Cascading Effects in Complex Maritime Networks and Supply Chains

CSP008_S_M

PRESENTATION BY:
DR. STEFAN SCHAUER
DR. ABDELKADER SHAABAN
AIT AUSTRIAN INSTITUTE OF TECHNOLOGY

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Overview

- Topic-1: Introduction to Critical Infrastructure
- Topic-2: Threat Landscape in the Maritime Sector
- Topic-3: Critical Infrastructure Interdependence
- Topic-4: Cascading Effects and their Impacts
- Topic-5: Simulating and Analysing Cascading Effects

Agenda

01. Critical Entities

02. Interdependencies

03. Cascading Effects

04. Example: Cascading Effects

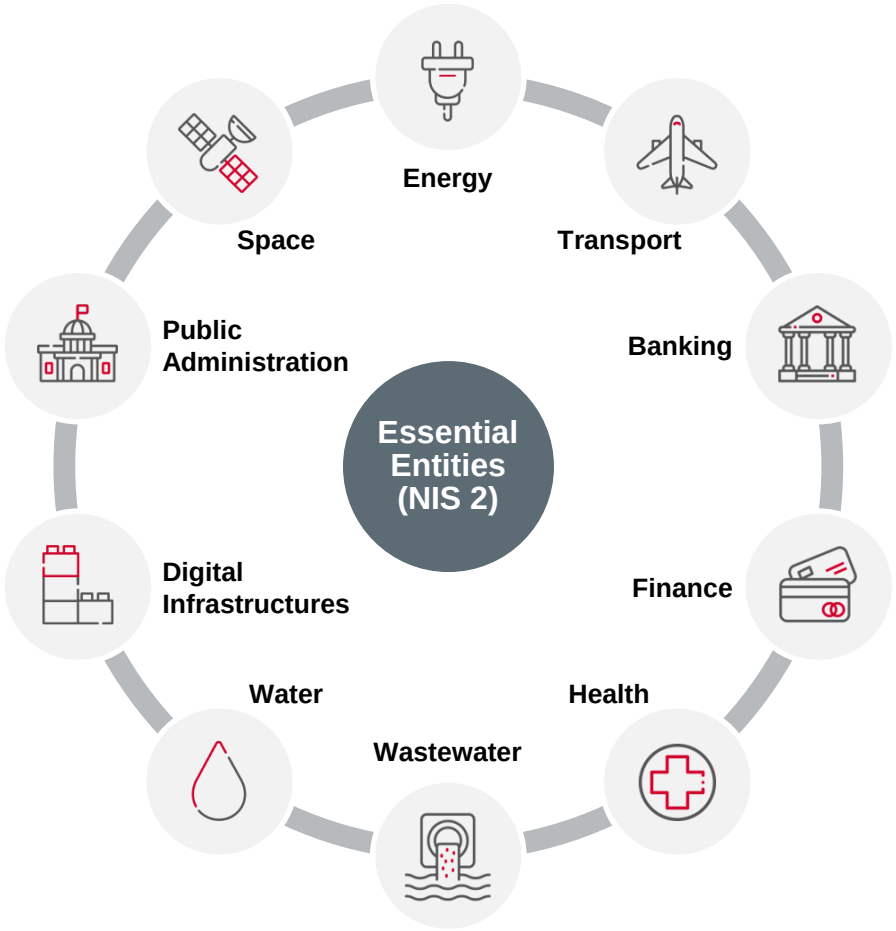
Critical Entities

What are critical infrastructures and the critical assets therein?

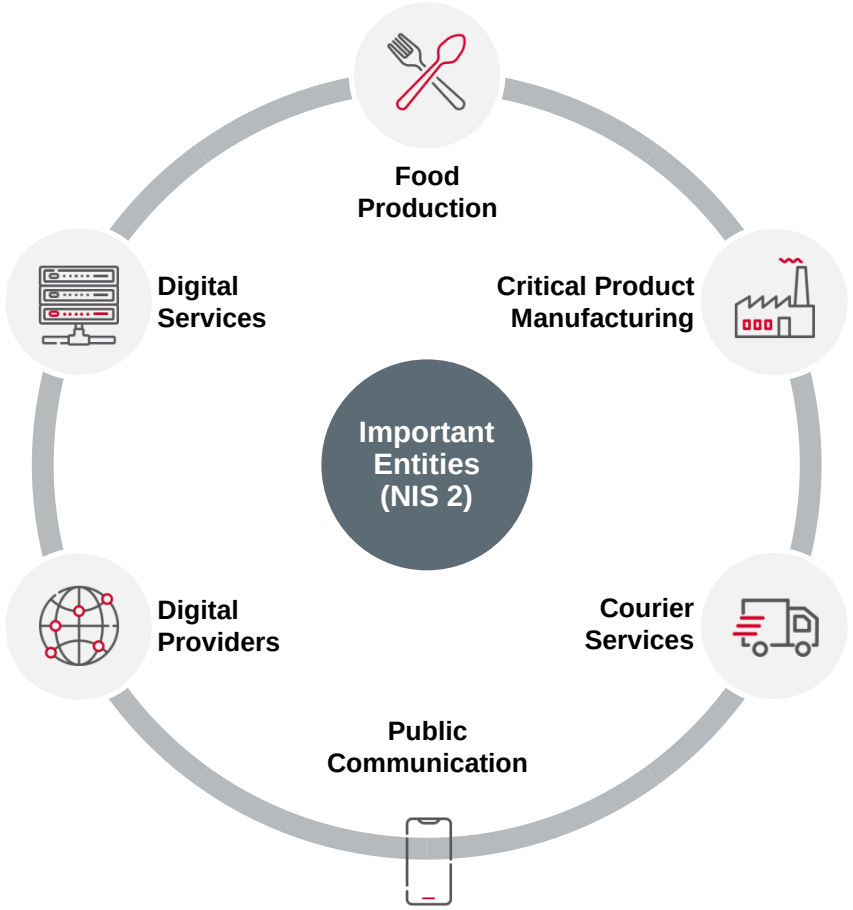
Critical Infrastructures

- Critical infrastructures (CIs) are essential for the maintenance of vital societal functions
- Basic supply chain networks (electricity, gas, water)
- Information and communication (ICT) networks
- Complex systems with high social impact (medical care, finance, transportation networks)

Critical Infrastructures



Critical Infrastructures

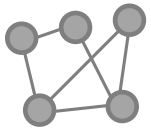


Critical Infrastructures


Food Supply

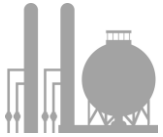

Transportation


Hospital


Gas Network


Power Plant


Government


Refinery


Sea Port

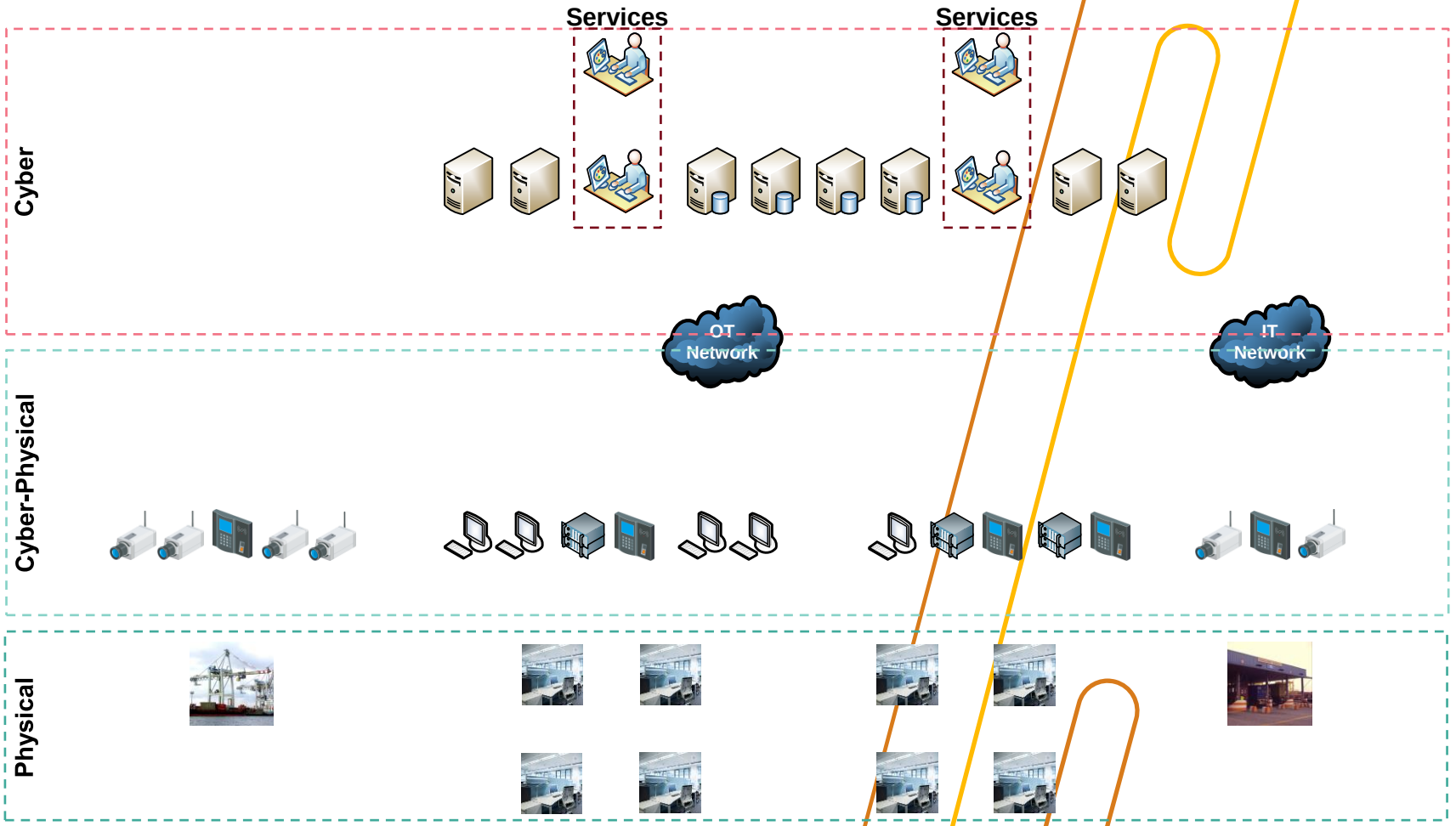

Finance

Critical Assets

- Within critical infrastructures or organisations in general
  critical assets or components can be defined
  - Provide core functionalities for the organisation
  - Required for maintaining the service of the organisation

- Such critical assets or components can be located in different domains
  - Physical: essential parts of the utility network (pumps, substations, pipes, etc.)
  - Cyber-Physical: monitoring and control systems (PLCs, sensors, switches, etc.)
  - Cyber: virtual infrastructure and software (servers, databases, applications)

Critical Assets

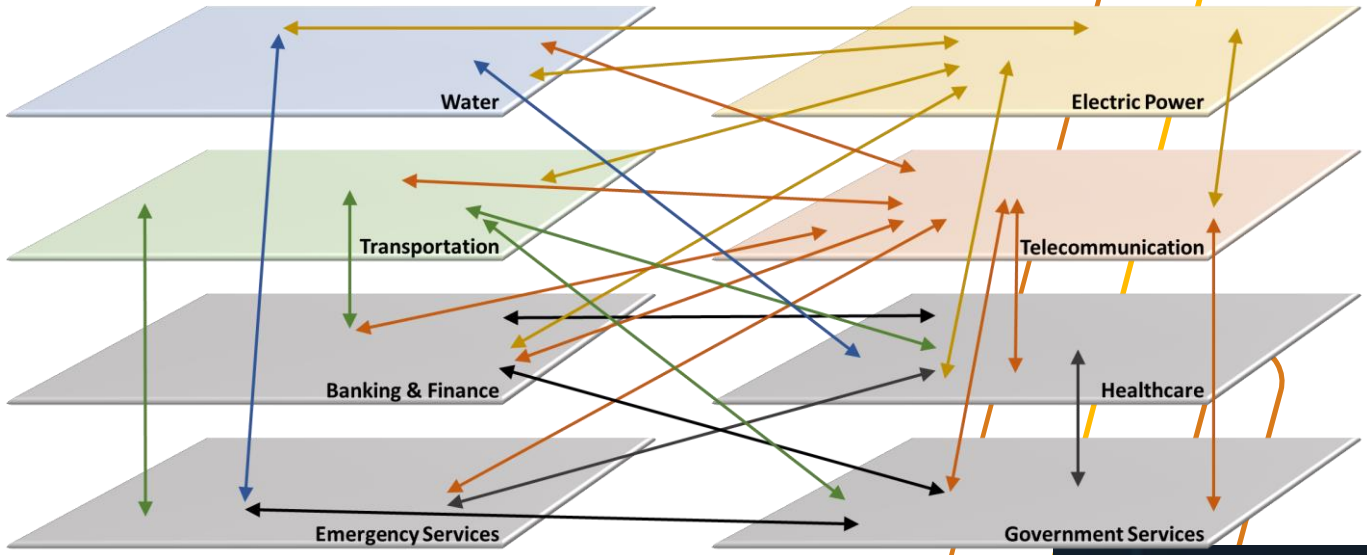


Interdependencies

How can dependencies among critical entities be characterised?

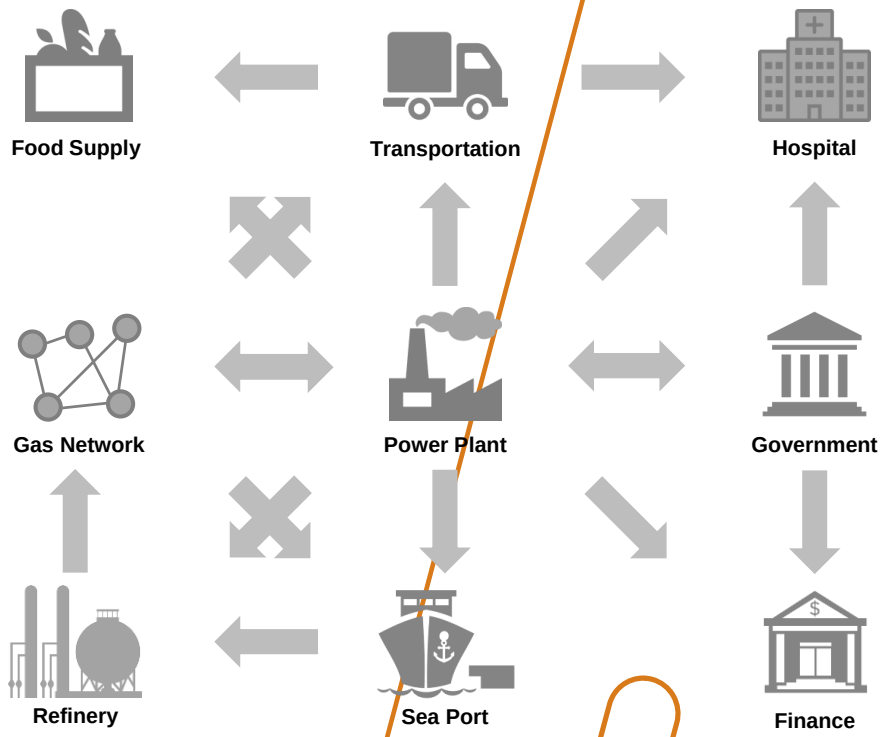
Infrastructure Interdependencies

- Over the last decades critical entities have become
  more and more interrelated and interdependent
  - Complex service provider and consumer relations among entities
  - Interwoven and often fragile supply chains on a national and international scale



Infrastructure Interdependencies

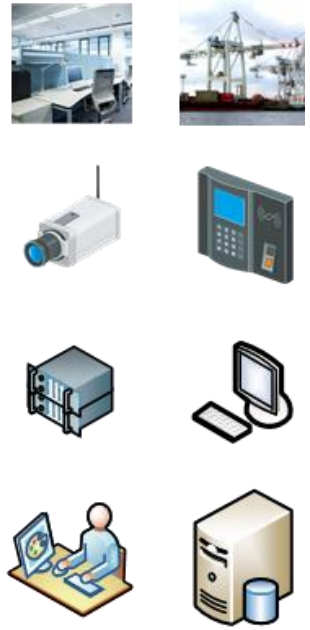
- Critical infrastructures cannot be considered in isolation
- Infrastructures act as suppliers of different resources and services
- Infrastructures also act as consumers of certain resources and services of other infrastructures to ensure functionality



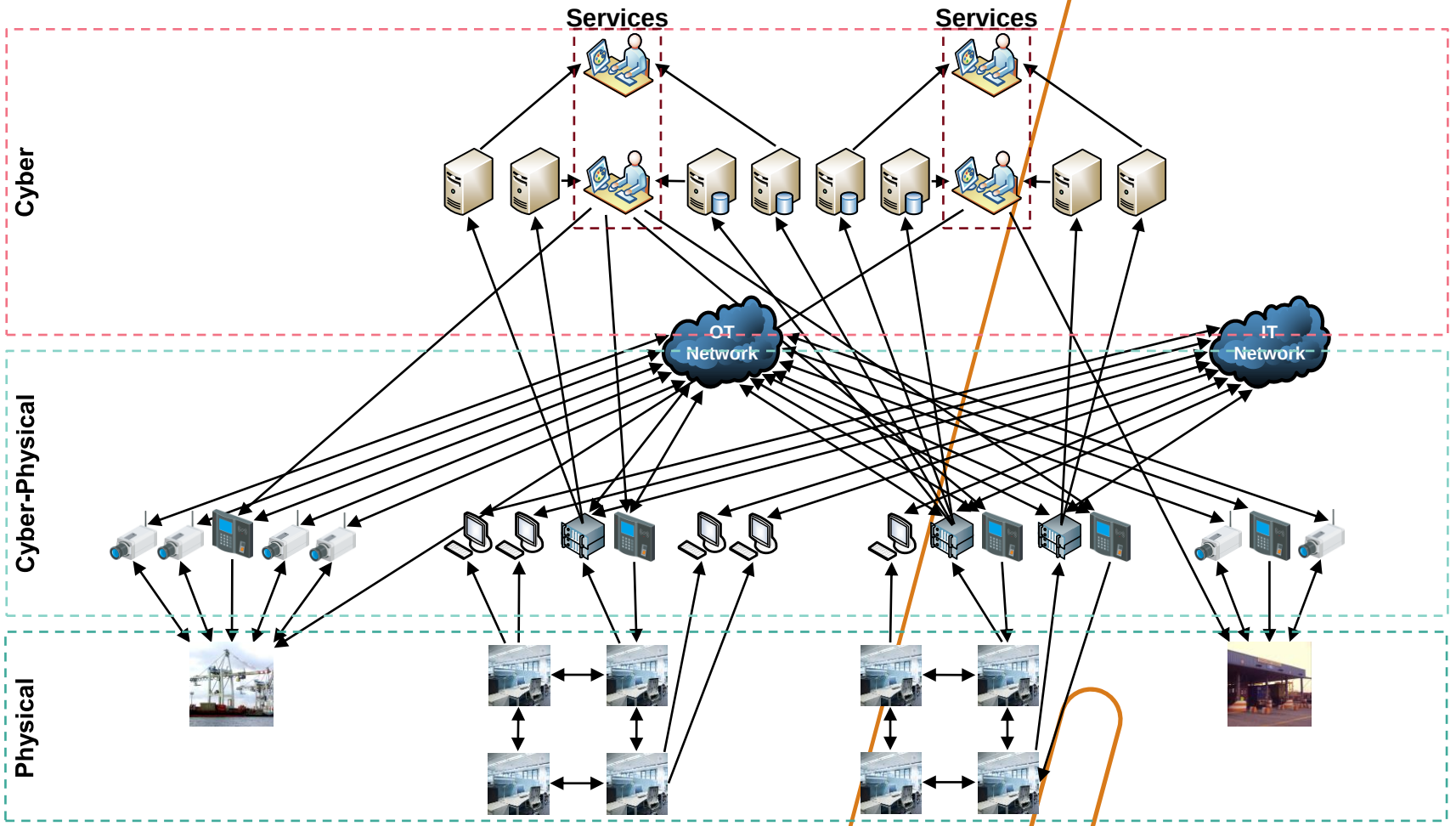
Infrastructure Interdependencies

- Interdependencies exist also within organisations and among their premises
  due to the increase of digitalisation and data exchange
  - Buildings and machinery are "smart" and are connected to digital systems
  - Video surveillance and access control systems can influence physical assets
  - Sensors and Internet of Things (IoT) devices connect physical and cyber assets
  - Services are provided by applications running on real or virtual servers

- Functionality and services of an infrastructure can only be maintained
  if these interrelations and dependencies are working properly

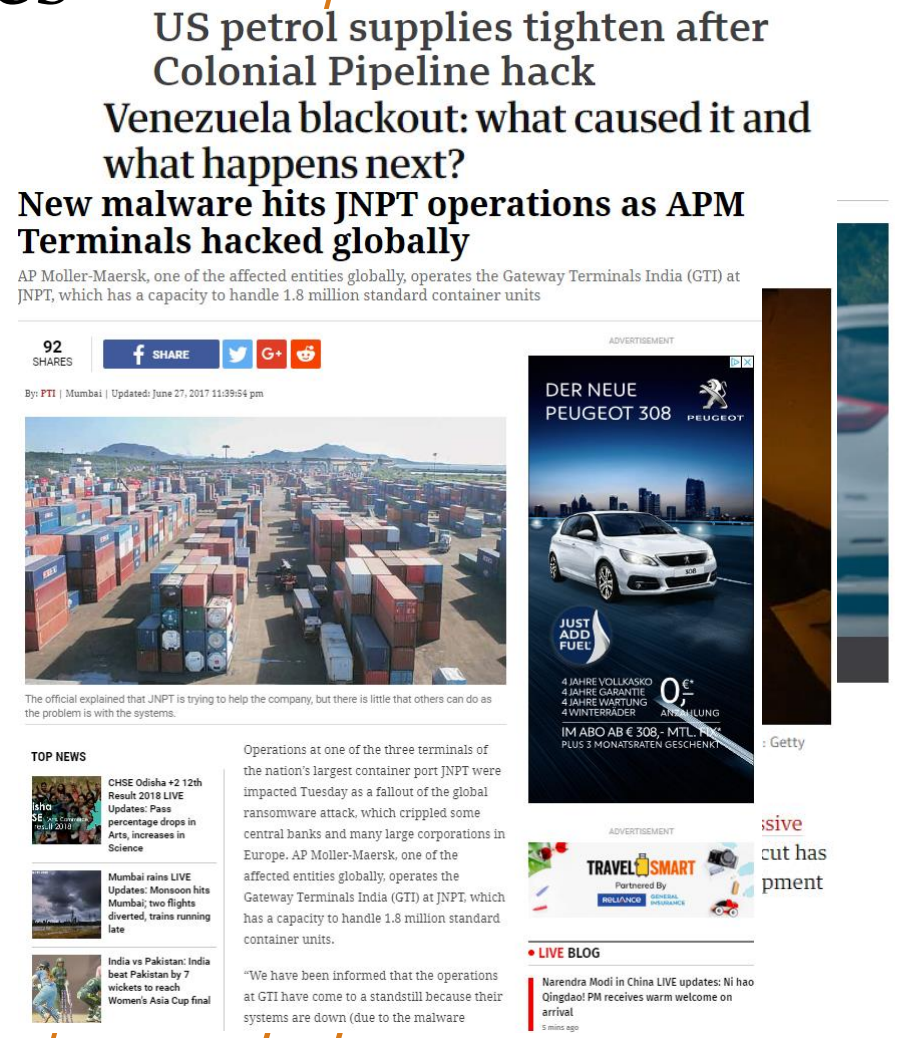


Infrastructure Interdependencies



Infrastructure Interdependencies

- Incidents within one critical infrastructure can have far-reaching consequences among multiple other infrastructures as well as society as a whole
  - 2021 Hacking of the Colonial Pipeline in USA
  - 2019 Power outages in Venezuela and Argentina
  - 2017 International Moeller-Maersk logistics breakdown



Interdependency Types

- Dependencies need to be identified and evaluated for a risk analysis
- Comprehensive analysis of the dependencies of a critical infrastructure
  - Considering both incoming and outgoing connections
  - Considering dependencies in potential impacts
  - Considering dependencies on potential threats

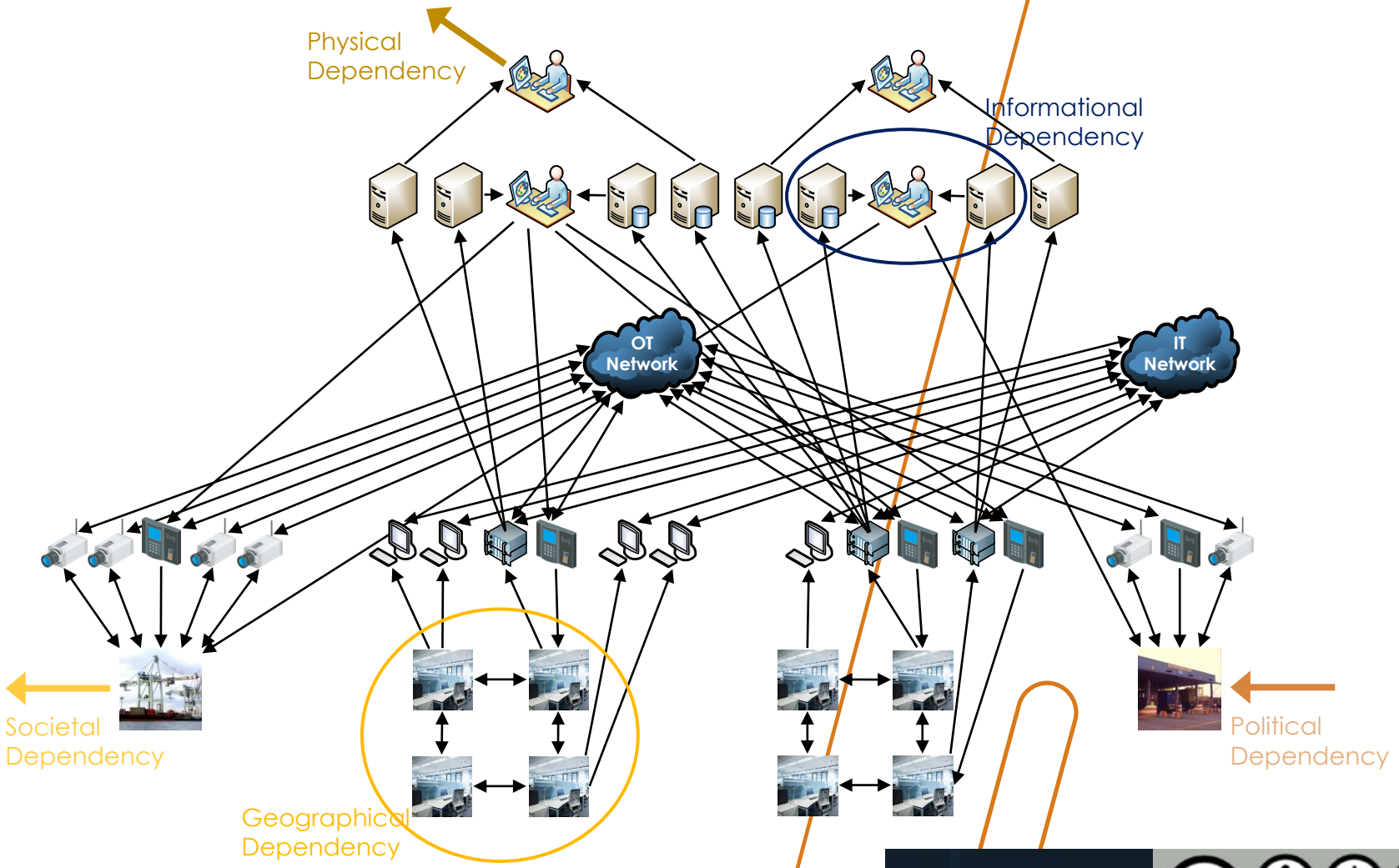
- Cascading effects can occur due to dependencies
  - Impact of a threat affects the operation of other critical infrastructures
  - Impairment can again have an influence on other infrastructures
  - Apparently insignificant causes have a great effect
  - Cascading effects are often not considered in detail

Interdependency Types

- In early literature, several types of dependencies can be found
  - Physical dependency
  - Information dependency
  - Geographical dependency
  - Political/procedural dependency
  - Social/societal dependency

- Type of a dependency determines the influence of a specific threat
  - For some types, an incident is perceived immediately and also stronger
  - In other cases, influences do not occur directly or have only minor impact
  - Some effects only spread when a certain type of dependency is present

Infrastructure Interdependencies



Novel Interpretations

- In real-life approaches, not all of those dependency types are relevant
  - Using all types makes the description of the overall system highly complex
  - Particularly the political and societal dependencies can be very vague
  - Importance and degree of dependency not easy to estimate
  - Nevertheless they are of interest when looking at critical infrastructures

- Physical and information (cyber) dependency
  are more important in day-to-day business life
- Geographical dependency is often relevant
  in the context of natural disasters or technical failures

Novel Interpretations

- Increasing digitalization has fostered the tight relation between physical and cyber dependency
  - Cyber-physical systems are at the heart of most critical infrastructures
  - Application of Industrial Control Systems (ICS) and Supervisory Control and Data Acquisition (SCADA) systems
  - Infrastructures' core processes are building upon those systems

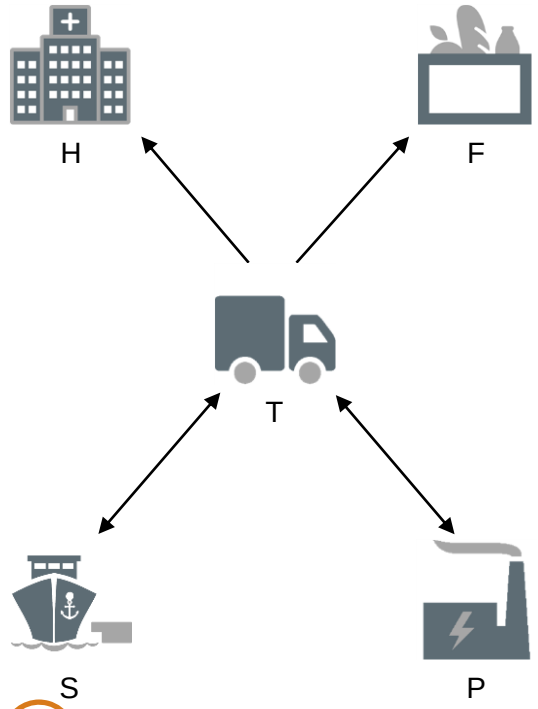
- Critical infrastructures have evolved into complex and highly sensitive ecosystems of strongly interconnected cyber-physical systems
- Important to consider these sensitive interrelations and needs to go into the risk analysis and risk management of critical infrastructures

Interdependency Graphs

- More abstract form of describing the dependencies among critical infrastructures is required
- Can be achieved by an interdependency graph
  - Nodes represent critical infrastructures
  - Edges represent dependencies among them
  - Edges are directed
    i.e. "P → W" means "W is depending on P"

- Specific type of the dependency can be neglected
  - Graph could contain different edges for physical and cyber dependency

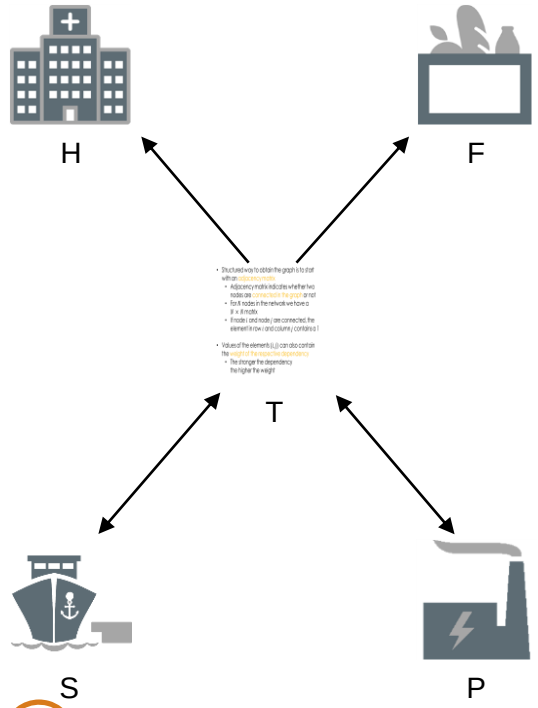
  ➢Graph would become much more complex



Interdependency Graphs

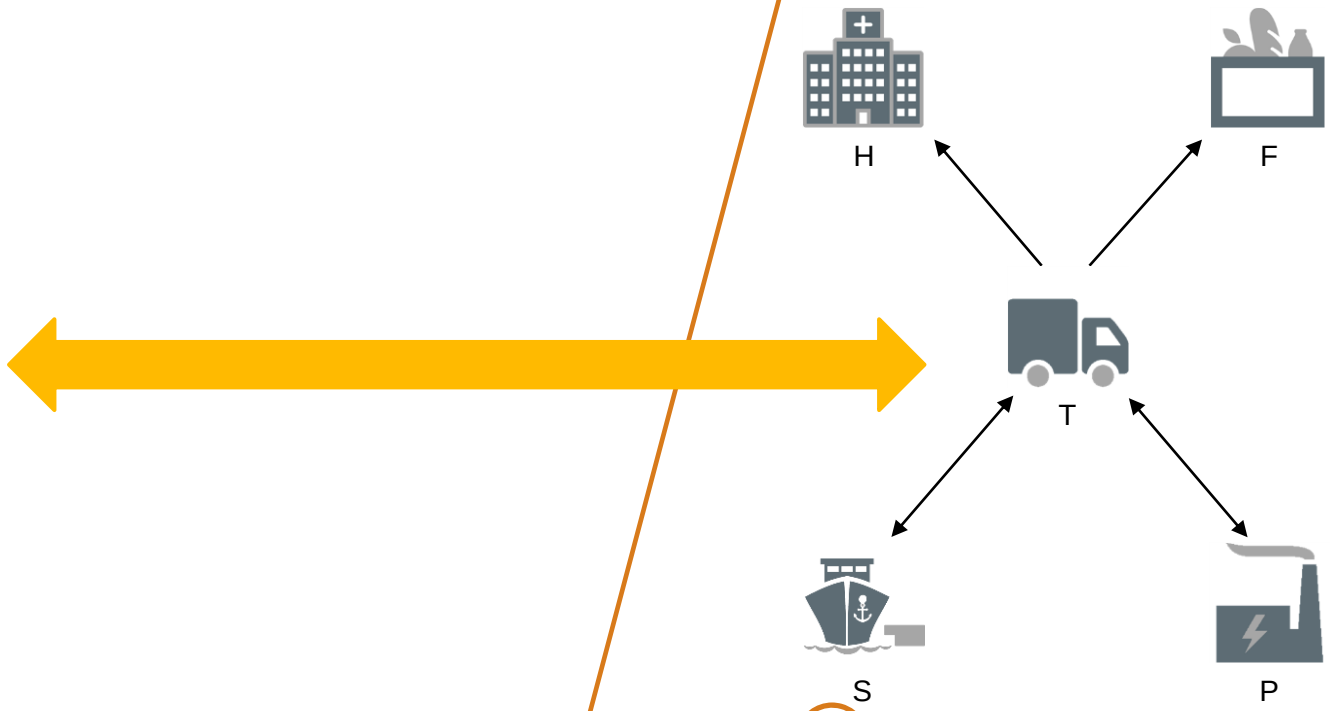
- Structured way to obtain the graph is to start with an adjacency matrix
  - Adjacency matrix indicates whether two nodes are connected in the graph or not
  - For N nodes in the network we have a $N \times N$ matrix
  - If node i and node j are connected, the element in row i and column j contains a 1

- Values of the elements (i, j) can also contain the weight of the respective dependency
  - The stronger the dependency the higher the weight



Interdependency Graphs

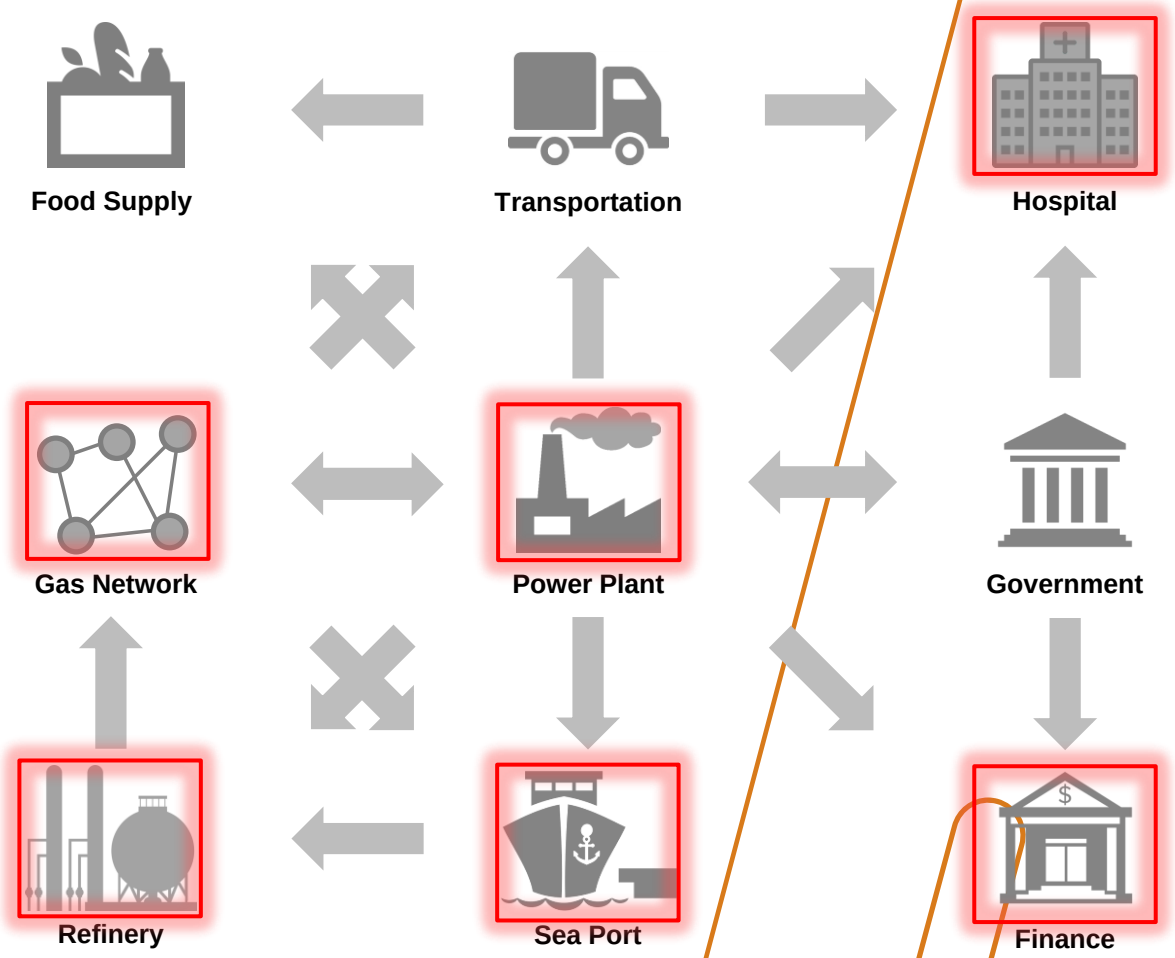
	P	T	W	H	F
P	0	0	1	0	0
T	0	0	1	0	0
W	0	0	0	1	1
H	0	0	0	0	0
F	0	0	0	0	0



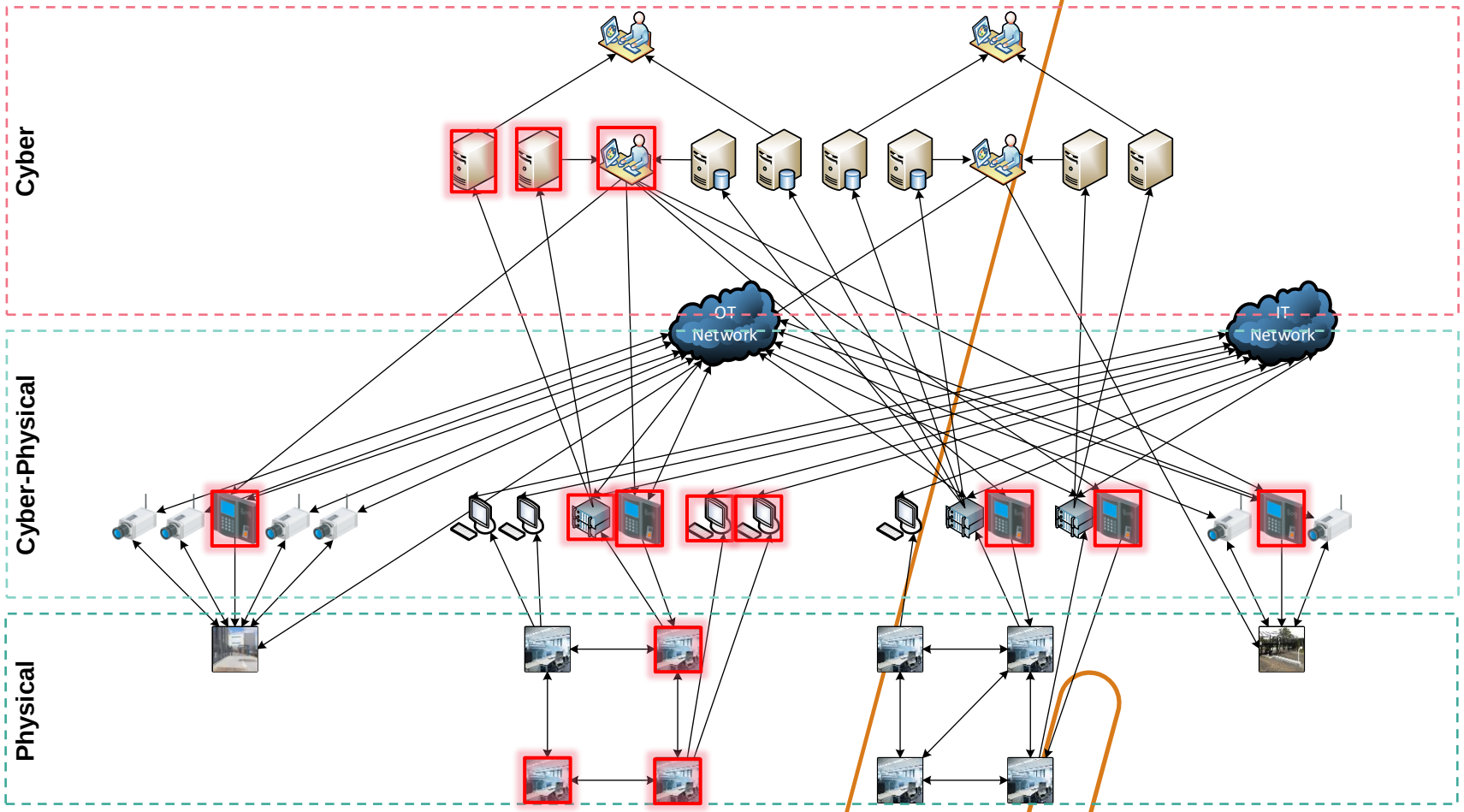
Cascading Effects

How can cascading effects be modelled and analysed?

Cascading Effects among Infrastructures



Cascading Effects among Infrastructures



Modelling cascading effects

- For describing the state of a critical infrastructure, a binary system might not be sufficient
  - "fully operational" vs "complete breakdown"

- In real life, infrastructures can have multiple different operational states
  - Depending on available resources, production capacity, etc.
  - Operational states can influence depending infrastructures in various ways

- More differentiated scale to describe the operational status of a critical infrastructure will provide better insight into the evolution of the overall system

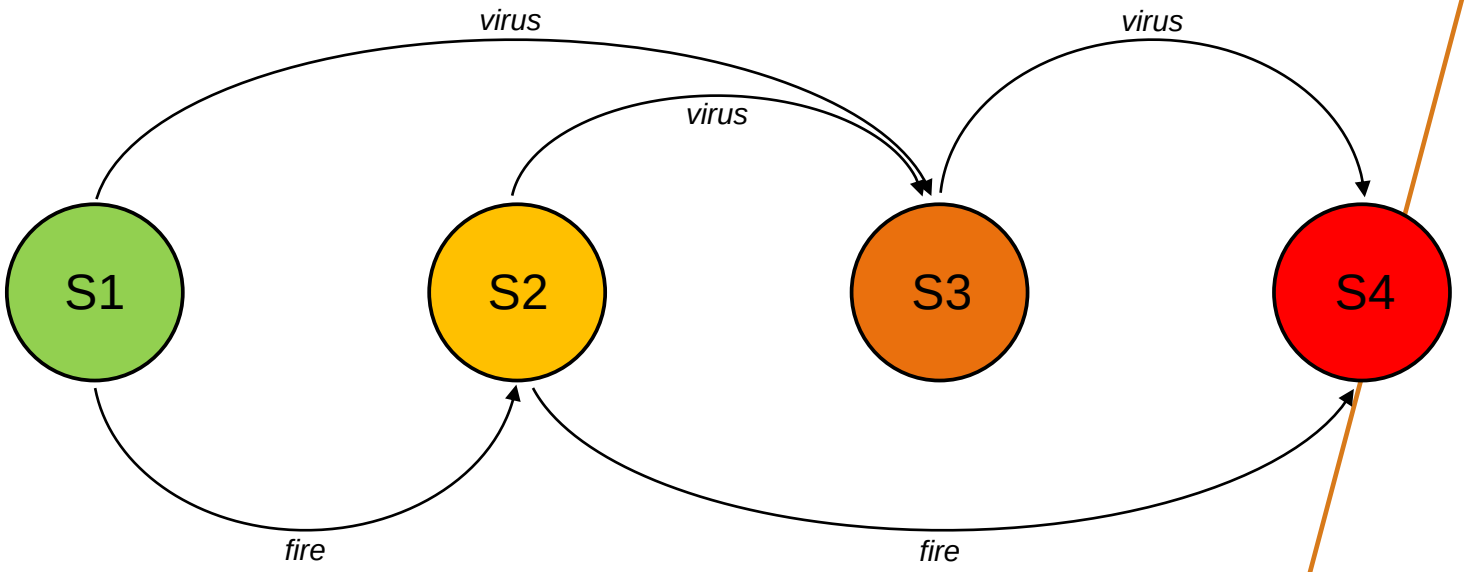
Modelling cascading effects

- One approach is to model the critical infrastructure as an automaton or state machine

- Number of different operational states
  - Abstract representation of the various states the infrastructure can be in
  - Detailed description can be formulated separately (e.g., internal specifications, etc.)

- Well-defined transitions among those states
  - Conversion from one state to another
  - State change is based on a specific input

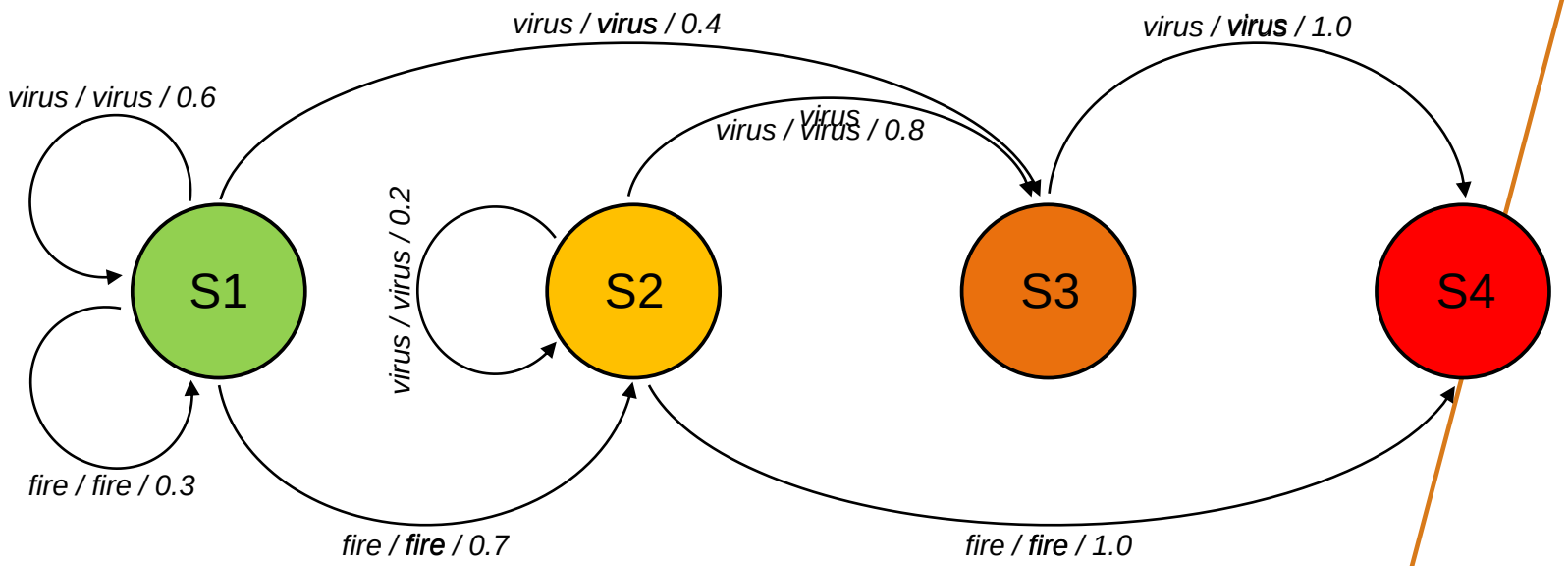
Modelling cascading effects



Modelling cascading effects

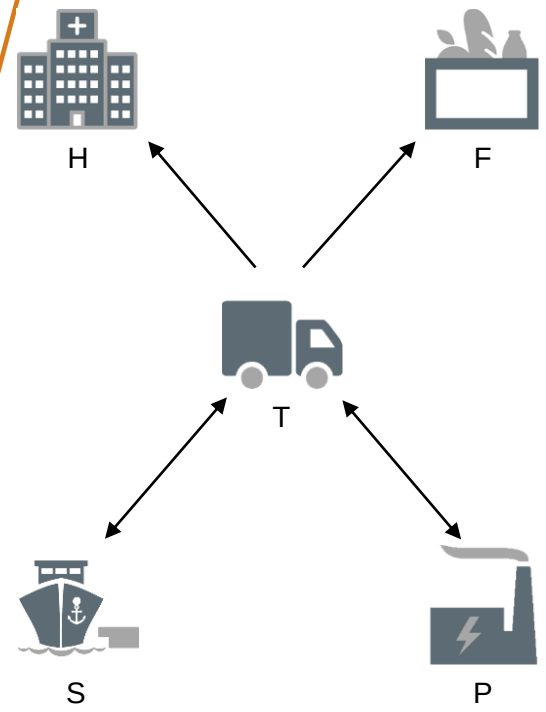
- Additional information is required to describe real-life scenarios
- States need to handle input events and also deliver output events
  - Triggering incident can originate somewhere else (i.e., external event)
  - State change can trigger another event (i.e., at another internal system)
- Infrastructures will react differently on distinct events
  - Current state and triggering event define the resulting state
- Transitions won't be deterministic
  - Real-life operation of infrastructures contains too much uncertainty
  - Probability needs to be included in the transitions

Modelling cascading effects

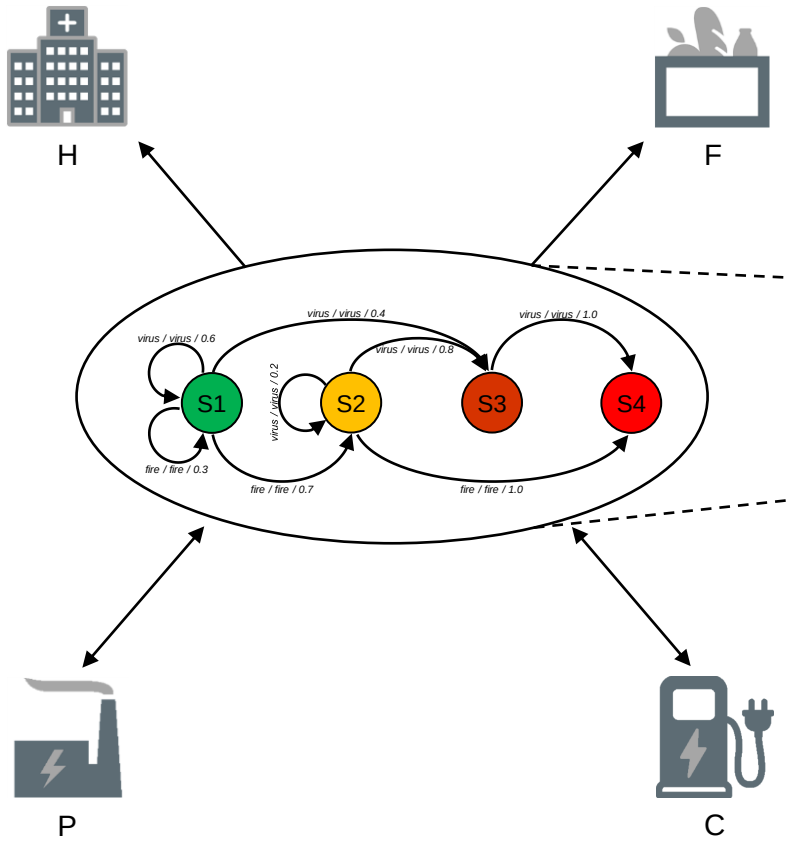


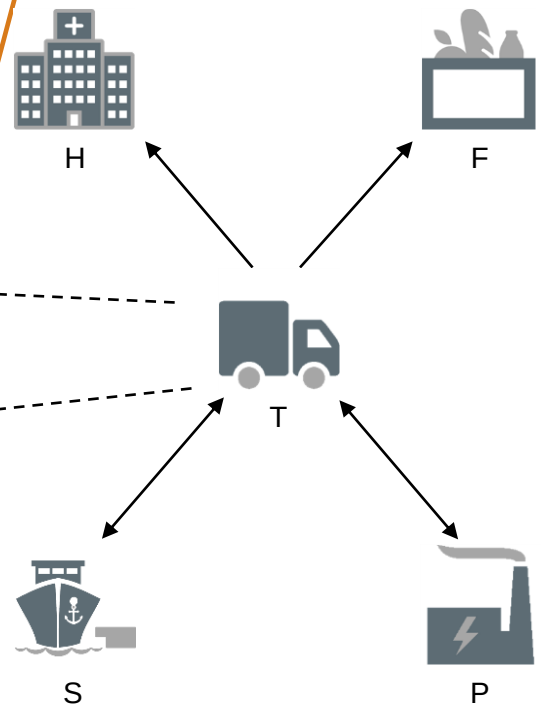
Modelling cascading effects

- Combine this more dynamic approach with the interdependency graph
- Each infrastructure can be in one of several operational states
  - Ranging from "fully operational" ("1") to "complete breakdown" ("3")
- Change of the operational state is based on
  - the supplier infrastructures
  - an external event (i.e., an incident)
- Change of the operational state happens with a specific probability

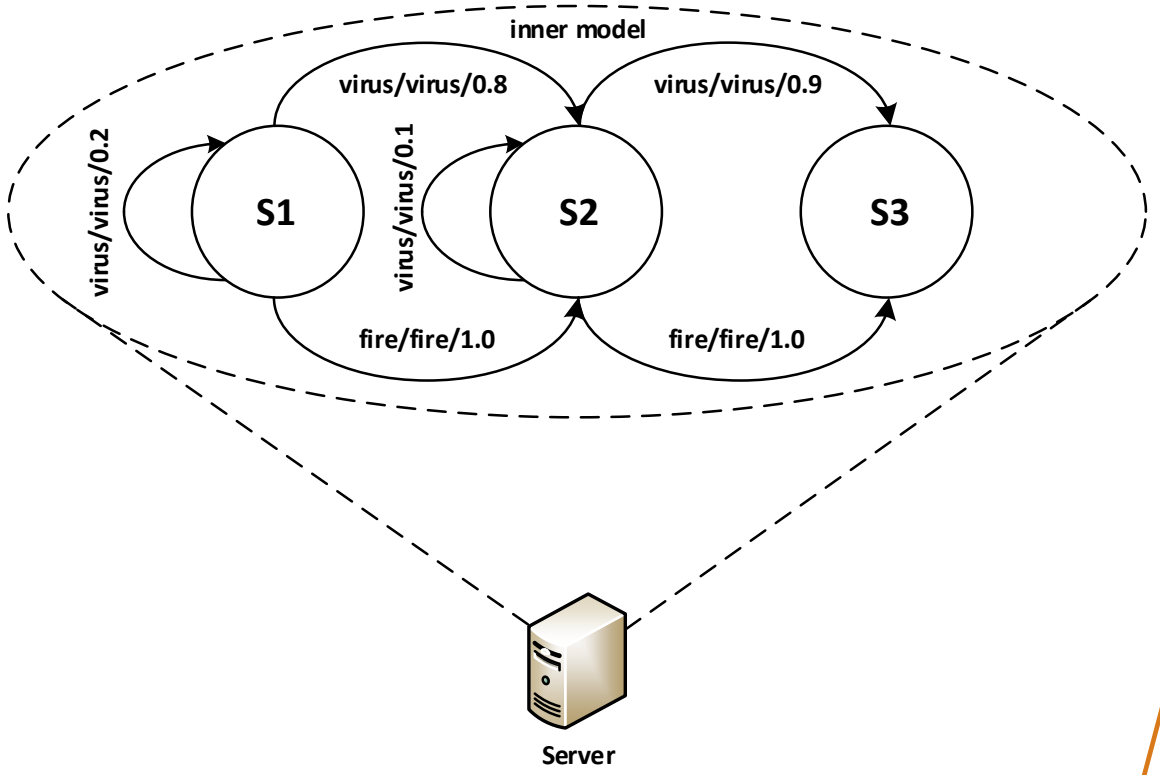


Modelling cascading effects

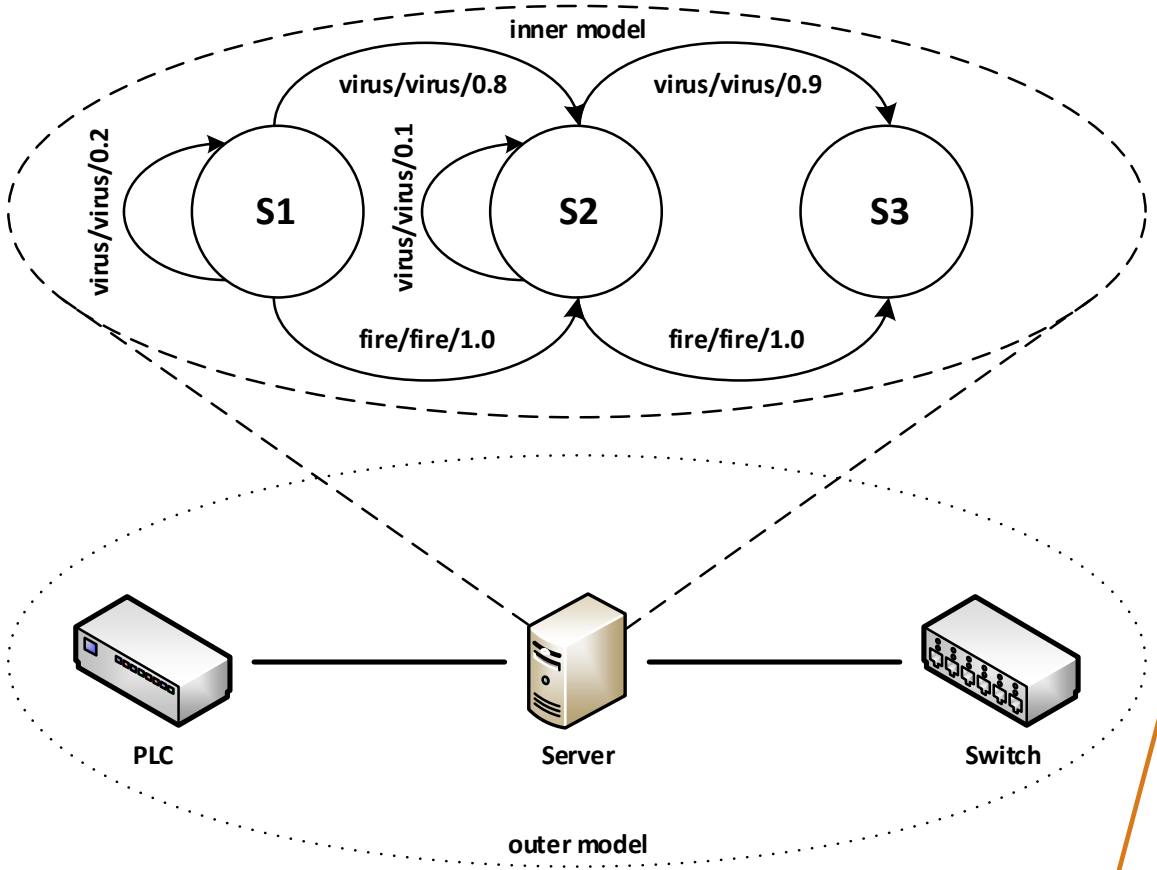




Modelling cascading effects



Modelling cascading effects



Simulating Cascading Effects

Simulation model describes the evolution of the overall CI network

- Stochastic risk model is instantiated
- Large number of simulation runs are carried out to evaluate a specific incident happening on one infrastructure

Incident/attack changes the operational state of the target CI

- Dependent CIs change their state, too (according to the probability distribution)
- Effects of the incident propagate through the CI network

Total impact is measured based on the final state of all CIs after the simulation has finished

Simulating Cascading Effects

Simulation model has been implemented in the SAURON project

Focus lies on the physical and cyber assets within maritime ports

- Model various assets in the physical and cyber domain
- Define the operational states
- Specify the interdependencies among them
- Define the transition probabilities

Scenarios with incidents from different domains can be simulated

- Physical incident affecting the cyber domain
- Cyber incident affecting the physical world

Simulating Cascading Effects

Tool records all state changes and the final states of each of the simulation runs

Simulation runs return an overview on the system evolution

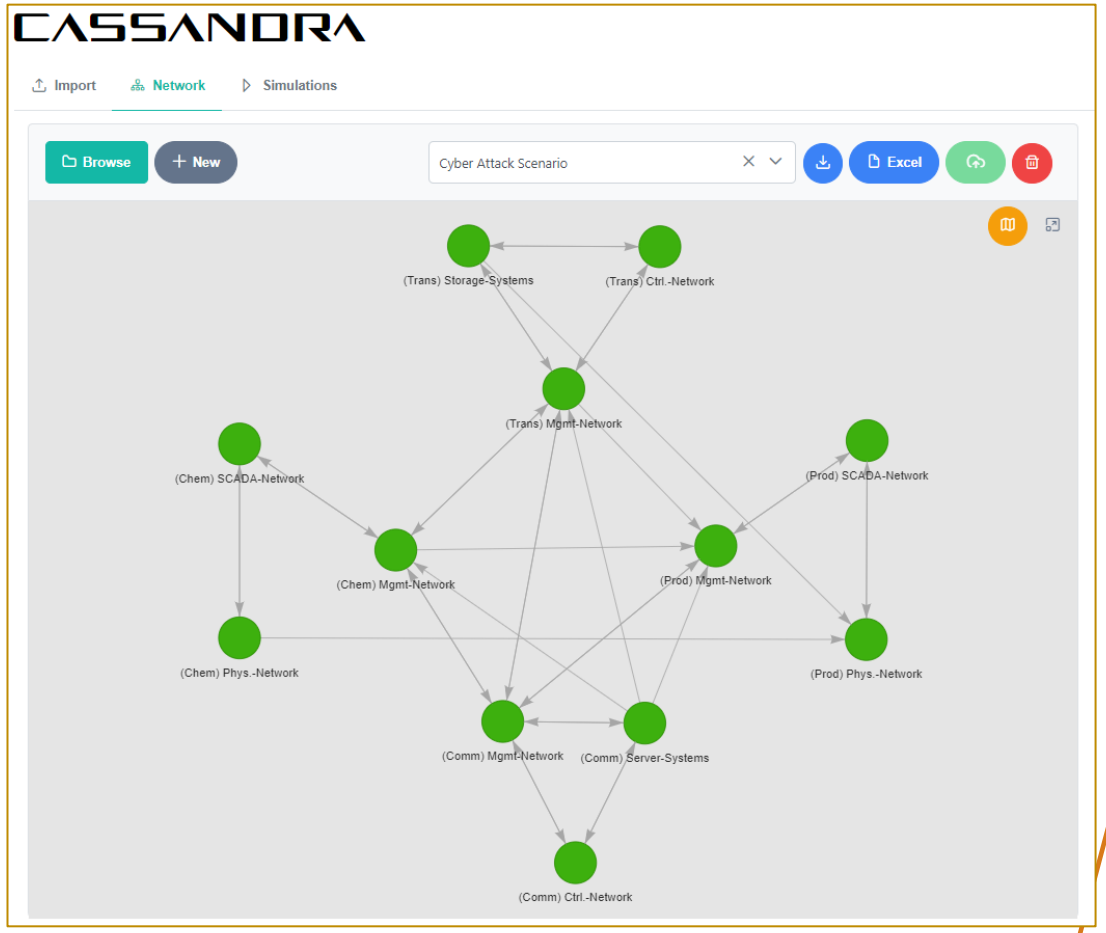
- Which asset has been "infected" in which step
- What is the new state of the asset
- Which asset caused the state change

Final states reflect the overall impact of an incident on the infrastructure

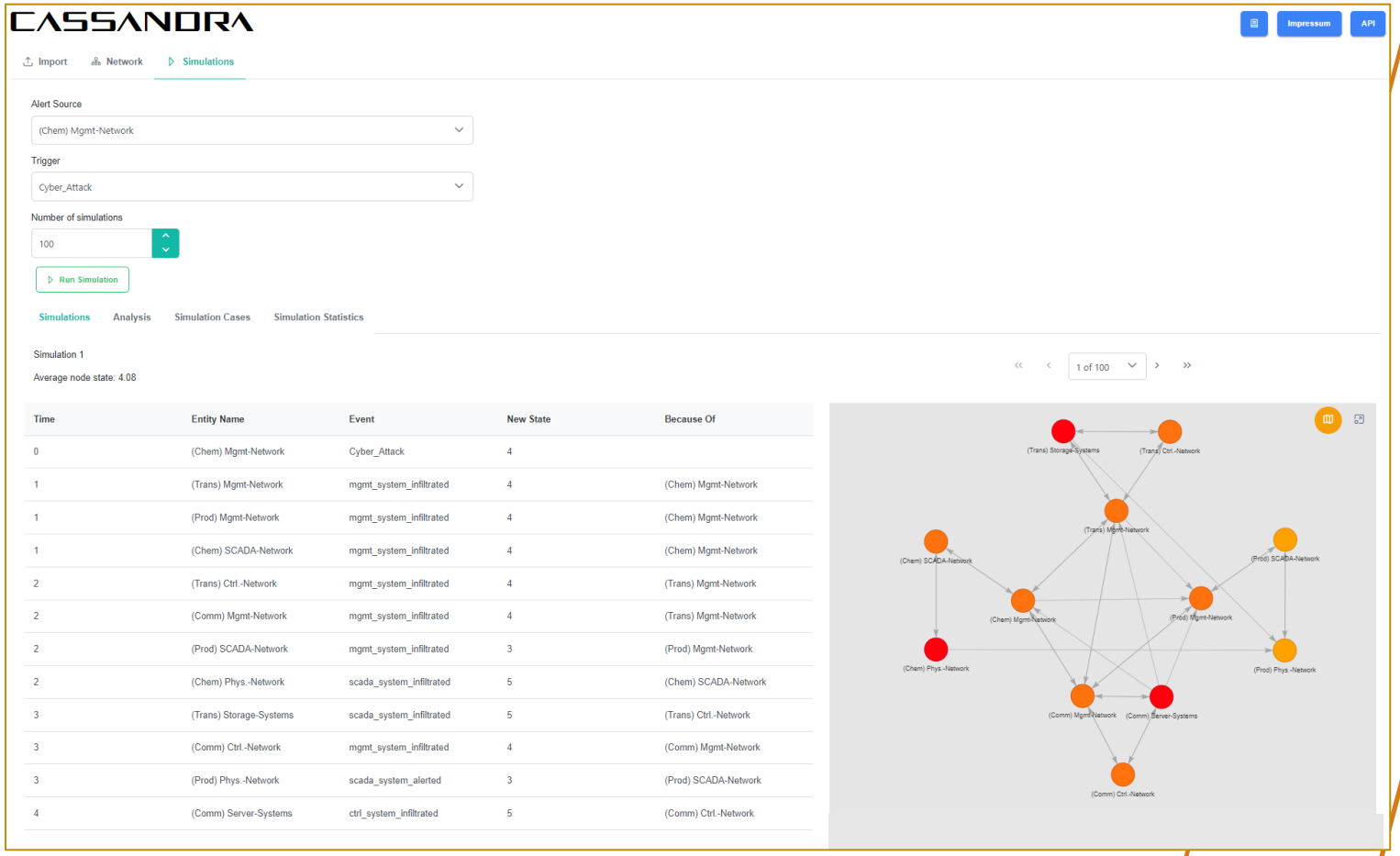
Different visualizations and reports can be generated

- Average final state of an asset
- Average case scenario
- Worst case scenario

Simulating Cascading Effects



Simulating Cascading Effects



Example: Cascading Effects

How are cascading effects simulated in a realistic scenario?

Scenario "Port Infrastructure"

Physical Infrastructures

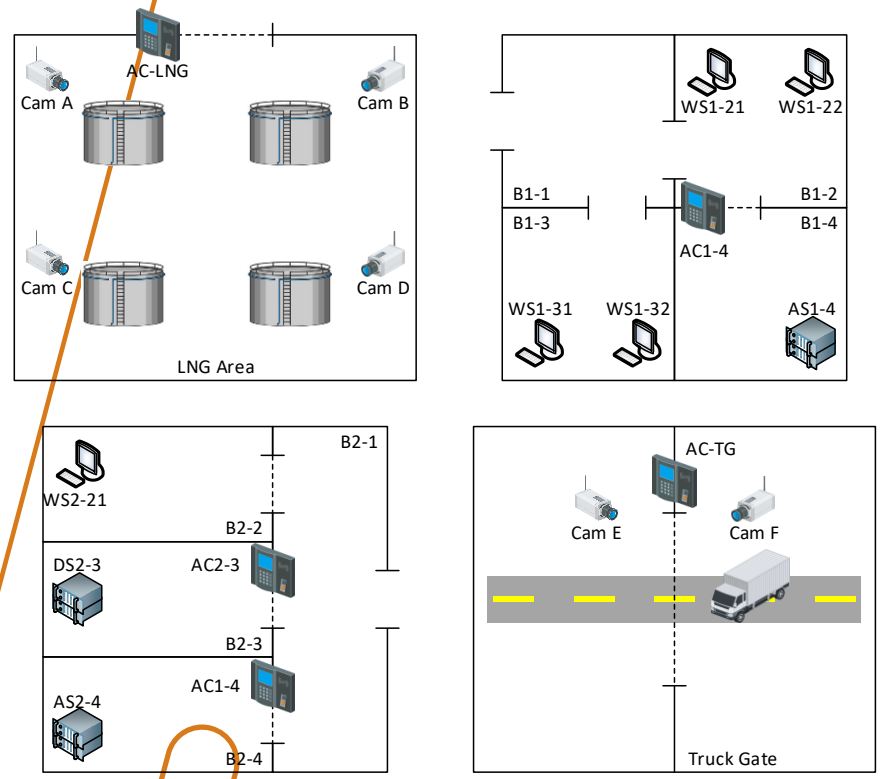
- LNG area and truck gate
- Two office buildings

Cyber-physical Infrastructures

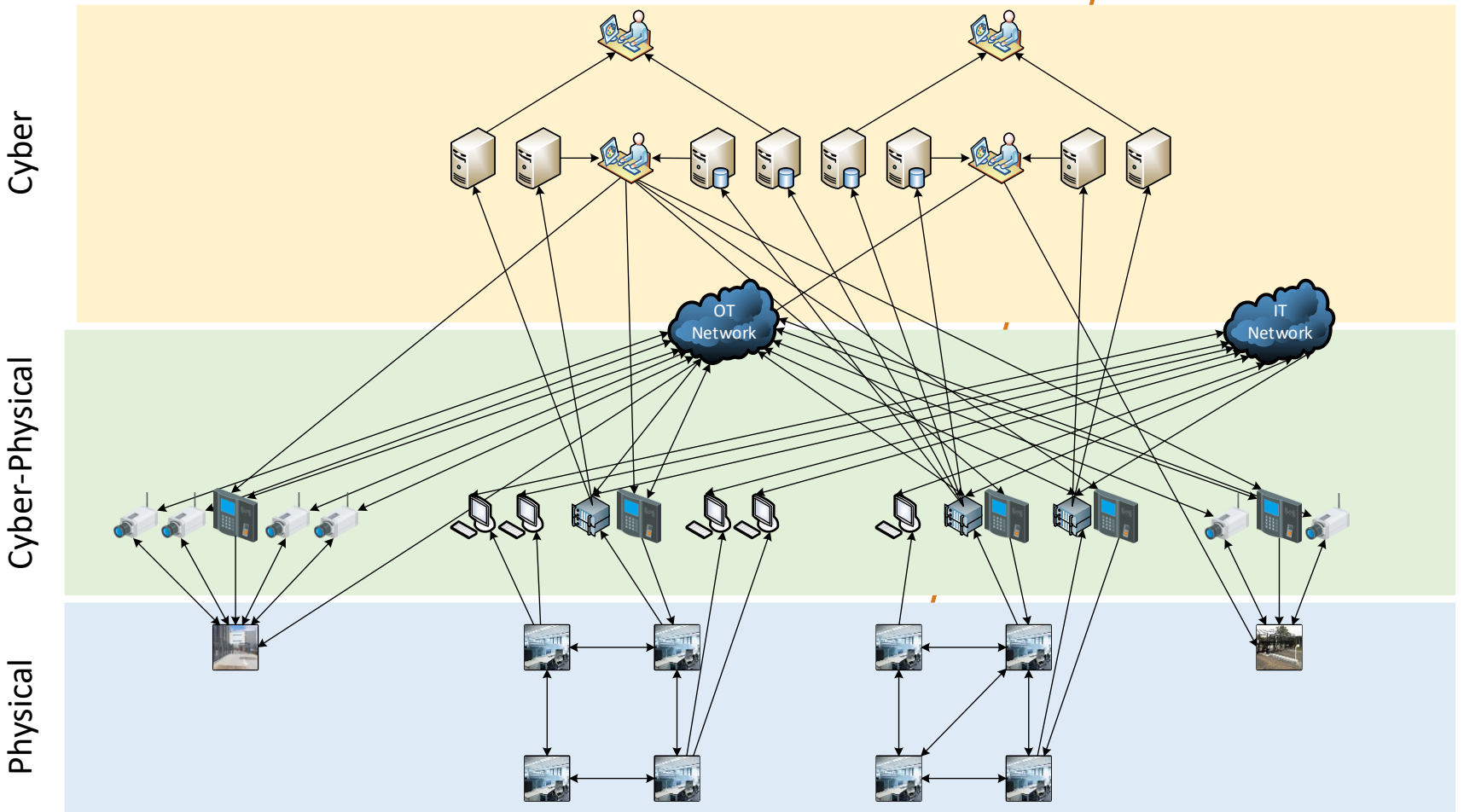
- Access control at specific gates
- Various surveillance cameras
- Three server racks
- Several work stations

Cyber Infrastructure

- Database and application servers
- Several important services

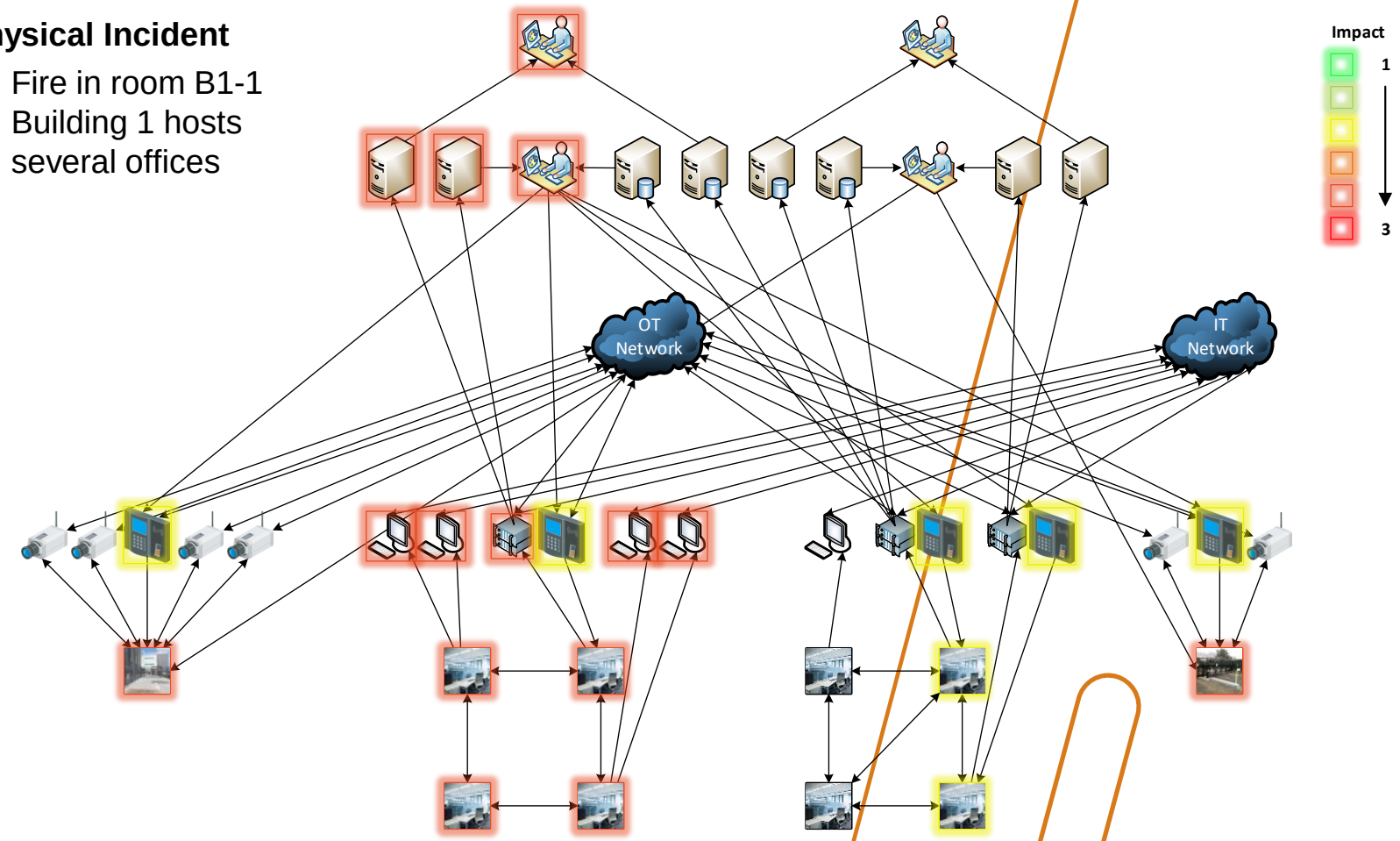


Scenario “Port Infrastructure”



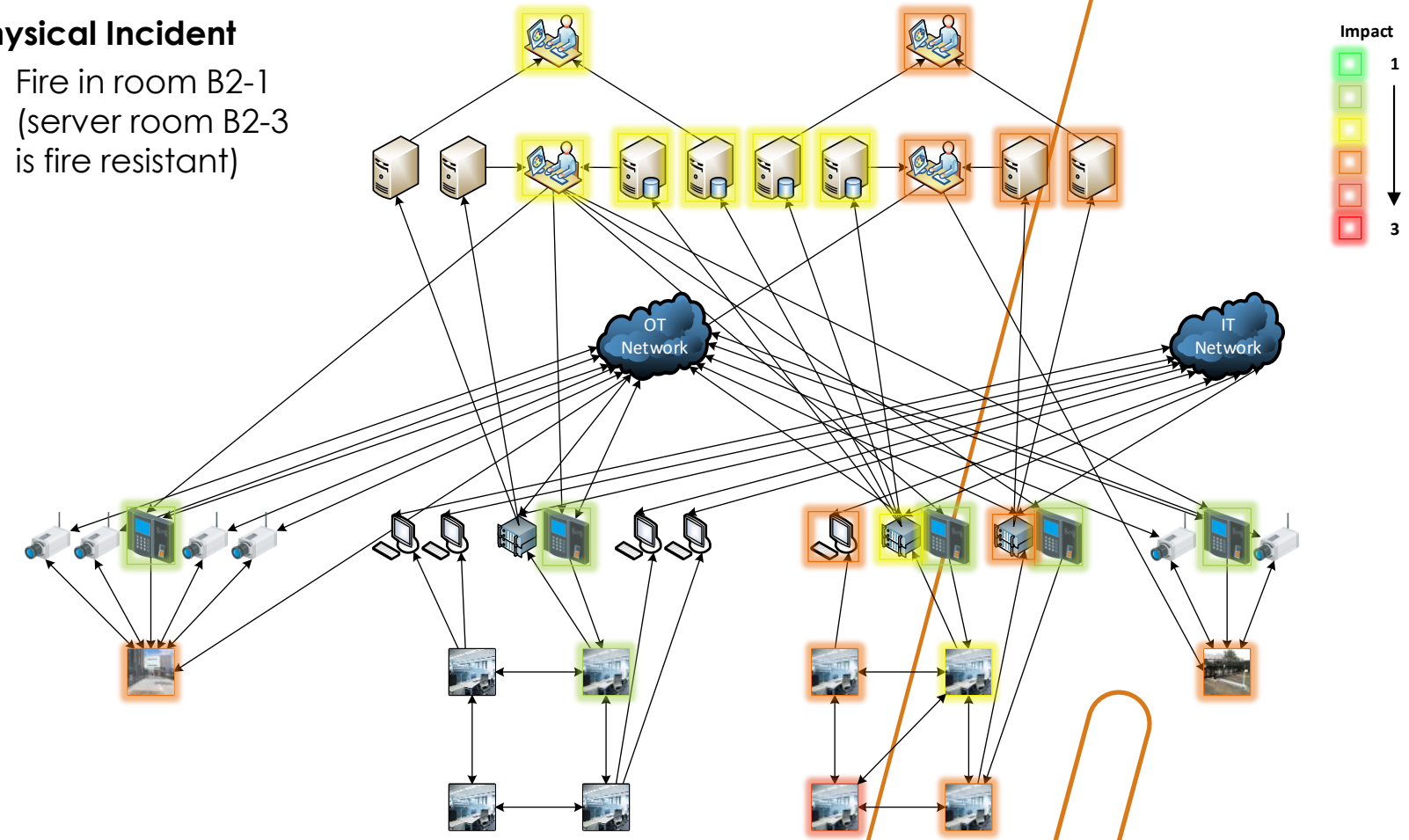
Simulation Results

- **Physical Incident**
  - Fire in room B1-1 Building 1 hosts several offices



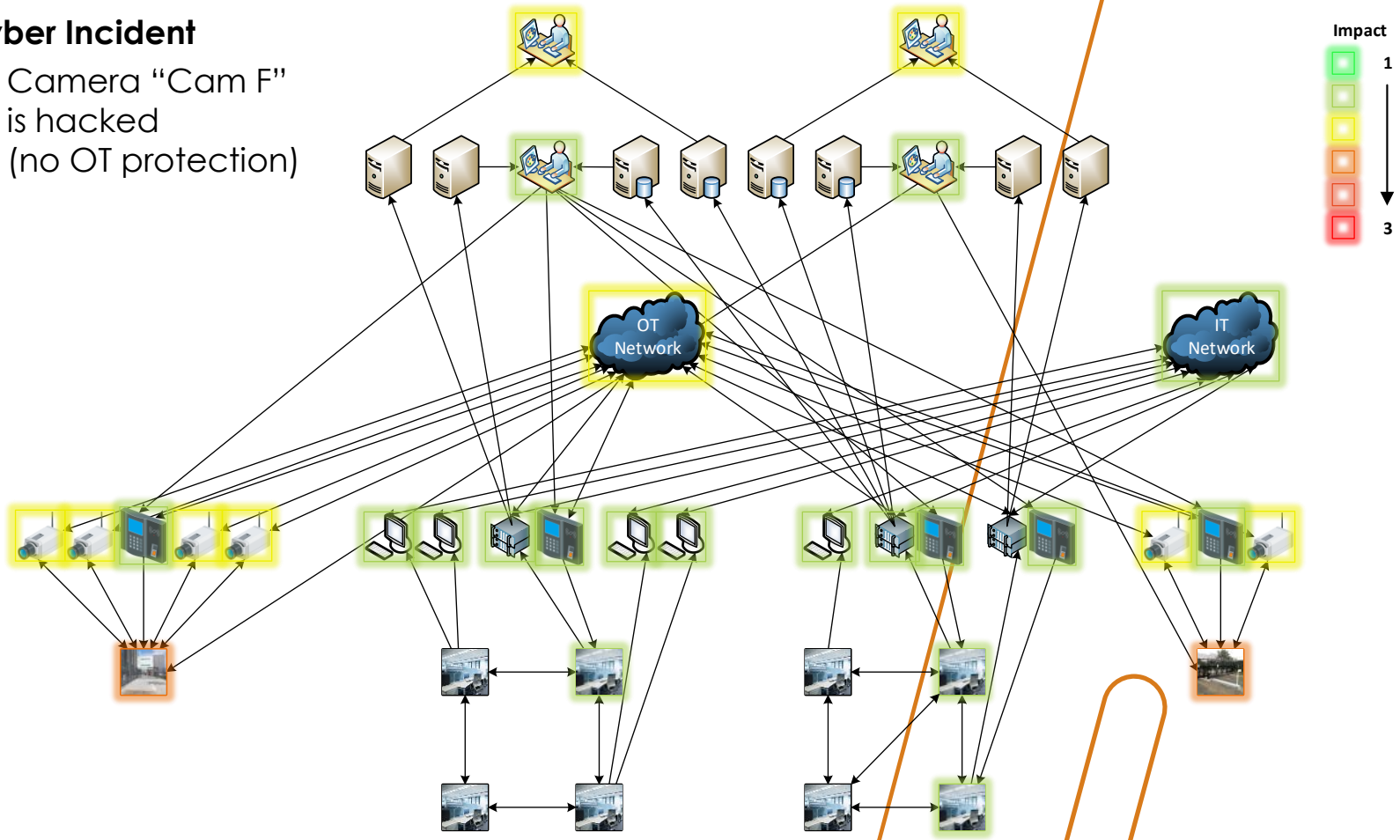
Simulation Results

- **Physical Incident**
  - Fire in room B2-1 (server room B2-3 is fire resistant)



Simulation Results

- **Cyber Incident**
  - Camera "Cam F" is hacked (no OT protection)



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Thank you

Please send all questions to:
Stefan Schauer,
Stefan.Schauer@ait.ac.at
Abdelkader Shaaban
abdelkader.Shaaban@ait.ac.at