Welcome back! In the previous lecture we discussed the importance of standardization in systems-of-systems. Next, we'll talk about interconnected networks.

In tightly coupled interconnected systems, a disturbance happening in some part of the system may have far reaching consequences. If the disturbance cannot be contained and remediated at the local level, it will cascade through the network and affect the service level in a wide region.

This is what happens in a power blackout, and if such a complete blackout occurs, it is hard to restart the system again because of the tight couplings between subsystems. In countries where the supply of electricity cannot keep up with increasing demand, system operators will try to prevent blackouts by planned demand curtailment in parts of the network.

This is called a brownout. The system operator may inform you that your neighborhood will be out of power for certain hours on certain days, and during the hours that your neighborhood is supplied, other neighborhoods will be curtailed. Being out of power severely limits you in doing the things you want to do and it is detrimental to the economy.

This is evident when you think about all the economic activities that depend on electricity. The electricity infrastructure is a so-called critical infrastructure. If malfunctioning, society and the economy will be disrupted. At this point, let me take the notion of systems-of-systems to another level, that is, to the level of interconnections and interactions between infrastructures in different sectors.

The definition of critical infrastructure varies between countries, but in all cases includes electricity and telecommunications as "most" critical infrastructures, which all other critical infrastructures depend upon. Emergency services, financial services, public health services, agriculture and food supply and many other sectors, including government, cannot be maintained for any sustained period of time without electricity and telecommunication.

However, electricity and telecom infrastructures themselves use resources that are, in part, provided by other infrastructures. To supply telecom services, the telecommunication system uses electricity, water and natural gas, to name just a few of the required infrastructure related services. At the same time, the electricity infrastructure uses telecommunication services, water, et cetera. In other words, there is a high level of interdependency between infrastructure systems across different sectors.

These interdependencies come in various types:

Physical (or functional) interdependencies exist when resources are exchanged: when the resources produced by some infrastructure are used by another infrastructure to produce its own resources and the other way around.

Geographic interdependencies occur as a consequence of geographic proximity between infrastructures, so that a problem (for example a fire or a pipeline burst) in one infrastructure can adversely affect other infrastructure

Cybernetic interdependencies are related to the exchange of data on computer systems

Logical interdependencies are due to contextual circumstances, such as market realities.

The web of interdependencies between critical and not-so-critical infrastructures creates a highly complex system-of-systems, in which the failure of a single element or a single resource may cause a domino effect that affects all critical infrastructures in a region and could bring the entire region to a stand-still.

Many governments have been working and are still working on strategies to reduce their vulnerability to outages of critical infrastructures. Critical functions such as hospitals are very well aware of their dependence on electricity and have installed backup generation capacity, such as batteries or diesel fueled generators, to keep going in the event of a power blackout. However, in the case of a prolonged outage, the supply of diesel will become a bottleneck. You can imagine that a study of those interdependencies, from first order to second order interdependencies and so on, is a hell of a job, and that these interdependencies vary widely between different locations. For example, whereas in some places the entire drinking water system needs electrical pumps, it is gravity based in other places, which would therefore be less vulnerable to power outages.

The vulnerability of the system-of-infrastructure systems can be reduced in many ways, for example by keeping strategic reserves of critical resources, by building redundancy in critical conversion units (for example, parallel units, with one always stand-by), and by building redundancy in the transportation network in such a way that, if one path gets blocked, the service can be delivered through an alternative pathway. The latter refers to the network topology, about which you will learn more next week. Please note that all these measures require substantial investment, which makes it unlikely that such measures will be taken just for the sake of a very low probability event, even if the consequences may be disastrous.

The system-of-systems character of infrastructure systems, both within and across infrastructure sectors, implies that strategies to avoid or recover from a breakdown require a multitude of actors to interact, including infrastructure owners and operators, producers of infrastructure resources, service providers and government. Some of these actors will probably be based in the private sector, others in the public sector, implying that they are subject to different laws and regulation. Especially since all infrastructure providers are subject to economic efficiency incentives, the interdependencies across infrastructure sectors are unlikely to be properly managed without government intervention.

Thank You!