such as fairness and social inclusion. This can be considered as a framework for decision making which, obviously, includes ethical and political issues and dilemmas.

Infrastructure systems and services need to be designed, regulated, operated, and maintained. This has become so complicated that a conventional top down engineering design approach is no longer feasible. The design process must become what we call a co process. This means that systems and services are shaped simultaneously by a bottom-up process of emerging technological innovation and a top-down regulatory and design process. The ultimate goal is to have compliance-by-design; this means that technologies and mechanisms are being designed in such a way that actor behavior becomes naturally compliant with top-down rules and regulations.

For example, the liberalization of the electricity market in Europe is an interplay between on the one hand a large variety of commercial companies focusing on producing, trading and distributing energy and which will take into consideration different technology options, operational algorithms and consumer choices. This creates new and spontaneous - often called emergent behavior. On the other hand there are the national governments and the European Commission that have the responsibility to safeguard public values, including the protection of consumer interests, and which have designed electricity market rules and installed regulatory bodies in such a way as to guarantee a level playing field for energy providers, while ensuring fair prices and sustainable and reliable energy services for all citizens.

Enjoy and remember: after this course you will embrace complexity!