FP7 Grant Agreement N° 312450

CIPRNet

Critical Infrastructure Preparedness and Resilience Research Network

Project type: Network of Excellence (NoE)

Thematic Priority: FP7 Cooperation, Theme 10: Security

Start date of project: March 1, 2013 Duration: 48 months

D9.51 Periodic Training Event

Due date of deliverable: 30/04/2014
Actual submission date: 28/05/2014

Revision: Version 1

Università Campus Bio-Medico di Roma (UCBM)

Project co-funded by the European Commission within the Seventh Framework Programme (2007–2013)		
Dissemination Level		
PU	Public	**X**
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

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Security Assessment	Dominique Serafin (CEA)
Approval Date	19/05/2014
Remarks	No security issues detected in the document

The project CIPRNet has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement no 312450.

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1 Introduction

Internal and external training activities represent a mandatory cornerstone for the creation of a European community able to support the realization of EISAC (European Infrastructures Simulation & Analysis Centre) and to exploit its functionalities. CIPRNet will arrange specific training activities aiming to provide basic and advanced knowledge about Critical Infrastructure MS&A (Modelling, Simulation and Analysis) targeted at a broad range of personnel related to CI (including, but not limited to, local administrations, utilities personnel, emergency operators and managers, security & safety operators and managers, CIP researchers, CIP policy makers, etc.).

This deliverable describes in details the activities performed for CIPRNet training in terms of material prepared and used, results and feedback from attenders.

The training activities will consist of three training episodes scheduled for 2014 in Paris, for 2015 in Rome and for 2016 in Bonn. These episodes will be pre-run at the rehearsal internal editions (Edition 0 in 2014 in Delft and two 1-day events for the following Editions).

The training episodes will consist of a fixed part, devoted to teaching basic aspects of MS&A (repeated at each edition), followed by a more advanced part that will focus, at each edition, on a different topic, specifically:

- ✓ Edition 1: Federated Simulation and Open MI platform
- ✓ Edition 2: Decision Support System (DSS)
- ✓ Edition 3: What-if Analysis

During the training events, the attendees will have also the chance to practice with the tools developed within the CIPRNet project.

This document will present the activities performed for the Edition 0 (i.e. the internal rehearsal before the Edition 1). The structure of this document is as follows: Section II presents the training activities in terms of venue, programme and attendees. Material prepared for the training and/or collected during the training will be reported in the Appendixes.

1.1 Acronyms

Acronym	Explanation
CI	Critical Infrastructure
CIP	Critical Infrastructure Protection
CIPMA	Critical Infrastructure Protection Modelling and Analysis
CIPRNet	Critical Infrastructure Preparedness and Resilience Research Network
CISIA	Critical Infrastructure Simulation by Interdependent Agents
DB	Database
DIESIS	Design of an Interoperable European Federated Simulation Network for CI
DSS	Decision Support System
EISAC	European Infrastructures Simulation & Analysis Centre
EU	European Union
FP	Framework Programme
FR	Functional Requirement
GIS	Geographic Information System
GPS	Global Positioning System
I2SIM	Infrastructure Interdependencies Simulator
IIM	Input Output Inoperability Model
MS&A	Modelling, Simulation and Analysis
NFR	Not Functional Requirement
NISAC	National Infrastructure Simulation and Analysis Center
OpenMI	Open Modelling Interface
PA	Public Authority
QoS	Quality of Service
RAFI	Risk Assessment Forecast Interval
S&A	Simulation and Analysis
VCCC	Virtual Centre of Competence and expertise in CIP
V&V	Verification and Validation

2 Modelling, Simulation and Analysis of Critical Infrastructure Training School (Edition 0)

This was a pre-edition (Edition 0) of the training event, arranged for an internal audience with the aim of testing lesson topics and the accompanying pedagogical material.
Edition 0 was a two-day training event; the first day was devoted to introduce basic concepts about S&A (Simulation and Analysis) of CI while the second day was focused on the federated simulation and the use of the Open Modelling Interface (OpenMI).

Edition 0 was profitable, since draft material was shared among speakers and the Scientific Committee in order to harmonize it and also because, through the analysis of customer satisfaction forms collected at the end of the event, it was possible to re-schedule the programme and make the necessary adjustments on the treated arguments and their balancing in the lectures .

2.1 Venue

The Edition 0 of Master Class on Modelling, Simulation and Analysis of CI was held in Deltares Headquarters, Delft (The Netherlands) on 3rd-4th February 2014.

This event was organised by University Campus Bio-Medico of Rome and Deltares.

Figure 1: Venue of the Master Class, Deltares Headquarters

2.2 Program

The program of the Training course was based on the design of the general training course, as described in D9.1 CIPRNet training Plan [chapter 2.2]. The first day was devoted to introduce basic concepts about S&A (Simulation and Analysis) of CI while the second day was focussed on the federated simulation and the use of the Open Modelling Interface (OpenMI).

During the second day, participants have been allowed to visit the large technological hall at the Deltares premises, which represents a relevant research facilities for water-related technologies at Deltares.

A detailed programme with short CV of all the authors is reported in Appendix A, while in Appendix B all the material used for the different lessons has been collected.

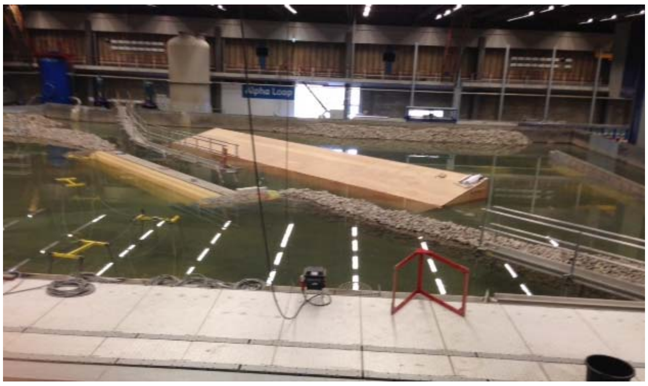

Figure 2: Tour at the research facilities, Deltares Headquarters

2.3 Attendees

The training course was attended by 24 participants from Italy, Germany, France, Portugal, and the Netherlands. In most cases, the attendees work at the partner institutes of the CIPRNet project, as Staff scientists or as Advisors. Figure 3 shows the percentage presence of partners that attended to the Training School. Notice that people from 9 out of 11 Consortium partners were present to the Training School (Acris and UBC have not specific obligations to attend to the training activities).

The list of all the attendees is reported in Appendix C. All the attendees received a "Certificate of Attendance" whose template is reported in Appendix D.

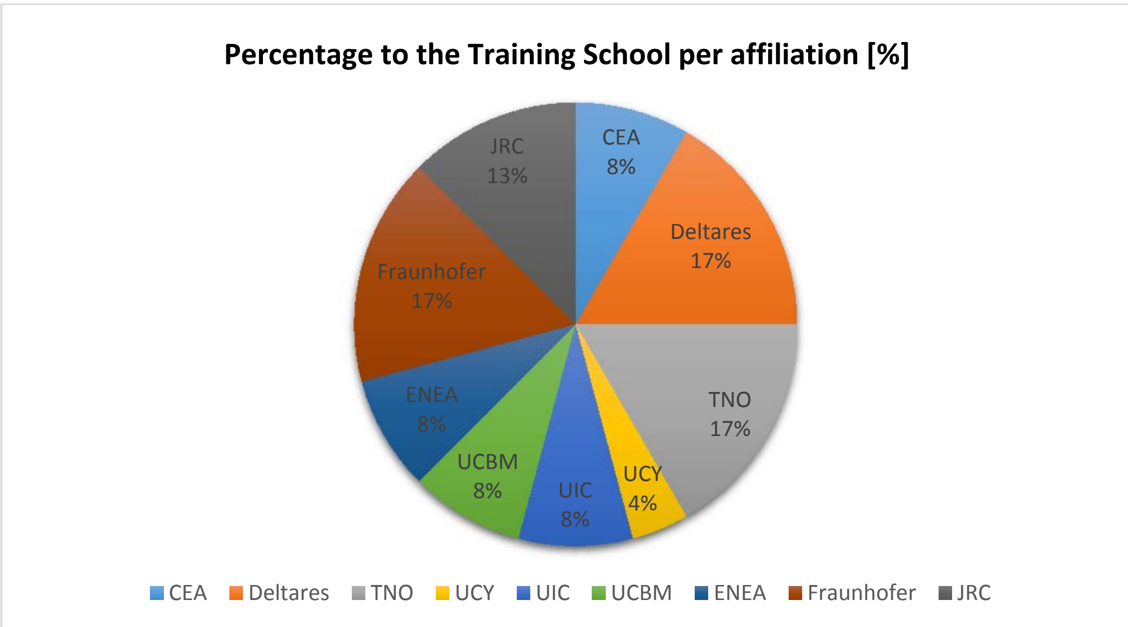

Figure 3: Presence of partners that attended to the Training School as a function of their provenience

Figure 4: Group of participants

Figure 5: Classroom and Audience view impressions

2.4 Feedback

The effectiveness and the quality of the training have been evaluated on the basis of the feed-backs received from the attendees. To this end, a specific Customer Satisfaction Form (CSF) has been elaborated and submitted to all the attendees.

On the basis of the 13 collected CSF, it emerged that the Training School provided to attendees a wide overview on critical infrastructure research.

The most positive aspects reported by attendees were the opportunity to interact with experts in the field and the acquisition of directions regarding some of the software tools that can be used.

The Training School has made possible to adjust the order in which lectures follow each other and to regulate duration of each lecture following a logical sequence, for the following edition.

In several cases valuable suggestions have been received from the audience: thanks to the exchange of opinions between audience and speakers, a standardization of the terminology among the speeches has been achieved, allowing a better lexical coherence among the presentations.

The feedback from the audience has been very positive, showing a proactive interest of the participants to actively contributing to the lectures quality, attitude which has allowed the improvement of lectures clarity in their academic and technological aspects.

Finally, from the collected CSF has emerged that the Training School has covered the expectation of the audience, for almost all participants, in terms of time scheduling, logistic facilities and contents. In the chart in Figure 6 a histogram, where bars height represents a satisfaction value between 0 and 5, is reported.

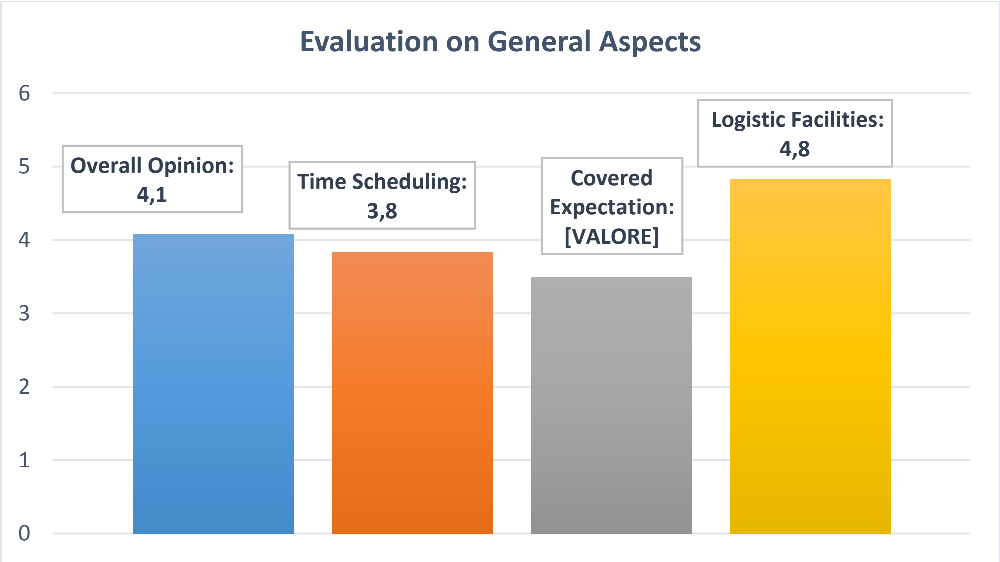

Figure 6: Data collected from customer satisfaction forms

This is valuable information that is used to improve the training material, scheduling, organization and focus for the following editions.

Notice that in the CSF is foreseen that, as well as the previous analysed general comments, each attendee has to provide feedbacks for any specific lesson. These specific comments have been addressed to the related speaker, in order to improve the effectiveness of each lecture.

Detailed general comments provided by attendees have been collected and reported in Appendix E.

2.5 Comments

The Edition 0 of the CIPRNet Master Class proved to be a very useful instrument for preparing a high-quality Master Class training event for a broad audience. Sharing material and information was necessary to gain a clearer picture about the best overall structure and specific scope of all presentations and exercises. It was also a very valuable event for all participants in terms of broadening their own expertise: everyone could learn from the knowledge and experience of all project partners.

Appendix A – Book of Abstracts

CIPRNet

Critical Infrastructure Preparedness and Resilience Research Network

WP9: TRAINING

Training event Edition 0

BOOK OF ABSTRACTS

Revision: Version 1
Date: 29th January 2014

Università Campus Bio-Medico di Roma (UCBM)

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Contributor(s)	

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1 Detailed program

1.1 Day 1 - 3rd February 2014

Introduction to Modelling and Simulation of systems (E0-D1-M1) **Teacher: Mohamed Eid (CEA)**	**9.00 – 10.40**
TOPICS: • What simulation of complex systems means • Qualitative and quantitative representation of phenomena • Model and mathematical models • Complex systems and emergent properties • Critical Infrastructure as a System-of-Systems	
ABSTRACT: Illustration of the concept of model and peculiarities of mathematical models. Analytical vs. simulation solutions of a model. Introduction to peculiarities of systems composed by several and interacting components. Representation of Critical Infrastructures as collection of heterogeneous interacting components.	

Dependencies and interdependencies (E0-D1-M2) **Teacher: Roberto Setola (UCBM)**	**11:00 - 11:50**
TOPICS: • Dependency phenomena • Taxonomy of dependencies • Model of (inter)dependencies	
ABSTRACT: Introduction to the concept of (inter)dependency and their classification. Elements to qualify and quantify dependencies. How to model some of the most common dependency phenomena.	

Holistic modelling (E0-D1-M3) **Teacher: Roberto Setola (UCBM)**	**11:50 - 12:40**
TOPICS: • Qualitative and semi-quantitative approaches • Criticality Matrix	

- Input-Output Inoperability Model

ABSTRACT:

Description of some of the most diffused holistic models illustrating their pros and cons (limits). Specific attention will be given to approaches based on criticality matrix and IIM (Input Output Inoperability Model).

Topological properties of complex networks and their relevance in functional and vulnerability assessments of Critical Infrastructures (E0-D1-M4) **Teacher: Vittorio Rosato (ENEA)**	**13:30 - 14:20**

TOPICS:

- Networks and their topological properties
- Dynamical assessment of functional properties based on static (topological) properties
- Case studies: roads and traffic dynamics, topological properties of electrical networks and their impact on power flow dynamics

ABSTRACT:

The lecture is aimed at introducing graph theory and methods for the analysis of complex system's dynamics in the area of Critical Infrastructures (CI).

Many CI grows in an unsupervised way, as much as living systems, under the effect of a selective pressure able to drive those systems to assume structures allowing to fulfil robustness and functionality criteria at the same time. It will be shown that these criteria could be met when the networks representing CI assume specific topological shapes.

As there is an intimate relation between topological structure and functioning in CI networks, it will be shown how, in many cases, the evaluation of topological properties of complex networks provides correct insight on the properties of their functioning.

Specific cases will be analyzed by using graph theory and system's dynamical models: for road networks and traffic, for electrical and telecommunication networks, also in view of the adoptions of those methods in the design of tools for the analysis and the simulation of CI for their protection against natural and anthropic hazards.

Geomatics as a basic technique to describe interacting scenarios between natural and technological systems (E0-D1-M5) **Teacher: Maurizio Pollino (ENEA)**	**14:20 - 15:10**

TOPICS:

- Geomatics basics: Introduction to Geographical Information Systems (GIS); Geodesy and Map Projections; Data formats and concepts; DBMS and GIS; GPS.
- Basic functions provided by a GIS system: Spatial data analysis (Geoprocessing, Overlay, Buffering, etc.); Thematic mapping

- Examples of applications of integration of GIS and computational modules in a complex application: impact and consequence analysis of structures and infrastructures upon an earthquake

ABSTRACT:

The GIS structure as a basic technique to describe interacting scenarios between natural and technological systems

Introduction to Federated Simulation **(E0-D2-M1a)** **Teacher: Wim Huiskamp (TNO)**	**15:30 - 16:20**

TOPICS:

- Federated Simulations
- Architectures and Standards

ABSTRACT:

Introduction to the simulation of complex system using the "federated" approach, i.e. allowing a set of simulators, each tailored to analyse a specific phenomena or component/infrastructure, to share data in order to simulate complex scenarios where those elements have to interact each other.

Modelling and Simulation Techniques for Critical Infrastructure Protection **(E0-D2-M1b)** **Teacher: Andrij Usov (Fraunhofer)**	**16:20 - 17:10**

TOPICS:

- Role of simulation for critical infrastructure protection
- Integrated (I2Sim) vs. federated modelling and simulation approaches
- Scenario-oriented federation design and DIESIS architecture

ABSTRACT:

This presentation focuses on scenario- and purpose-driven design of federated simulation systems in the area of critical infrastructure protection. We start with a brief comparison between integrated and federated modelling and simulation approaches. Then, practical challenges related to design and implementation of large heterogeneous simulation systems will be discussed. Finally, we handle some essential concepts of the DIESIS architectural approach and interoperability middleware that allow to overcome the aforementioned challenges.

1.2 Day 2 - 4th February 2014

Verification and Validation (E0-D1-M6) **Teacher: Jeroen Voogd (TNO)**	**8:30 - 9:20**

TOPICS:

- What are Verification and Validation (V&V)
- How to approach V&V
- Overview of main V&V techniques
- Techniques for V&V of CI models

ABSTRACT:

After a brief introduction to Verification and Validation, an approach to organizing the V&V activities is presented that leads to the choice of which V&V techniques to employ. An overview of the main V&V techniques is presented with a discussion on which of these can be applied in V&V of CI models.

Simulations of CI - relevant examples (E0-D1-M7) **Teacher: Marieke Klaver (TNO), Eric (H.A.M.) Luiijf (TNO)**	**9:20 - 10:10**

TOPICS:

- Overview of the most relevant projects and results of MS&A of CI
- NISAC (US Sandia Lab)
- CIPRSim modelling and simulation framework (US INL)
- CIPMA's CI MS&A activities (Australia)
- DIESIS framework
- I2Sim platform
- CISIA platform

ABSTRACT:

Overview of the most interesting international activities in MS&A of Critical Infrastructures.

Introduction to OpenMI (E0-D2-M2) **Teacher: Andreas Burzel (Deltares)**	**10:30 - 10:55**

TOPICS:

- Coupling flow simulation models
- What is OpenMI?
- Example application cases
- Application range

ABSTRACT:

Open Modelling Interface (OpenMI) is an standard interface that allows time-dependent models to exchange data at run-time. When the standard is implemented, existing models can be run simultaneously and share information at each time step making model integration feasible at the operational level.

Hands-on training: my first OpenMI composition (E0-D2-M3) **Teacher: Bernhard Becker (Deltares)**	**11:00 - 12:40**

TOPICS:

- The OpenMI configuration editor
- Working with omi-files
- Setting up an OpenMI composition
- Coupling mechanisms
- External coupling one-directional
- Bi-directional coupling
- Iterative coupling
- Analysing the results

ABSTRACT:

In the hands-on workshop, the participants configure the OpenMI input files to set up a composition consisting of a hydraulic model and a model for human operations (real-time control). Students follow the data exchange mechanism in the simulation results and learn the added value of the model coupling.

OpenMI behind the scenes: how to migrate my own code to OpenMI compliance (E0-D2-M4) **Teacher: Bernhard Becker (Deltares)**	**13:30 - 14:00**

TOPICS:

- How to organise the code
- Basic OpenMI functions
- Wrapping native code

ABSTRACT:

Within this lecture, the participants learn which steps need to be taken in order to make an existing simulation programme OpenMI compliant.

Training session (E0-D2-M5) **Teacher: Andreas Burzel (Deltares)**	**14:00 - 15:40**

TOPICS: Examples of OpenMi applications
ABSTRACT: Various projects and cases where OpenMI has been applied illustrate the added value of model coupling. Participants learn how different processes were coupled and the application range of different coupling techniques.

2 List of teachers

Andreas Burzel Deltares (The Netherlands) 	2003 – 2009: Studies 'Infrastructure and Environment', Bauhaus-University Weimar, Germany 2009 – 2012: Research Associate at the Department Hydromechanics and Coastal Engineering, Leichtweiss-Institute, Technische Universität Braunschweig, Germany: Joint Research Project XtremRisK – Integrated Risk Analysis for Extreme Storm Surges 2013 – present: Researcher at Deltares, Department Water Risk Analysis, Delft, The Netherlands: Research on Integrated Flood Risk and Spatial Modelling andreas.burzel@deltares.nl

Roberto Setola University Campus Bio-Medico of Rome (Italy) 	Mr. Setola has held university level courses since 1996 and is currently Director of the Second Level Master in Homeland Security at UCBM. He has been the supervisor of four PhD students and more than 100 MS and BA thesis projects. He has authored 3 textbooks on Modelling and Simulation and more than 100 scientific papers r.setola@unicampus.it http://www.coseritylab.it/People.html

Vittorio Rosato

Italian National Agency for New Technologies, Energy and Sustainable Economic Development (Italy)

Vittorio Rosato received the Laurea degree in Physics from the University of Pisa (1979) and a Ph.D. in Physics from the University of Nancy (1986). He is currently Head of the ENEA Laboratory of Technological and Computing Infrastructure, President of the Industrial Spin-Off Commission of ENEA. He acts as supervisor and project evaluator for the Italian Ministry of University and Research, and that of Economic Development and in the Scientific Boards of several Italian Regions. He is also the project's referee for the European Union. He has been Coordinator of several national projects and responsible of ENEA's activity in several EU-funded projects. He is co-founder of the Ylichron Srl company. He is author of more than 100 scientific papers on peer reviewed journals; he acts as referee for high-IF journals (Physical Review and Physical Review Letters, Europhysics Letters etc.).

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Maurizio Pollino

Italian National Agency for New Technologies, Energy and Sustainable Economic Development (Italy)

Civil Engineer. PhD in Agroforestry and Environmental Engineering. From 2000 Staff Scientist at ENEA. From 2003 to 2008, Adjunct Professor of "Geographical Information Systems" (University of Rome "Sapienza"). Main interests in Remote Sensing and GIS applications to environmental studies and analyses (Land monitoring and planning, Spatial analysis, Risk Assessment, Decision Support Systems). Author of several scientific publications and contribution to conferences. Referee of international journals. Member of Programme Committee of ICCSA, GEOG-AN-MOD, CTP and GEOProcessing international Conferences.

http://utmea.enea.it/people/pollino/index.php

Jeroen Voogd

Netherlands Organisation for Applied Scientific Research, The Hague (The Netherlands)

Jeroen Voogd is a member of the scientific staff in the Defence, Security and Safety Division at TNO. He holds a Ph.D. (1998) in Computational Physics from the University of Amsterdam in the field of modelling and simulating of biophysical systems on parallel and distributed computing platforms. A recurring theme in his work of the last years is the quality of simulations. This includes Verification and Validation of simulator assets, as well as quality assurance within TNO. He is also one of the Technical Representatives of Q-tility: an organisation specialized in verification and validation solutions for models, simulations and serious-games.

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Marieke Klaver

Netherlands Organisation for Applied Scientific Research,The Hague (The Netherlands)

Marieke Klaver PhD studied Mathematics at the University of Leiden. After her PhD in 1990, she joined TNO. Since 1997, Marieke takes part in TNO's R&D efforts in the area of Critical (Information) Infrastructure Protection (C(I)IP). She contributed to several studies on CIP for the Dutch government, like the vulnerability of the Internet (KWINT) and the Quick-scan on Dutch CI. As project manager and senior scientist she has been involved in many CIP studies (ACIP, VITA, CI2RCO, IRRIIS, EURAM, EURACOM, DIESIS), and was project manager of the EU DH Home study RECIPE – Good Practices for CIP Policy-makers. She is also managing the R&D programme on Cyber Security and Infrastructures, commissioned by the Dutch Ministry of Security and Justice.

marieke.klaver@tno.nl

Eric Luiijf Netherlands Organisation for Applied Scientific Research,The Hague (The Netherlands) 	Eric Luiijf MSc(Eng) obtained his master's degree in mathematics (informatics thesis) at the Technical University Delft in 1975. After his duties as officer in the Royal Netherlands Navy, he joined TNO. In 1995, Eric became Principal Consultant Information Operations and Critical Infrastructure Protection. Since 2001, he is TNO's R&D leader in a sequence of Dutch national Critical (Information) Infrastructure Protection (C(I)IP) studies, e.g. looking after the vulnerability of the Internet (KWINT) and the Quickscan on Dutch CI. Eric has been work package leader and core team board member in the EU projects ACIP, CI2RCO, IRRIIS, DIESIS, and participated in EURACOM, EURAM, and RECIPE projects. Eric maintains a unique international database on CI disruptions and cascading effects. Eric has published many scientific and popular papers on CIP and cyber security. eric.luiijf@tno.nl

Bernhard Becker Deltares (The Netherlands) 	Bernhard Becker studied civil engineering at RWTH Aachen University in Germany. At the RWTH Institute of Hydraulic Engineering and Water Resources Management he worked in research projects of groundwater modeling, risk assessment of reservoir dams and fish-friendly turbine operations in runoff-river hydropower plants. For his PhD thesis entitled "On the coupled numerical modeling of subsurface floods" he was awarded with the "Konrad-Keilhack-Preis für angewandte Wasserforschung". Currently Bernhard works at Deltares as reasearcher/consultant. He is involved in the development of Deltares open source flow simulation package Sobek, and is the product manager of the real-time control toolbox RTC-Tools. One focus of his project work at Deltares is numerical modeling and model coupling with OpenMI. Bernhard published several papers in international and national journals and on conferences. bernhard.becker@deltares.nl

Mohamed Eid Atomic Energy and Alternative Energies Commission, Paris, (France) 	Mohamed Eid is a Senior Expert in the French Commissariat of Atomic Energy (CEA) and an Associated Professor in the National Institute of Applied Science (INSA) of Rouen. His research and teaching activities cover fields such as: Probabilistic Risk Analysis, System Reliability and Safety, Monte-Carlo simulation, Multi-States System Reliability, Systems Dependency and Interdependency. He is the author of some 50 scientific papers in the field of systems safety, reliability and stochastic modelling. mohamed.eid@cea.fr

Wim Huiskamp TNO, Netherlands Organisation for Applied Scientific Research, The Hague (The Netherlands) 	Wim Huiskamp is Chief Scientist Modelling & Simulation and Gaming at TNO. The main focus of his research has been on distributed simulation architectures (DIS-Distributed Interactive Simulation (IEEE1278) and HLA - High Level Architecture (IEEE1516)). The applications of M&S included army and airforce related training- and analysis studies. A substantial amount of these activities was related to international research projects in the M&S domain. He has been Program Manager of the Live, Virtual and Constructive Simulation research program (2008-2012) and leads the current M&S research program carried out on behalf of Dutch MoD. Wim is a member of NATO Modelling and Simulation Group (NMSG) and has served as Chairman of the NATO Modelling & Simulation Standards Subgroup (MS3) and was elected NMSG chairman in Spring 2013. wim.huiskamp@tno.nl

Andrij Usov

Fraunhofer Institute for Intelligent Analysis and Information Systems (IAIS), Sankt Augustin, Germany

Andrij Usov received a diploma in Computer Science from the University of Dortmund In 2006 (main focus in simulation and modelling). After working one year at PTV AG he joined the Fraunhofer IAIS as a researcher in the department ART. Since 2007 he was involved in various conception, development and coordination activities in the EU-Projects IRRIIS, DESIRE, DIESIS and EMILI as well as in a project related to the German Armed Forces.

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Appendix B – Training Material

FROM RESEARCH TO INDUSTRY

WP9: EDITION_0

MODELLING, SIMULATION AND ANALYSIS OF CRITICAL INFRASTRUCTURE TRAINING SCHOOL

Introduction to MS&A of CIP

Delft, Netherlands, 03/02/2014

www.cea.fr

THE ISSUE

Understanding the behaviour of critical infrastructures, their dependences and their interdependences.

Through the development and the use of advanced modeling and simulation technologies

In order to increase their robustness and resilience against threats

DEPENDENCE & INTERDEPENDENCE

- Physical/Structural
- Functional
- Procedure

MODELING: 1.CONCEPTUAL MODELS

- Fluid Mechanics: Navier-Stockes Equation
- Heat Transfer: Newton Equation
- Electro-magnetic propagation: Maxwell Equations
- Electrical Circuits: Kirchhoff's Law
- Structure Dynamic: (Multi-degree) Equation of motion / Lagrange's Equation
- Neutron transports: Boltzmann Equation

MODELING: 2.EMPIRICAL & STATISTICAL MODELS

- Rains Flow & Distribution
- Wind Velocity & Direction Distribution
- Loss of Pressure in Pipes (in case of turbulent flow)
- Radiative Heat Transfer (Stefan’s Law)
- Traffic & Road Accidents
- Components & Systems Failures
- Detection & Monitoring Failures

MODELING: 3.LOGICAL/RELATIONAL MODELS

- Event “C” occurs if Events “A” AND/OR “B” occur (Boolean Algebra): minimal cut-sets, critical paths and disjoint cut-sets
- Event “E” occurs if Events “A” AND “B” AND “C” occur in that order: sequence analyses
- Fault Trees/Dynamic Fault Trees
- Event trees
- Decision Trees
- Reliability Block Diagrams
- Graphs (networks, states & transitions)

SIMULATION

- ***The easy job :*** is to describe the behavior (in space and time) of any system whose functioning involves any of the previous models
- ***The hard job :*** is to describe the behavior (in space and time) of any system whose functioning involves many of the previous models at different places and at different time (multi-scale, multi-physics, varying relational)
- ***the hardest :*** is to describe the behavior (in space and time) of any system whose functioning involves any of the previous models, mixing deterministic and probabilistic models

System Complexity

SIMULATION OF COMPLEX SYSTEMS

- Needs for Integration Tools
- Integration at different levels of models: Data level, application interface level, method level, and the user interface level
- Stochastic Integration Tools: Monte-Carlo Simulation, Petri-Net & Stochastic Petri-Net, Genetic Algorithms, …
- Smart Agents: active, proactive and social

RECALL THE ISSUE

Understanding the behaviour of critical infrastructures, their dependences and their interdependences.

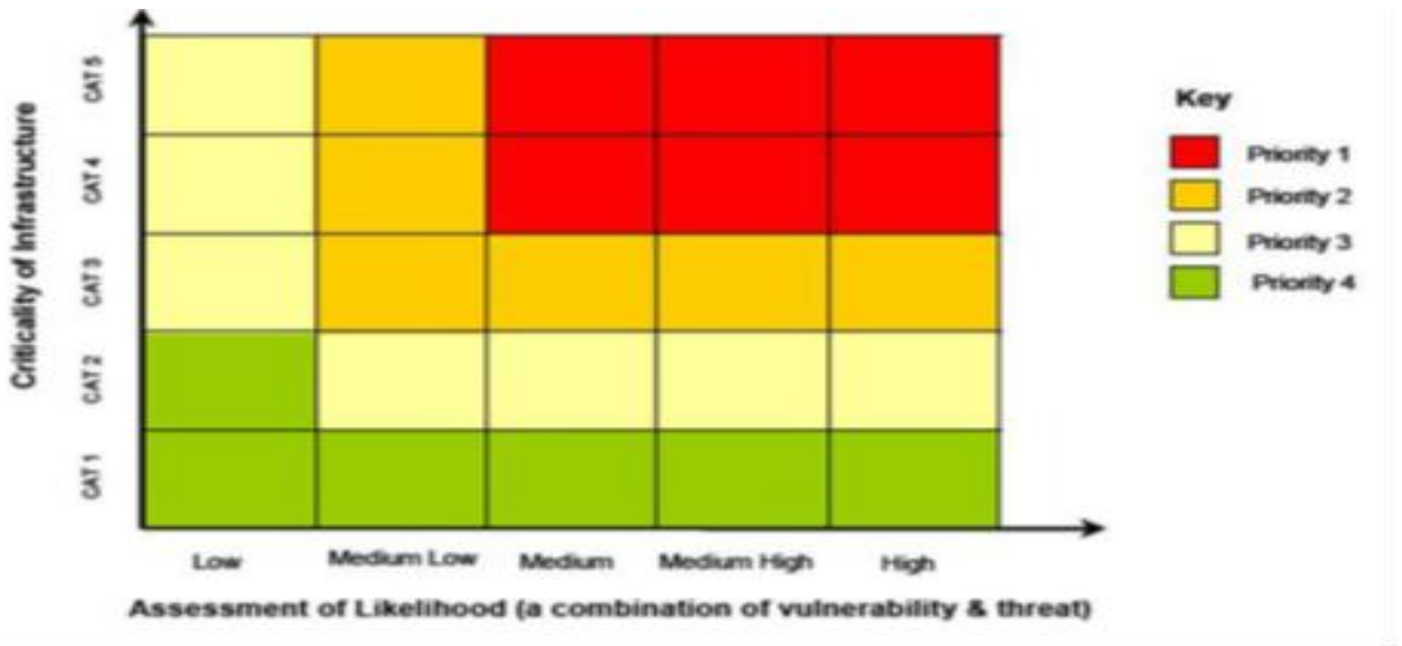
Through the development and the use of advanced modeling and simulation technologies

In order to increase their robustness and resilience against threats

ROBUSTNESS & RESILIENCE (1)

- Qualitative Modelling? [Sir Michael Pitt, "A comprehensive review of the lessons to be learned from the summer floods of 2007". Final report, June 2008.]

{In his report, Sir Michael Pitt, defined resilience "Resilience is the ability of a system or organisation to withstand and recover from adversity."}



ROBUSTNESS & RESILIENCE (2)

- Quantitative Modelling? [*to be developed*!!!]

Robustness $\propto \Delta 1$

Resilience $\propto 1/\Delta 2$

???

CIP VS RISK MANAGEMENT

The 3RG Focal Report, [*], argues that there are three main conceptualizations of the risk-resilience relationship in the theoretical literature and in CIP-policy documents: resilience as the goal of risk management, resilience as part of risk management and resilience as alternative to risk management.

* *3RG Report Focal Report 7 SKI, "Focal Report 7: CIP Resilience and Risk Management in Critical Infrastructure Protection Policy: Exploring the Relationship and Comparing its Use." Risk and Resilience Research Group Center for Security Studies (CSS), ETH ZürichZurich, Commissioned by the Federal Office for Civil Protection (FOCP), December 2011*

Resilience Oriented Risk Management

Resilience would be described as the overarching goal of protection policies and risk management as the method to achieve this goal. *Resilience replaces or complements the concept of protection,* which was previously defined as the goal of risk management activities.

CIP VS RISK MANAGEMENT: RESILIENCE IS PART OF RISK MANAGEMENT

Comprehensive Resilience Risk Mangement

Resilience is understood as a part of risk management. Activities to strengthen resilience are needed in order to deal with the so-called “remaining risks”, i.e. risks that have not been identified or underestimated and are thus not covered by appropriate protection (preventive) measures.

But a systematic resilience approach is still to be developed and it seems as if it can’t be deterministic, probabilistic, ..

Alternative to Risk Management

Challenges the traditional methods of risk management and promotes resilience as a new way of dealing *with* risks in a complex environment. It is argued that a probabilistic risk analysis is not an adequate approach for socio-economic systems that are confronted with non-linear and dynamic risks and are themselves characterized by a high degree of complexity. Instead of preventing risks and protecting the status quo, such systems should enhance their resilience by increasing their adaptive capacities.

BUT AGAIN, WHAT IS RESILIENCE?

Since resilience is defined as the ability to resist, absorb, recover or adapt to adversity of changes in conditions, it is obvious that the concept is related to risk management – as the concepts “adversity” and “changes in conditions” can be described as risks.*

* *UK Cabinet Office, “Strategic Framework and Policy Statement on Improving the Resilience of Critical Infrastructure to Disruption from Natural Hazards”. Publication date: March 2010.*

REMIND OUR ULTIME GOAL

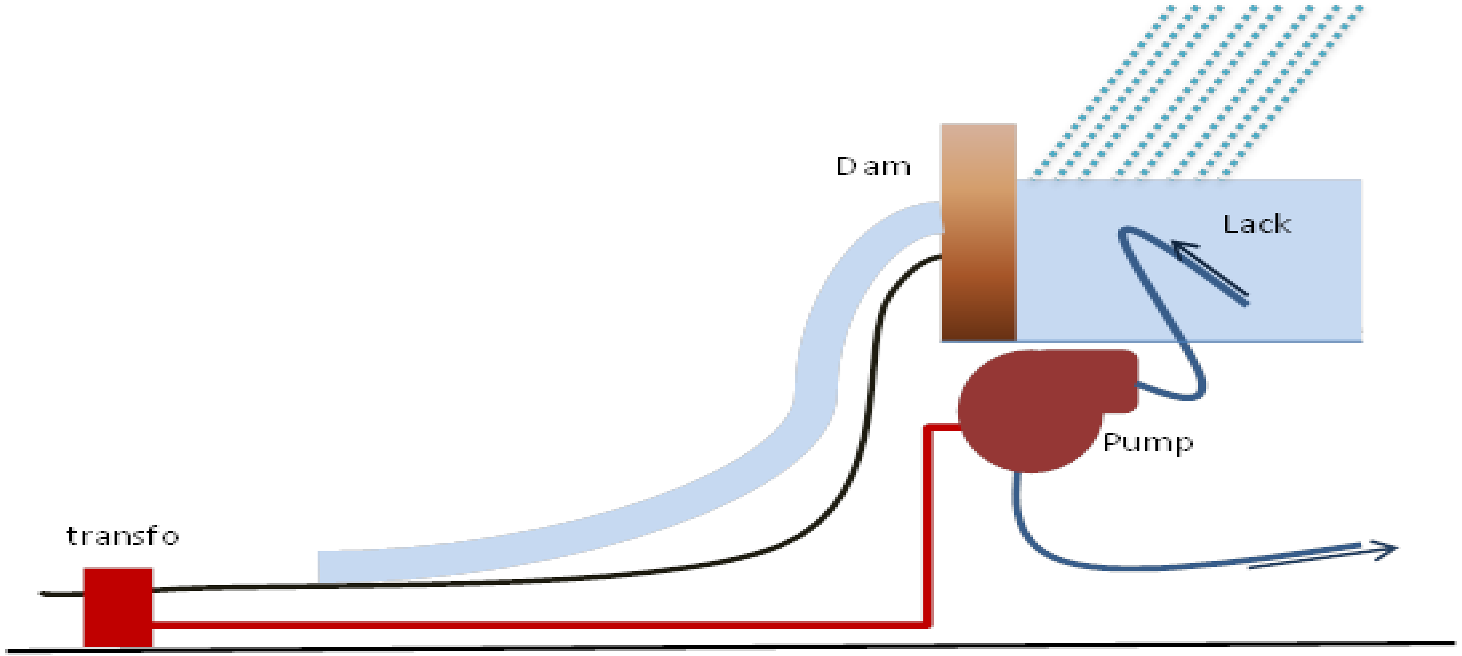
The main goal is

- to identify and assess risks associated to a well-defined threat

And to develop a range of options to;

- eliminate,
- reduce,
- transfer,
- accept or
- share those risks.

PRACTICALLY SPEAKING: A HYPOTHETICAL CASE



A hypothetical scenario of a crisis

THE THREAT & INVOLVED EVENTS

- E1 : Heavy rains (the quantity and the duration are beyond the design limits).
  Probabilistic Model
- E2 : Static head increasing rate (faster than the design limit).
  Deterministic Model
- E3 : Aged structure (material resistance with high uncertainties)
  Semi-Deterministic Model
- E4 : Un Emergency Pumping Station (EPS) pumps the excess water into a temporary retain lake. *Probabilistic Model*
- E4 : The EPS is equipped d'un feedback control loop system
  Probabilistic Model
- E5 : The EPS is electrically powered by a special underground Electricity Transmission Line (ETL) coming from the valley.
  Probabilistic Model

HOW TO SIMULATE THIS CRISIS IN VIEW OF DECISION MAKING?

The issue now is:

- To integrate all the models describing; threat, the systems, the control systems and the interdependence
- To simulate the evolution of the crisis in the time (dynamic)
- To iterate the simulation to better identify the worst paths the crisis evolution may take (what if?)
- To assess the decisions to be made in order to: intercept the threat, reduce, mitigate, accept or share the corresponding Risks

Dependencies and interdependencies

Roberto Setola (UCBM)
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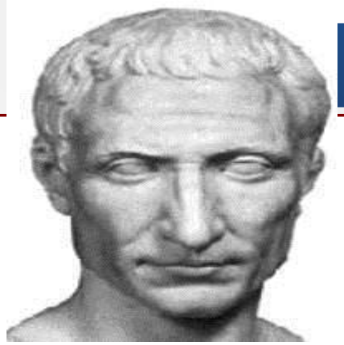
Modelling, Simulation and Analysis of Critical Infrastructure Training School (Edition 0)

Deltares Headquarters – Delft (The Netherlands) – 3-4 February 2014

Integration vs Dependability

…. for a lot of GOOD reasons

divide et impera



Social | Economical | Technological | Political

Integration

Many actors with clashing interests

No geographical contiguity

Interdependencies | **Domino effect** | **Global threats**

Same episodes

1998 – Galaxy IV (USA)

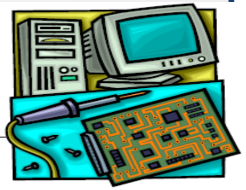
Source

Failure in a communication satellite

Consequences

- 40 millions pagers out-of-services
- 20 United Airline flights delayed
- Many radio stations unable to operate
- Congestion at high-way gas stations: due to impossibility to process credit card

2000 – Maroochy Shire (Australia)



Source

An ex-employer used a wireless Internet connection to penetrate into SCADA of sewage treatment plant

Consequences

- 47 "abnormal" accidents in January-April 2000
- 1.200.000 liters of raw sewage dispersed in the environment
- Potable water compromised in the area

2004 – Italy

Source

an incident in the air conditioned system of an important telco nodes in Rome

Consequences

- Blackout in mobile and wired communication for about 6 h in Roma
- About 5.000 banks and 3.000 post offices off-line
- 70% check-in desks at Fiumicino airport off-line
- ACEA (local electrical distributor) lost the control on half of the network (near miss)

2006 - Europe

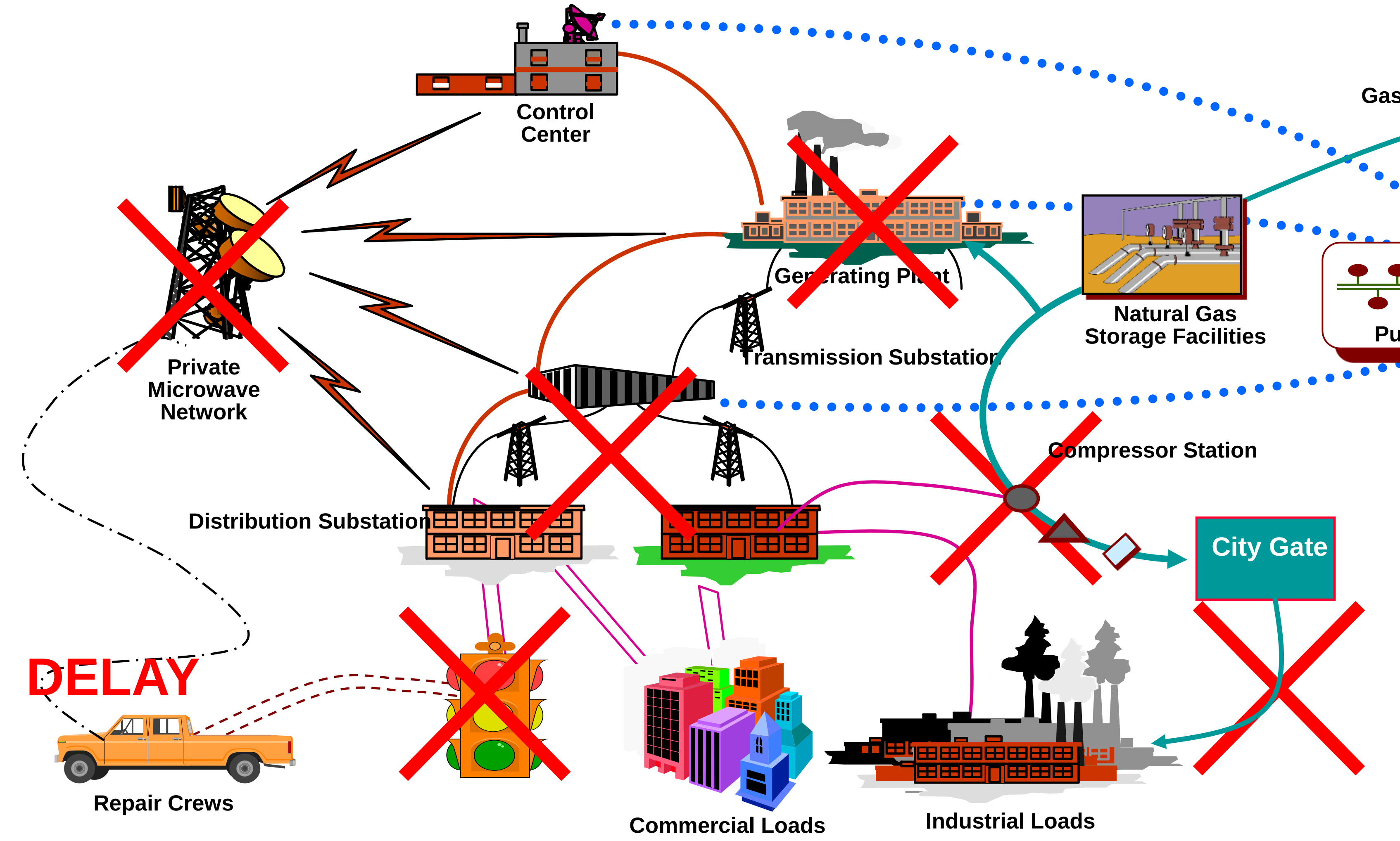
380kV lines across river Ems turned off at 21:30h to let the Norwegian Pearl through

A large number of lines in Germany, Austria, Hungary and Croatia automatically tripped one after the other in a "domino" effect, as their automated protection systems detected load flows over the safety limit

15 million households affected in 11 countries

Power restored in 30 minutes in some places, 2 hours in Italy

Example of Interdependencies



Types of failures:

- *Cascading*
- *Escalating*
- *Feedback*

Source

Office of Critical Infrastructure Protection

Italy black-out 2003 September 28th

Due a «problematic» configuration of the Italian grid, a problem in Switzerland, a misunderstanding between Italian and Switzerland TNO operators….

In a rapid sequences the two 400kV lines with France tripped and in 4s GRTN lost the control of the Italina grid

56 million people affected for up 9 hours

(Inter)-dependencies

Dependency vs interdependency

Dependency: is the capability of an infrastructure to influence the state of an other infrastructure. It is a *unidirectional* relationship.

Interdependency: is a *bidirectional* relationship between two infrastructures through which the state of each infrastructure is influenced or is correlated to the state of the other.

Notice that in literature, with an abuse of notation the term "Interdependency" is used with a broad meaning absorbing in part the "dependency" meaning

Dependency definiton (2)

A depend on B when an event able to reduce the operational capability of B is able to reduce the operational capability of A

In other terms dependency is a differential (or better detrimental) property. The degree of dependency is related to the detrimental variation induced in the dependent element

$$A \underset{\mu_A^T;\mu_B^T}{\Leftarrow} B \text{ if } \Delta x_A(t) = \varphi_A\left(t, t_0, T, x_A^0, x_B^0, \Delta x_B^o\right) > 0$$

R. Setola, “How to Measure the Degree of Interdependencies among Critical Infrastructures”, *Int. J. of System of Systems Engineering, (IJSSE)*, vol. 2,pp. 38 -59, 2010

First and high order dependency

When the dependency of infrastructure **A** on **B** is "mediated" by a third infrastructure **C**, i.e. an event in **B** influence the operational capability of **C** that consequently influence those of **A**, we say that **A** depend on **B** via a **second order dependency**.

The concept can be easily generalized to the **h-th order dependency**

When the sequence of influences create a **loop**, e.g. **A** > **B** > **C** > **A** then ALL the involved infrastructure are inter-dependent. Consequently any event that affect each infrastructure in the loop is spread and **exacerbated**

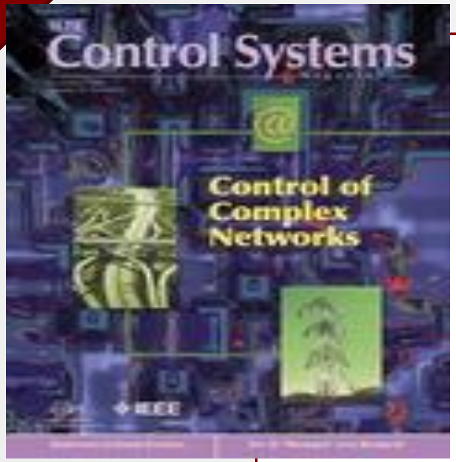
From **tree** (i.e. there is a root and the consequences go only downstairs to) a **graph** structure (the consequences has no more a preferential direction)

Planned vs Induced dependency

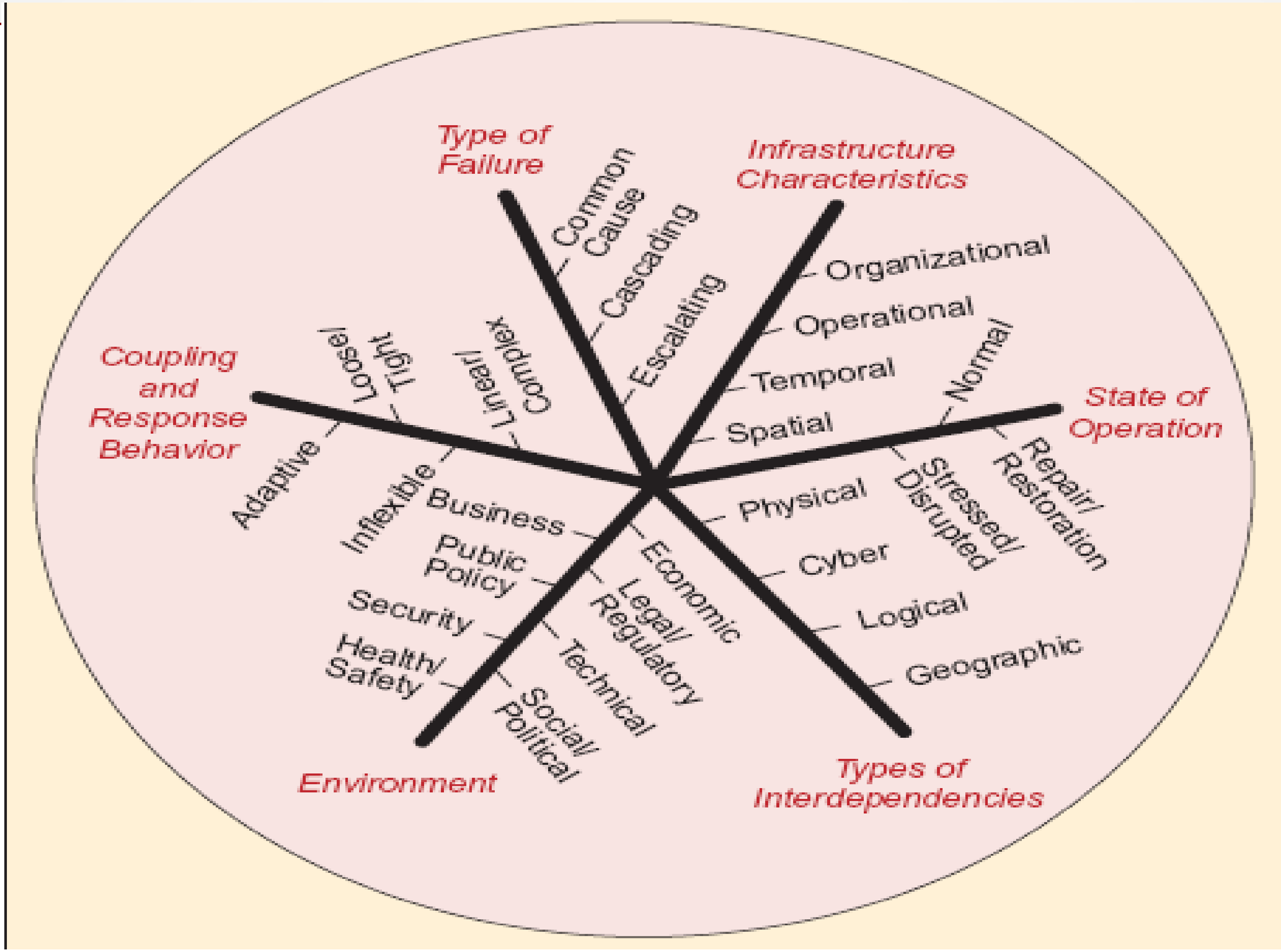
Planned: the dependency has been introduced at design stage (i.e it is "functional" to the prescribed goal) and it is well known and well documented

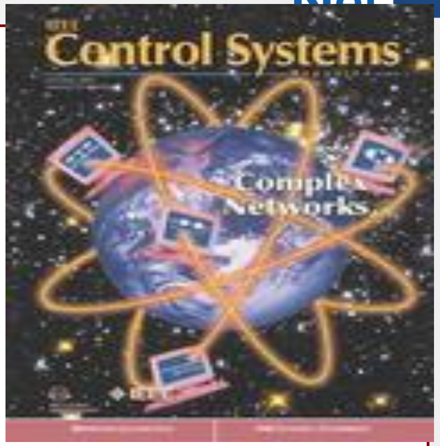
Induced: the dependency "*emerges*" due to modification of the environment (generally it is not present/evident in normal operation condition). It is generally not well documented, not perceived by the operators or even unknown

Dimensions for describing infrastructure interdependencies



September 2011

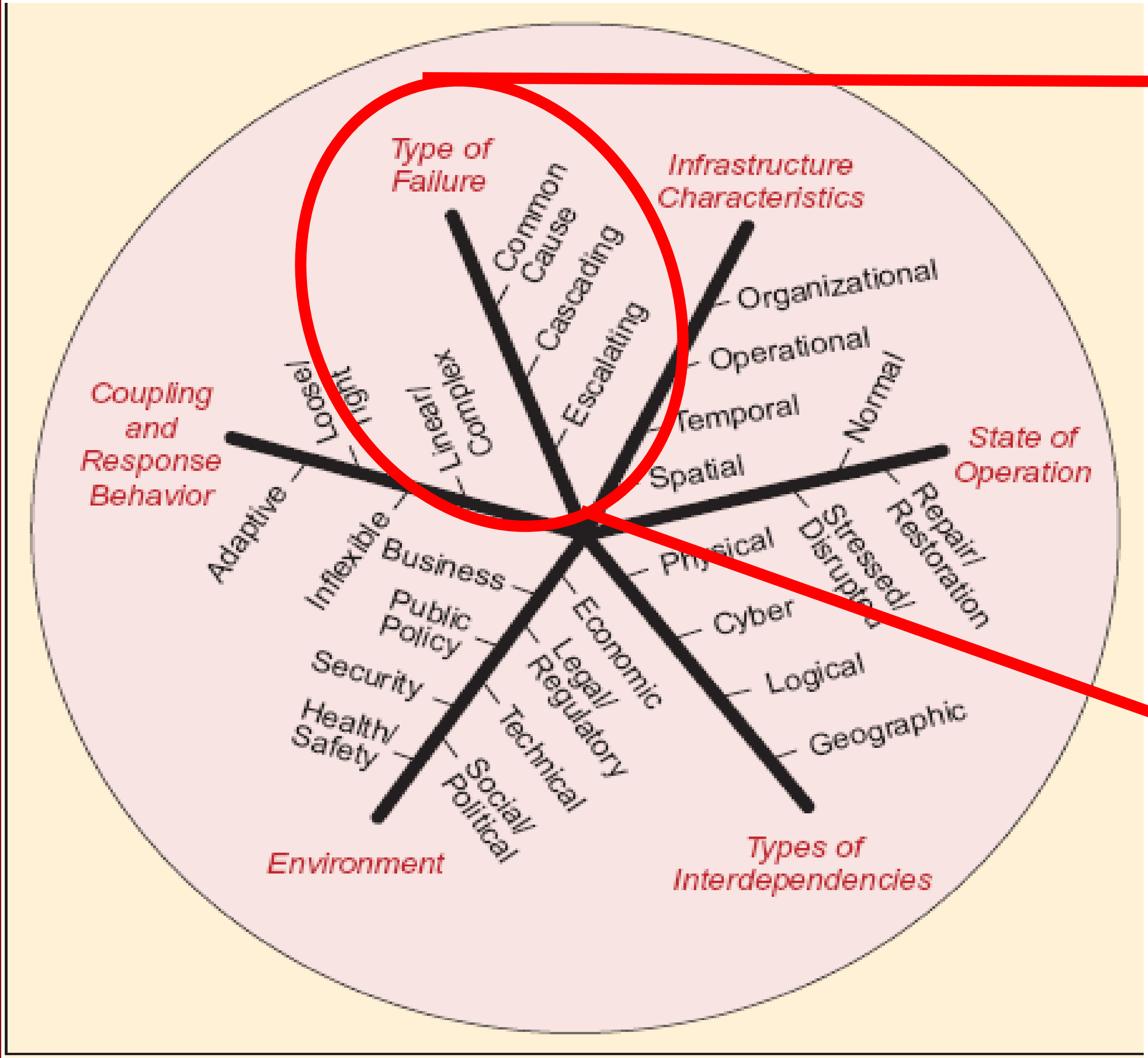




January 2012

S. Rinaldi, J. Peerenboom, and T. Kelly, "Identifying Understanding and Analyzing Critical Infrastructure Interdependencies," *IEEE Control System Magazine*, pp. 11–25, 2001.

Type of failure

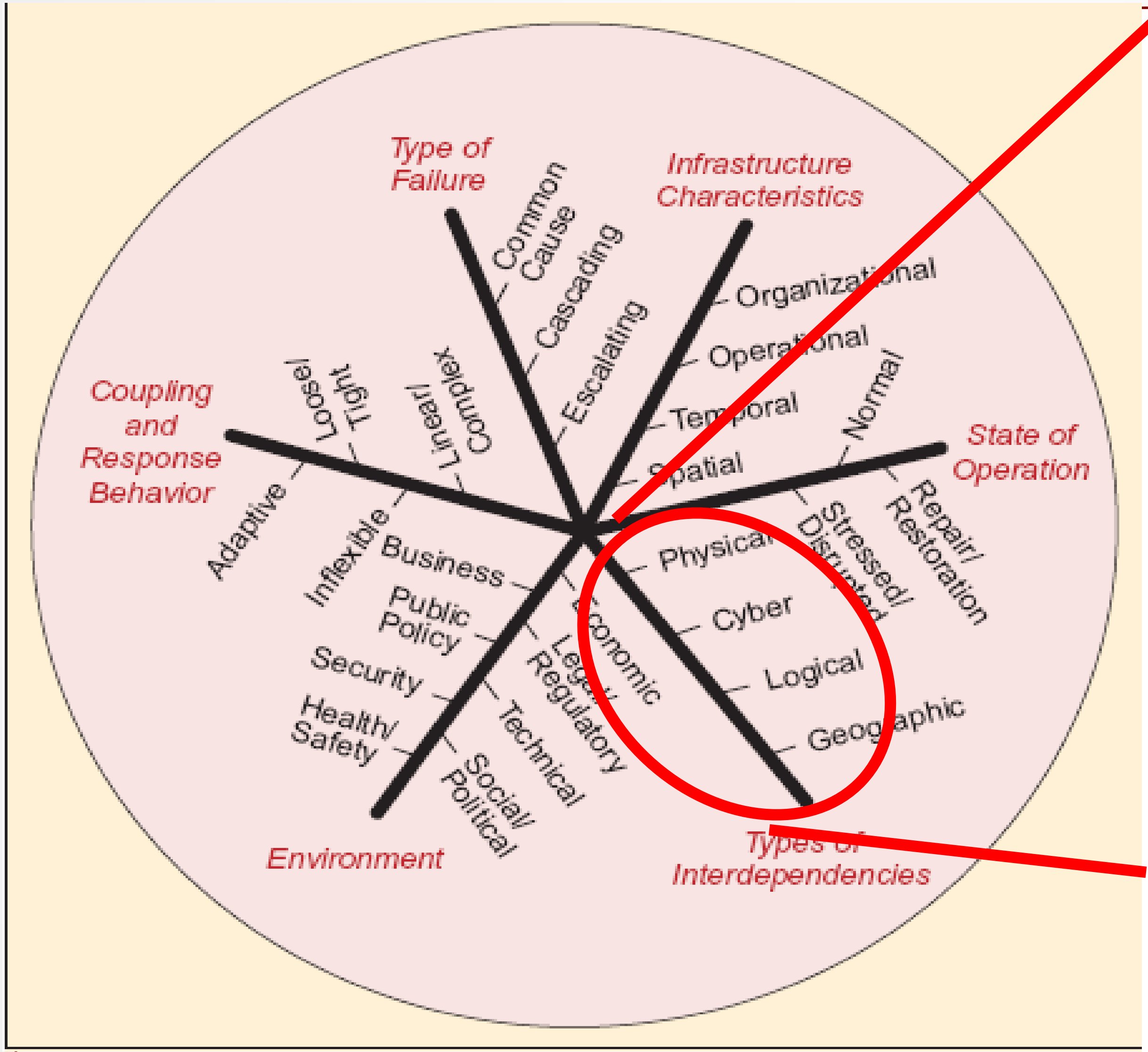


Common cause: the same event produce failure in two or more infrastructures.

Cascading: the failure into one infrastructure induce a domino effect on other infrastructures.

Escalating: the failure of one infrastructure exacerbate the consequences of failure induced by some other causes.

Dimensions for describing infrastructure interdependencies



***Physical** Interd.*: if the operations of one infrastructure depends on the physical output(s) of the other.

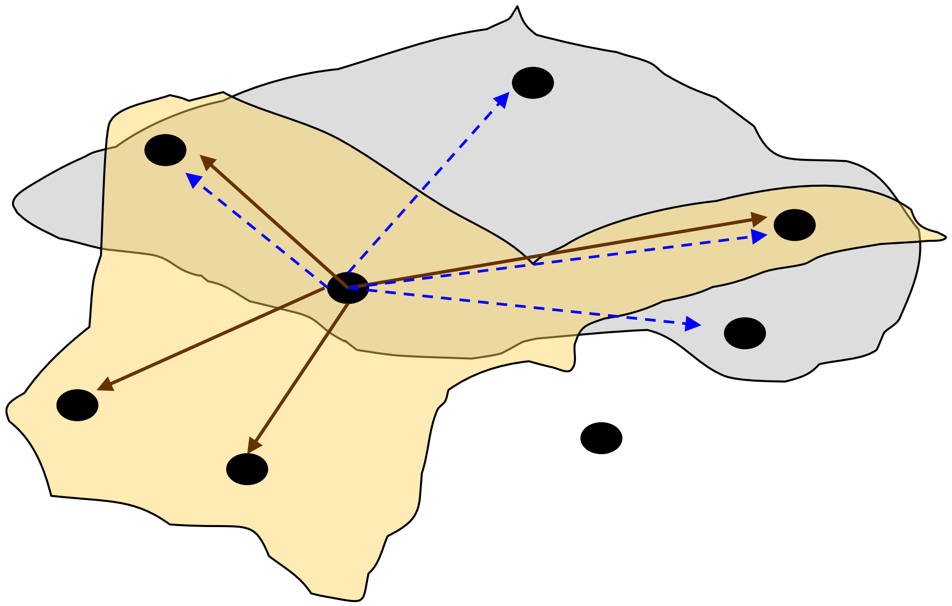
***Cyber** Interd.*: if its state depends on information transmitted via cyberspace.

***Geographical** Interd.*: when elements are in close spatial proximity.

***Logical** Interd*.: any other causes (e.g. regulamentatory)

***Sociologic** Interd*.: when coupling effects are mediated by (irrational) human behaviors

Several "concept" of proximity



Geographyc proximity .
Cyber proximity.

An entity has different set of neighbors identified on the base of the dependency mechanism.

Hence a given phenomena/failure propagates along common/different pathways

Consequently specific action may contrast the propagation of some phenomena (but be ineffective for others)

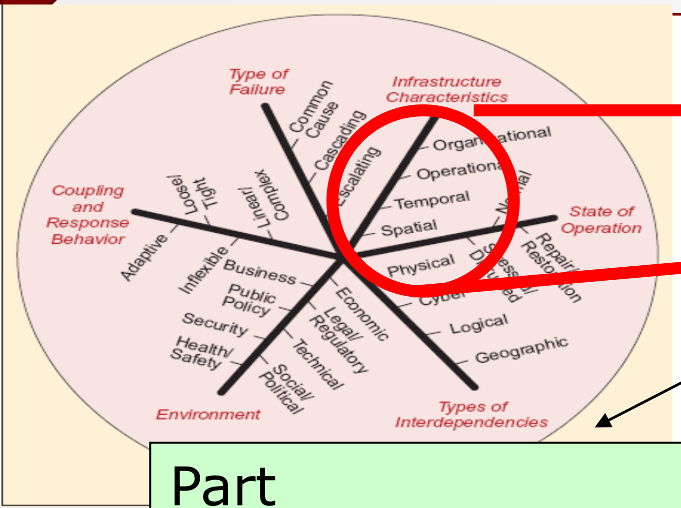
Notice that absence of service or failure can spread

Functional vs Failure dependency

Functional: the dependency is related to the absence (or degraded) outputs generated by an infrastructure (component) which affects the capability of the dependent infrastructure (component) to perform its intended function

Failure: the dependency induced by the spreading of failure or its consequences (e.g. explosion, fire, etc.) which affects the "neigbours" elements.

Infrastructure Characteristics



Spatial	Temporal	Operational	Organizational

- Part
- Unit
- Subsystem
- System
- Infrastructure
- Interd. Infrastr.

Interdependency are more relevant as scope increase

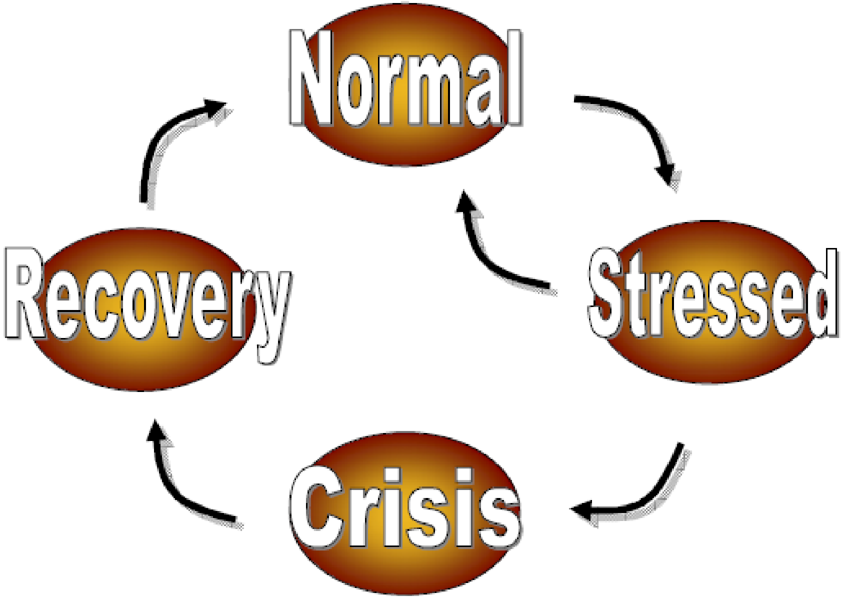
Relevant time scales vary from milliseconds to hours to years

The importance of each type of interdependency change w.r.t. time horizon

Operational conditions

The "effectiveness" of a dependency phenomena depends largely on the operational conditions of the dependent infrastructure:

- Normal
- Stressed
  - *Maintenance*
- Crisis
- Recovery



Notice that moving from "Normal" to "Stressed" can be induced by planned operation, operators decision or forced by some external (environments) situation

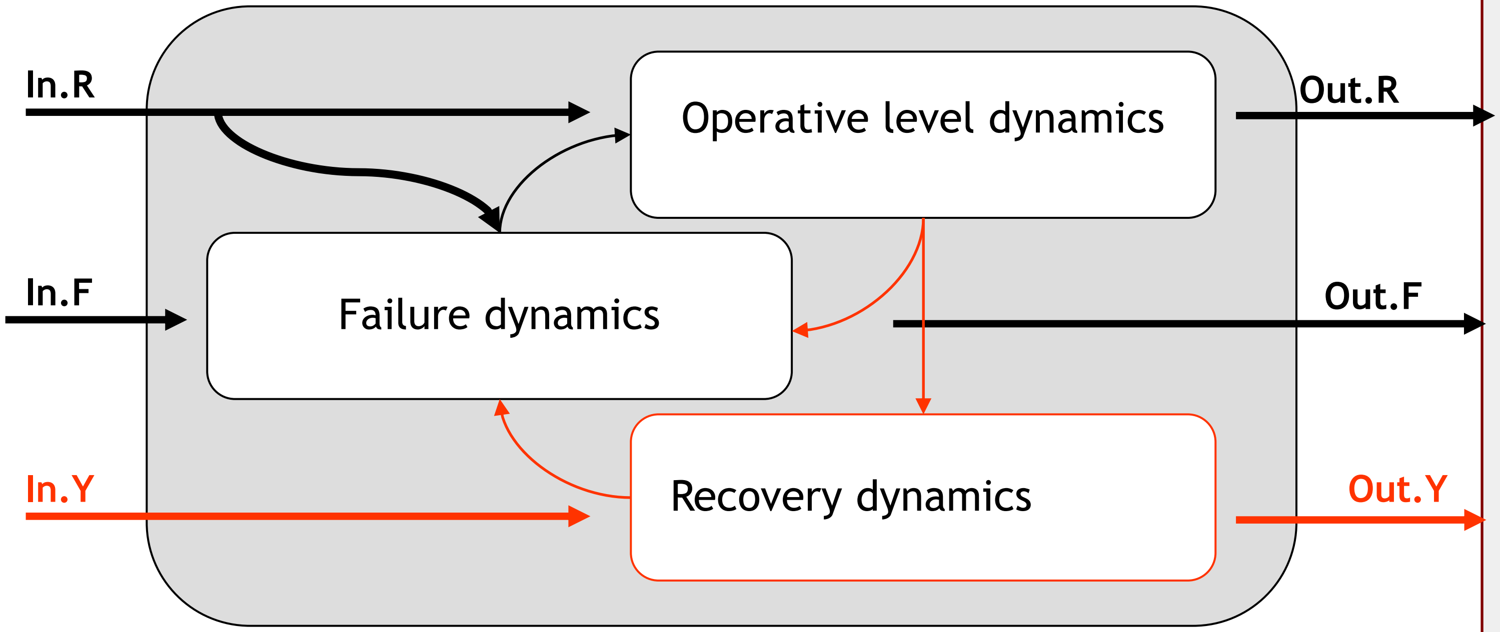
CISIA model with recovery dynamics

Inputs

- *Resources*
- *Faults*
- *Recovery*

Outputs

- *Resources*
- *Faults*
- *Recovery*



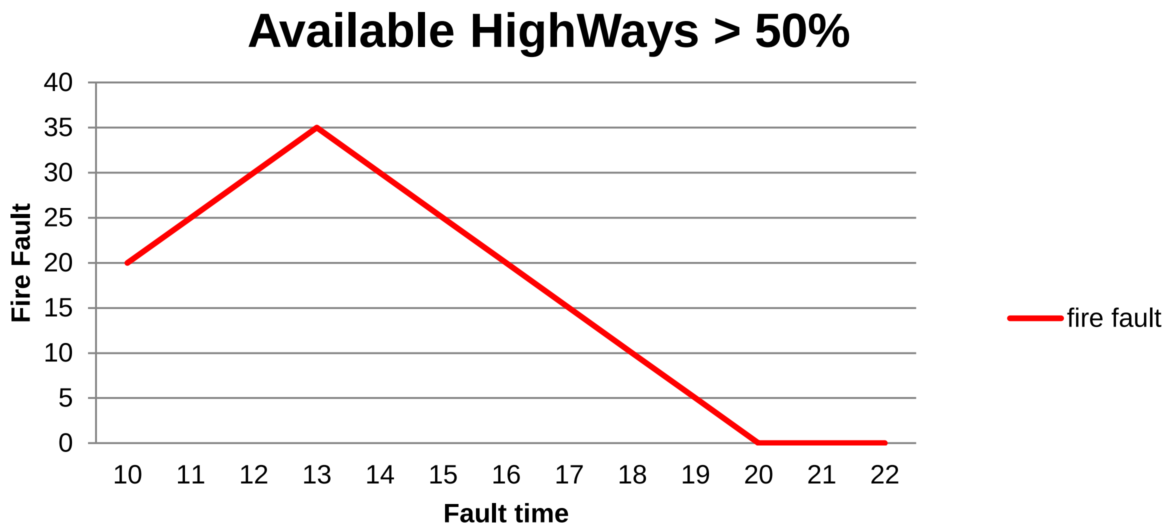
Failure dynamics may be damped or inverted through the influence of recovery dynamics. Recovery actions can have both endogenous or exogenous nature

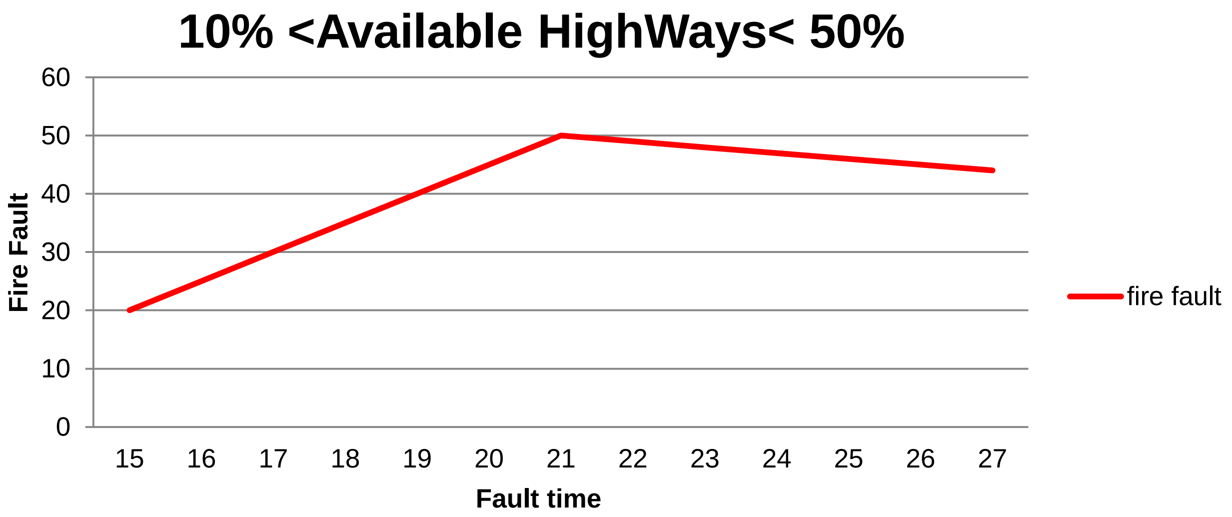
Recovery dynamics

Recovery at oil tank farm

Fire fault mitigation

Fire dousing at 13 minutes after the fire start. Every minute, its value will be reduced of 5%.





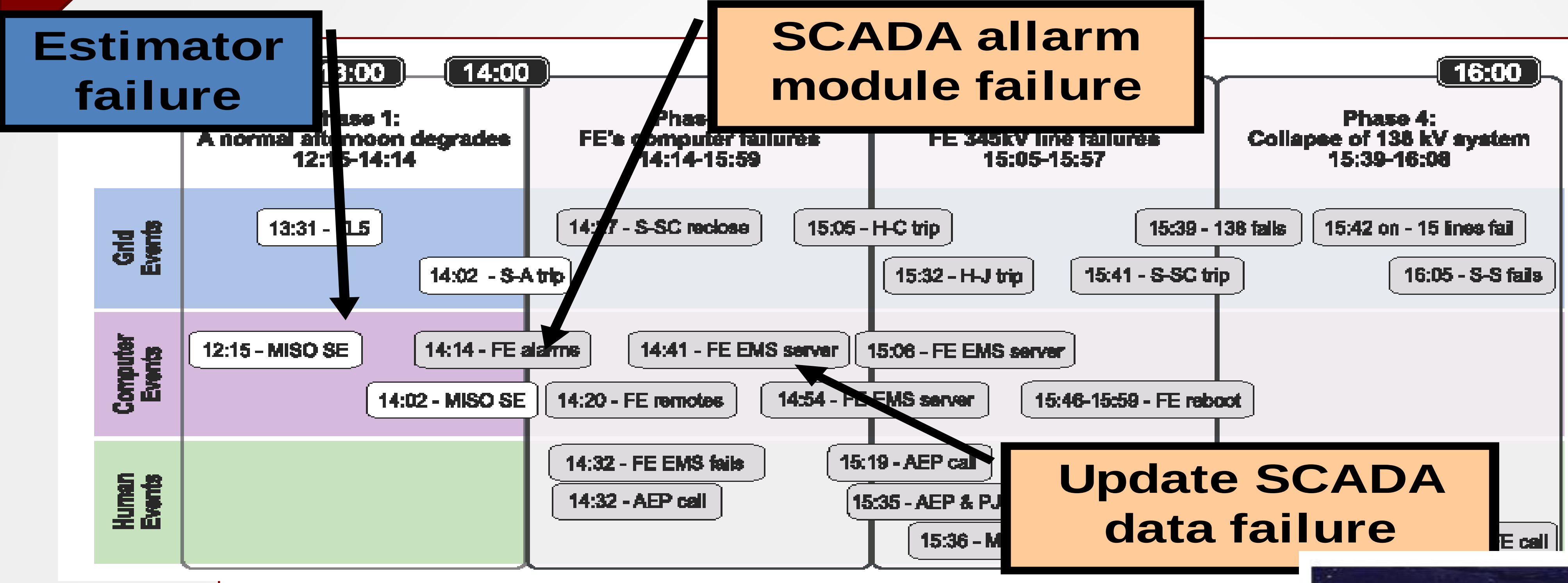
Fire dousing at 21 minutes after the fire start. Every minute, its value will be reduced of 1%.

Conditional Dependency

Infrastructure A *conditionally depends on the infrastructure B if, when the* condition *θ is true, an increment of the level of inoperability in the* infrastructure B induces an augment of the level of inoperability of Infrastructure A.

$$A \Leftarrow B\big|_{\theta} \;\; \text{if } \Delta x_A(t) = \varphi_A\left(t, t_0, T, x_A^0, x_B^0, \Delta x_B^o, \theta\right) > 0 \;\; \text{when } \theta \text{ is true}$$

2003 – US & Canada blackout



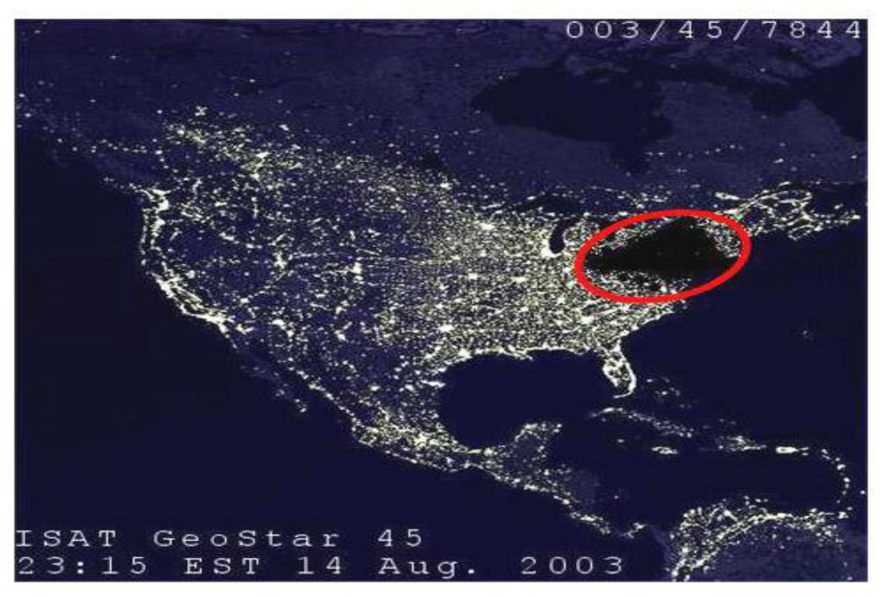
14 August 2003

loss of 61,800 MW of electric load

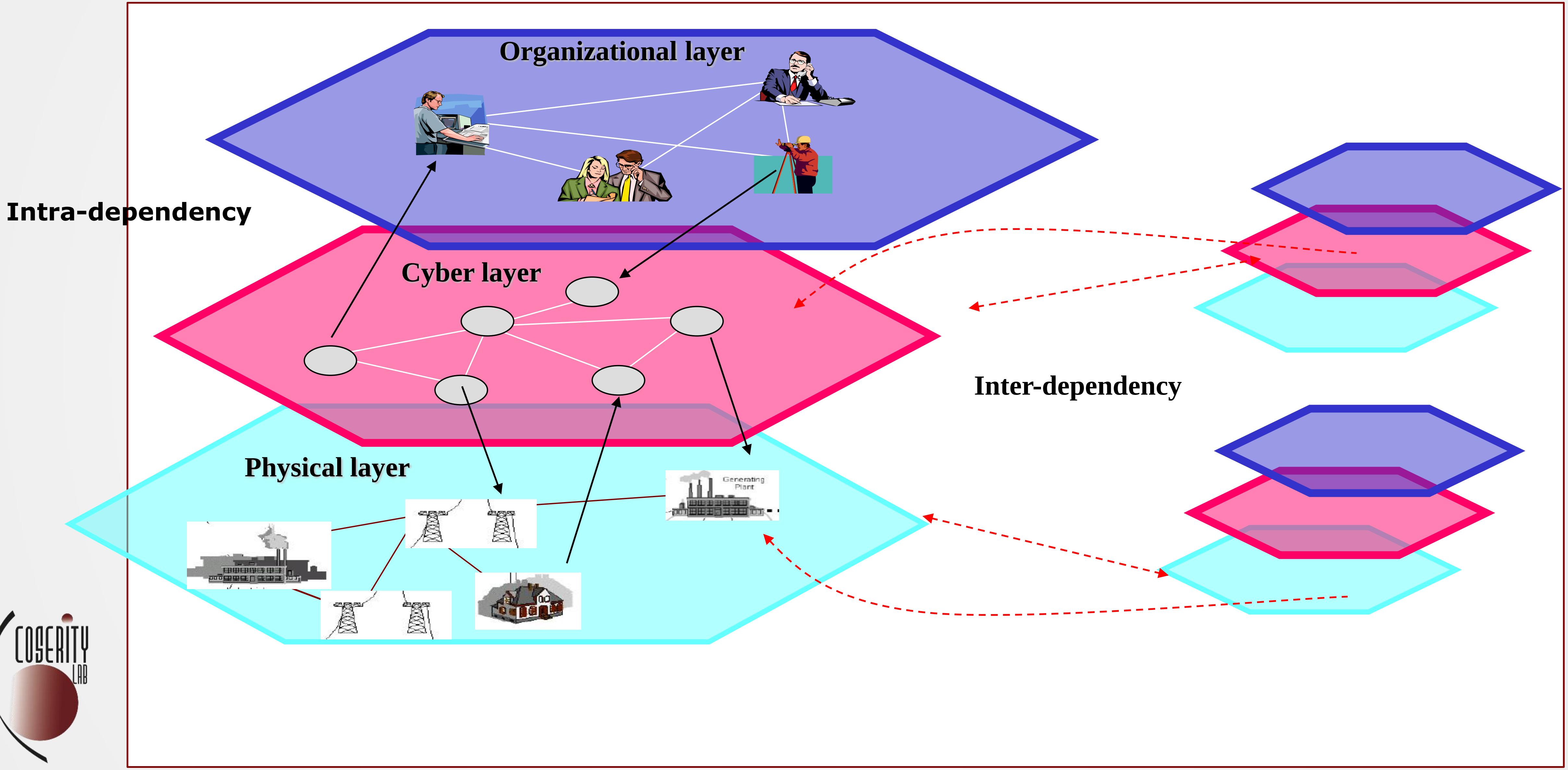
50 million people affected

Estimated cost: 4,5 B$ - 8.2 B$

https://reports.energy.gov/



Three Layer Model for e Critical Infrastructures



Other dependency taxonomy

Functional	The operation of one infrastructure system is necessary for the operation of another infrastructure system
Spatial	It refers to proximity between infrastructures systems

Zimmerman R., Social implications of infrastructure network interactions. Journal ofUrbanTechnology, 2001;8:97–119.

Physical	There are direct linkages between infrastructure systems from a supply/consumption/production relationship
Geospatial	There is co-location of infrastructure components within the same footprint
Policy	There is a binding of infrastructure components due to policy or high level decisions
Informational	There is a binding or reliance on information flow between infrastructure systems

Dudenhoeffer DD, Permann MR,Manic M., CIMS:a framework for infrastructure interdependency modeling and analysis. Proc. 2006 winter simulation conference, 2006,p.478–85.

Other dependency taxonomy (2)

Input	The infrastructure systems require as input one or more services from another infrastructure system in order to provide some other service
Mutual	At least one of the activities of each infrastructure system is dependent upon each of the other infrastructure systems
Shared	Some physical components or activities of the infrastructure systems used in providing the services are shared with one or more other infrastructure systems
Exclusive or (XOR)	Only one of two or more services can be provided by an infrastructure system, where XOR can occur within a single infrastructure system or among two or more systems
Co-located	Components of two or more systems are situated within a prescribed geographical region

Wallace WA, Mendonca DM,Lee EE, Mitchell JE, Chow Wallace JH, Managing disruptions to critical interdependent infrastructures in the context of the 2001 World Trade Center attack, 2003..

Functional	The functioning of one system requires inputs from another system, or can be substituted, to a certain extent, by the other system
Physical	Infrastructure systems are coupled through shared physical attributes, so that a strong linkage exists when infrastructure systems share flow right of way, leading to joint capacity constraints
Budgetary	Infrastructure systems involve some level of public financing, especially under a centrally-controlled economies or during disaster recovery
Market and Economic	Infrastructure systems interact with each other in the same economic system or serve the same end users who determine the final demand for each commodity/service subject to budget constraints, or are in the shared regulatory environment where the government agencies may control and impact the individual systems through policy, legislation or financial means such as taxation or investment

Zhang P, Peeta S., A generalized modeling framework to analyze interdependencies among infrastructure systems.Transportation Research part B: Methodological 2011;45(3):553–79.

Interdependency Metrics

How to measure dependency

A cornerstone question is how to measure the degree of (inter)dependency existing among any two infrastructure in order to qualify normal and pathological situation

Unfortunately very few (and partial) results exist on this topic based on:

- Influence coefficient (open and closed loop)
- Norm of transfer function

A more general approach is those to evaluate the degree of depency on a relative base, i.e. how much are amplified the negative consequences

$$I = \frac{f(coupled) - f(atomic)}{f(atomic)}$$

Dependency Measurement

The *dependency index is the ratio between the relative increments of the* inoperability in the depended infrastructure with respect to those experienced in the source Infrastructure

$$\delta_{A,B}^{T}\left(\Delta x_{B}^{o}\right)=\frac{\Delta x_{A}}{\Delta x_{B}^{o}}.$$

Complex Systems & Security Laboratory – www.coseritylab.it

Inter-Dependency Measurement

Internal interdependency index — *External interdependency index*

$$\delta^{I}_{A,B} = \frac{1}{T}\frac{\int_0^T \Delta x_B\left(\tau, \Delta x_B^o\right) d\tau}{\Delta x_B^o}$$

$$\delta^{E}_{A,B} = \frac{1}{T}\frac{\int_0^T \Delta x_A\left(\tau, \Delta x_B^o\right) d\tau}{\Delta x_B^o}$$

Internal interdependency index $\delta^{I}_{A,B}$ is the ratio between the injected augment of inoperability Δx_B^o and effective increment in the level of inoperability in the same infrastructure, i.e., $\Delta x_B(t)$.

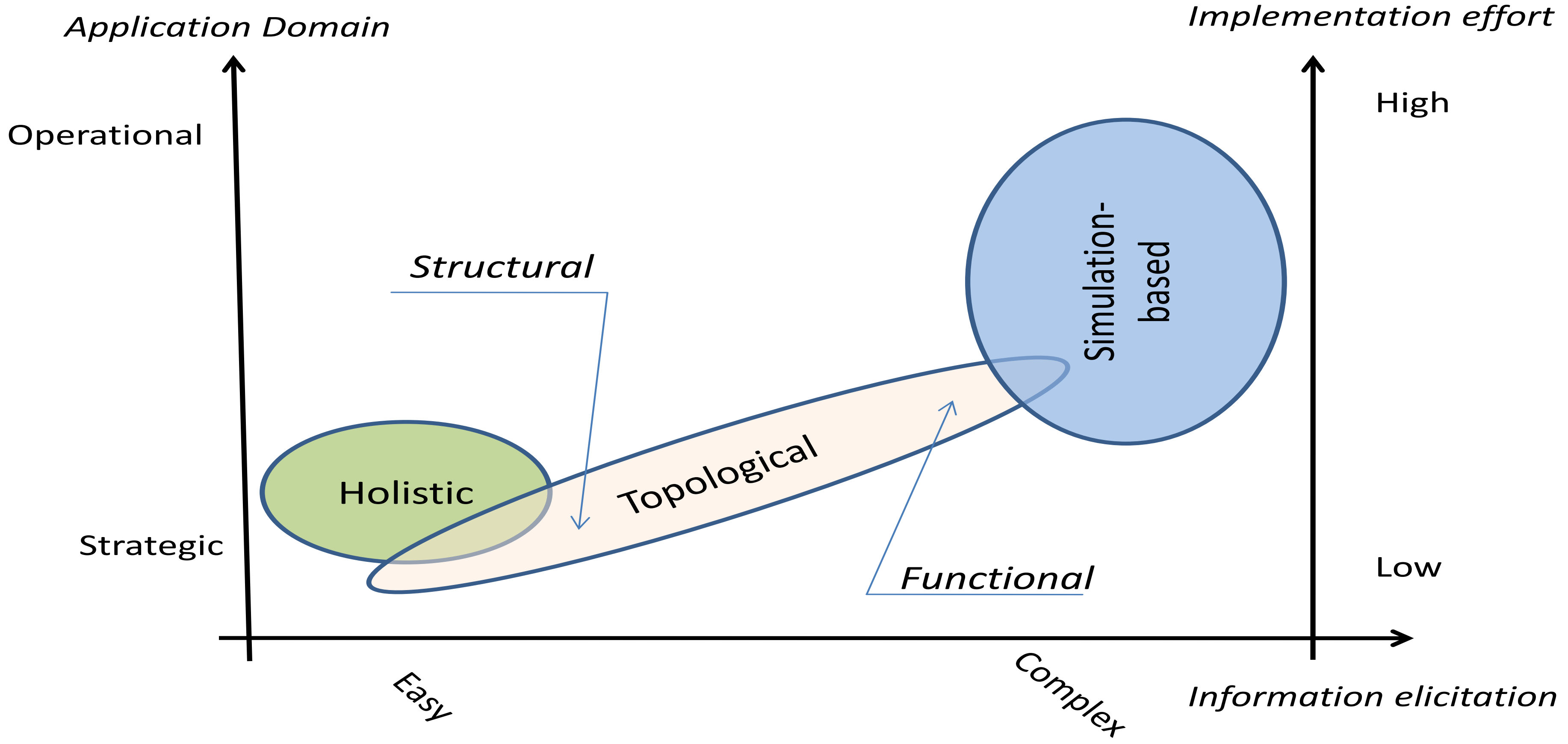
External interdependency index $\delta^{E}_{A,B}$ is the ratio between the injected augment of inoperability in infrastructure B (i.e., Δx_B^o) and increment in the level of inoperability experienced by infrastructure A (i.e., $\Delta x_A(t)$).

Complex Systems & Security Laboratory – www.coseritylab.it

Interdependencies modelling

Modelling classification

Holistic approaches	Topological based approaches	Simulation based approaches



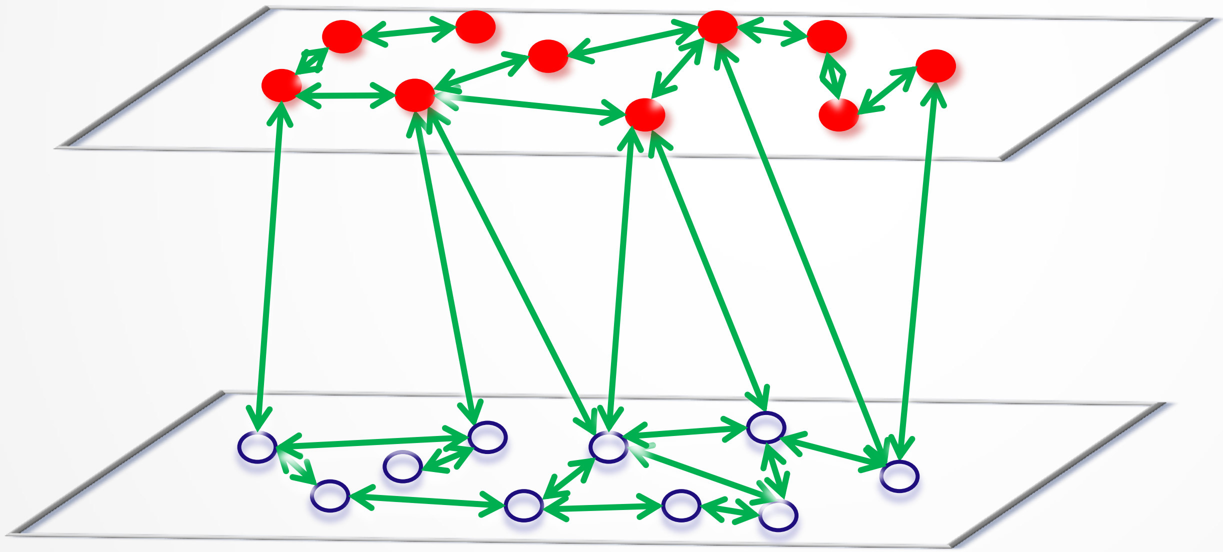
Holistic approaches

These approaches assume that each infrastructure can be modeled as a single entity, which depends on the availability of the services provided by the other infrastructure. They are largely infrastructure oriented.

These approaches assume, generally, economic or empirical data as source of information to infer dependencies and approaches generally operate with macro-scale aggregated information . This largely facilitates the set-up of the models.

They are not suitable for operative analysis.

Topological approaches



Topological based approaches

These approaches decomposes each infrastructure into a set of identical elements (nodes), while dependencies are the links.

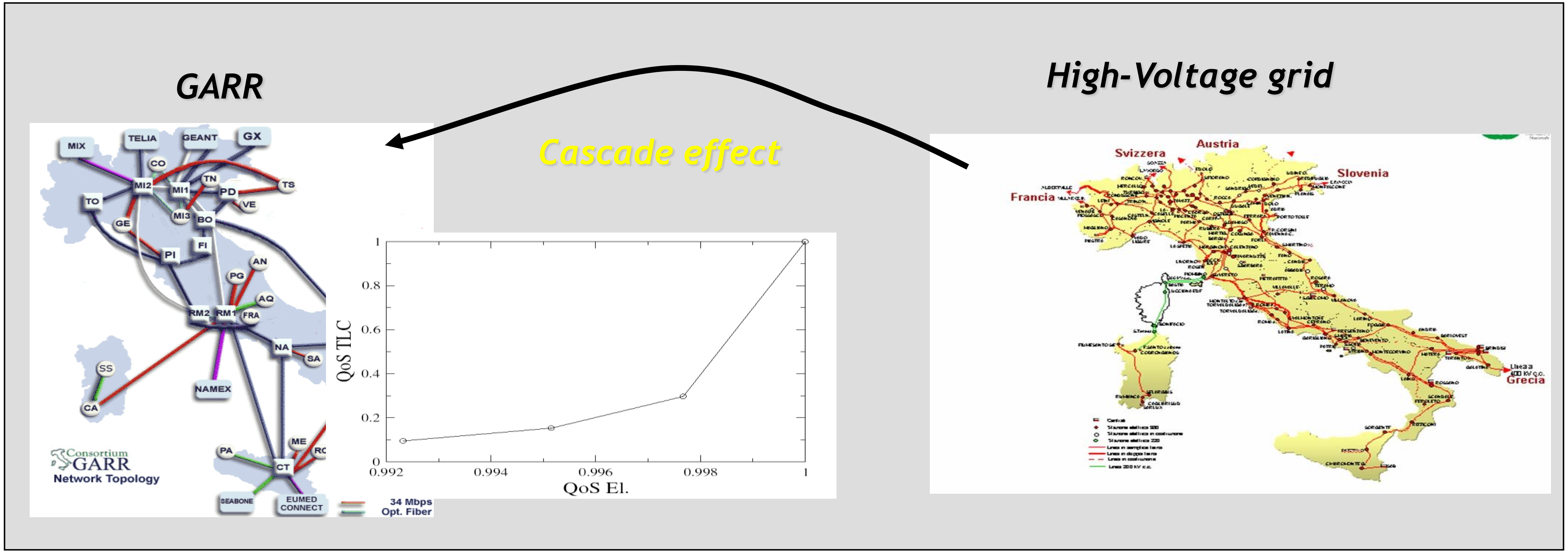
These approaches operate, genrally, with an ON/OFF assumption, i.e. each node is either fully working or completely out-of-work.

To implement these approaches in their basic formulation it is enough to have the topological structure of the infrastructure (which is a data quite easy to obtain).

This static formulation is able to capture the “structural” properties of the network. However, in several cases, e.g. for a telecommunication network, topologic analysis are unsatisfactory and there is the need to equip the topological structure with some kind of flow dynamic models (”**functional**” behavior). However, the data required to tune such dynamic models is hard to obtain.

Complex network analysis

$$\text{GARR node } k = \begin{cases} \texttt{on} & \text{if} \quad P_i \geq \alpha P_i^{(0)} \\ \texttt{off} & \text{otherwise} \end{cases}$$



S. De Porcellinis, L. Issacharoff, S. Meloni, V. Rosato, R. Setola, F.Tiriticco, “Modelling interdependent infrastructures using interacting dynamical models”, *Int. J. Critical Infrastructure (IJCI), 2007*

China- USA

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Academic Paper in China Sets Off Alarms in U.S.

A Chinese student, Wang Jianwei, above, and his professor, wrote an academic paper on the vulnerability of the American power grid to a computer attack. Scientists said the paper was merely a technical exercise.

By JOHN MARKOFF and DAVID BARBOZA
Published: March 20, 2010

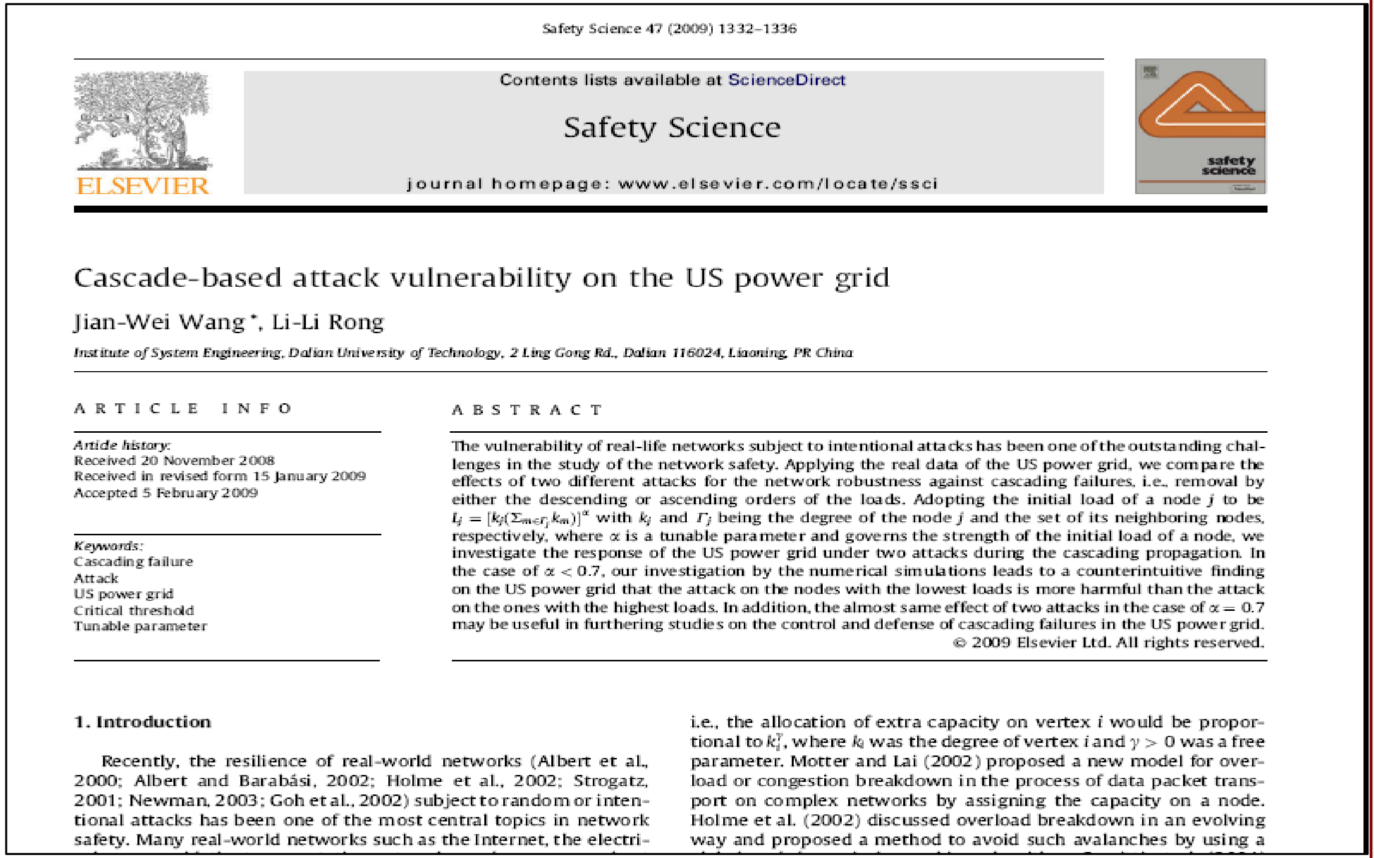
It came as a surprise this month to Wang Jianwei, a graduate engineering student in Liaoning, China, that he had been described as a potential cyberwarrior before the United States Congress.

SIGN IN TO RECOMMEND | TWITTER | SIGN IN TO E-MAIL | PRINT | SINGLE PAGE | REPRINTS | SHARE

Larry M. Wortzel, a military strategist and China specialist, told the House Foreign Affairs Committee on March 10 that it should be concerned because "Chinese researchers at the Institute of Systems Engineering of Dalian University of Technology published a paper on how to attack a small U.S. power grid sub-network in a way that would cause a cascading failure of the entire U.S."

Larry M. Wortzel, a military strategist, recently drew attention to the paper.

When reached by telephone, Mr. Wang said he and his professor had indeed published "Cascade-Based Attack Vulnerability on the U.S. Power Grid" in an international journal called Safety Science last spring. But Mr. Wang said he had simply been trying to find ways to enhance the stability of power grids by exploring potential vulnerabilities.



Safety Science 47 (2009) 1332–1336

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journal homepage: www.elsevier.com/locate/ssci

ELSEVIER

Cascade-based attack vulnerability on the US power grid

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ARTICLE INFO

Article history:
Received 20 November 2008
Received in revised form 15 January 2009
Accepted 5 February 2009

Keywords:
Cascading failure
Attack
US power grid
Critical threshold
Tunable parameter

ABSTRACT

The vulnerability of real-life networks subject to intentional attacks has been one of the outstanding challenges in the study of the network safety. Applying the real data of the US power grid, we compare the effects of two different attacks for the network robustness against cascading failures, i.e., removal by either the descending or ascending orders of the loads. Adopting the initial load of a node j to be $L_j = [k_j(\sum_{m\in\Gamma_j} k_m)]^{\alpha}$ with k_j and Γ_j being the degree of the node j and the set of its neighboring nodes, respectively, where α is a tunable parameter and governs the strength of the initial load of a node, we investigate the response of the US power grid under two attacks during the cascading propagation. In the case of $\alpha < 0.7$, our investigation by the numerical simulations leads to a counterintuitive finding on the US power grid that the attack on the nodes with the lowest loads is more harmful than the attack on the ones with the highest loads. In addition, the almost same effect of two attacks in the case of $\alpha = 0.7$ may be useful in furthering studies on the control and defense of cascading failures in the US power grid.

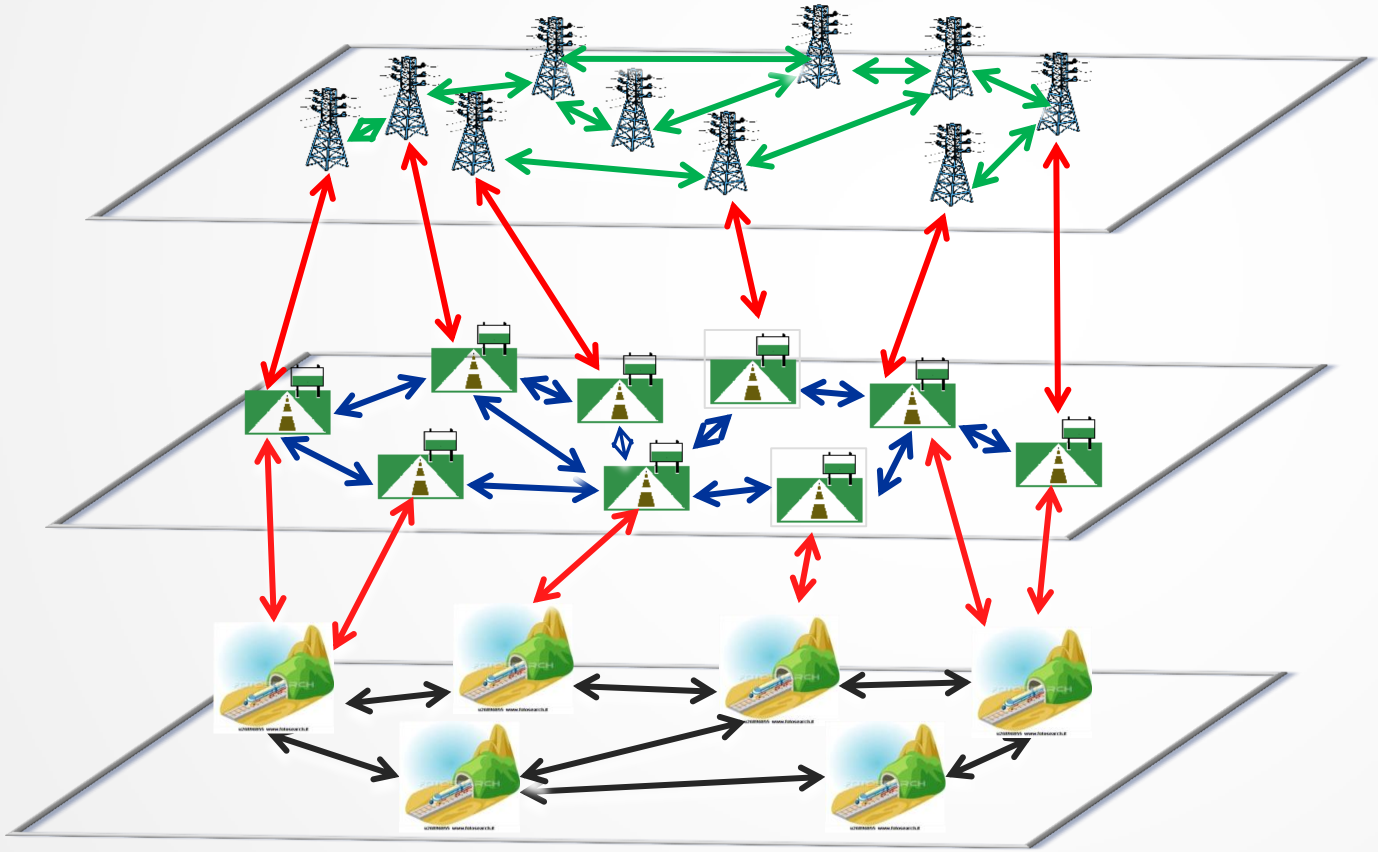
1. Introduction

Recently, the resilience of real-world networks (Albert et al., 2000; Albert and Barabási, 2002; Holme et al., 2002; Strogatz, 2001; Newman, 2003; Goh et al., 2002) subject to random or intentional attacks has been one of the most central topics in network safety. Many real-world networks such as the Internet, the electri-

i.e., the allocation of extra capacity on vertex i would be proportional to k_i^{γ}, where k_i was the degree of vertex i and $\gamma > 0$ was a free parameter. Motter and Lai (2002) proposed a new model for overload or congestion breakdown in the process of data packet transport on complex networks by assigning the capacity on a node. Holme et al. (2002) discussed overload breakdown in an evolving way and proposed a method to avoid such avalanches by using a

In March 2010 a young Chinese researcher has been indicated to the US Congress as a dangerous enemy, because he wrote a scientific paper on the vulnerability of the US electric grid to cyber attack

Simulation based approaches



Simulation-based approaches

These approaches are focused on the analysis of the dynamic of each single component.

Hence, they are generally able to consider a continuous level of degradation in the component functionalities and the concurrent presence of several types of phenomena (like absence of resources, external failures and internal dynamics).

Starting from the component-based behavior, they try to obtain information about the “interdependence” existing among the infrastructures.

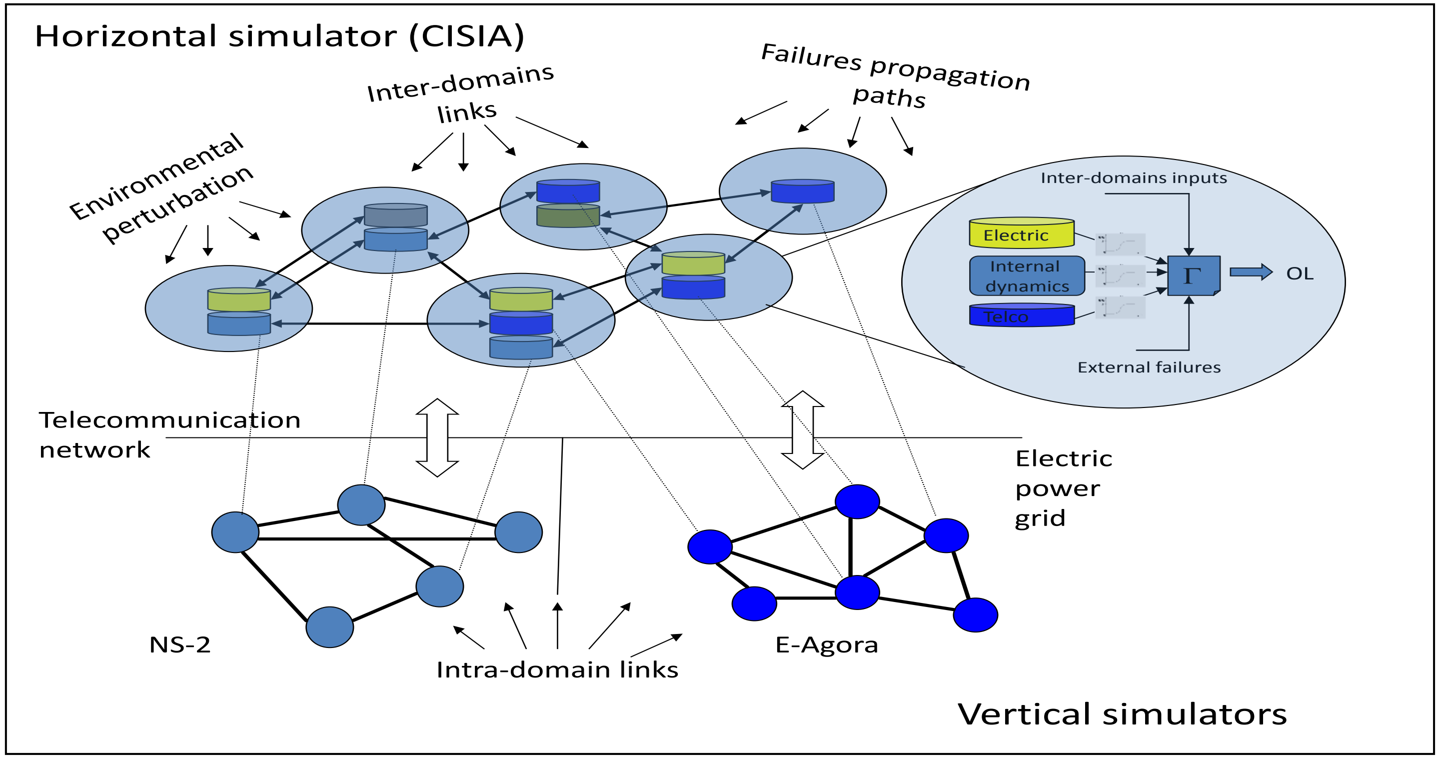
Generally, these approaches are intrinsically quantitative and operation oriented.

However, the complexity of the simulation platforms tend to mask, in several cases, subjective hypothesis which influence the correctness of the solutions.

Federation

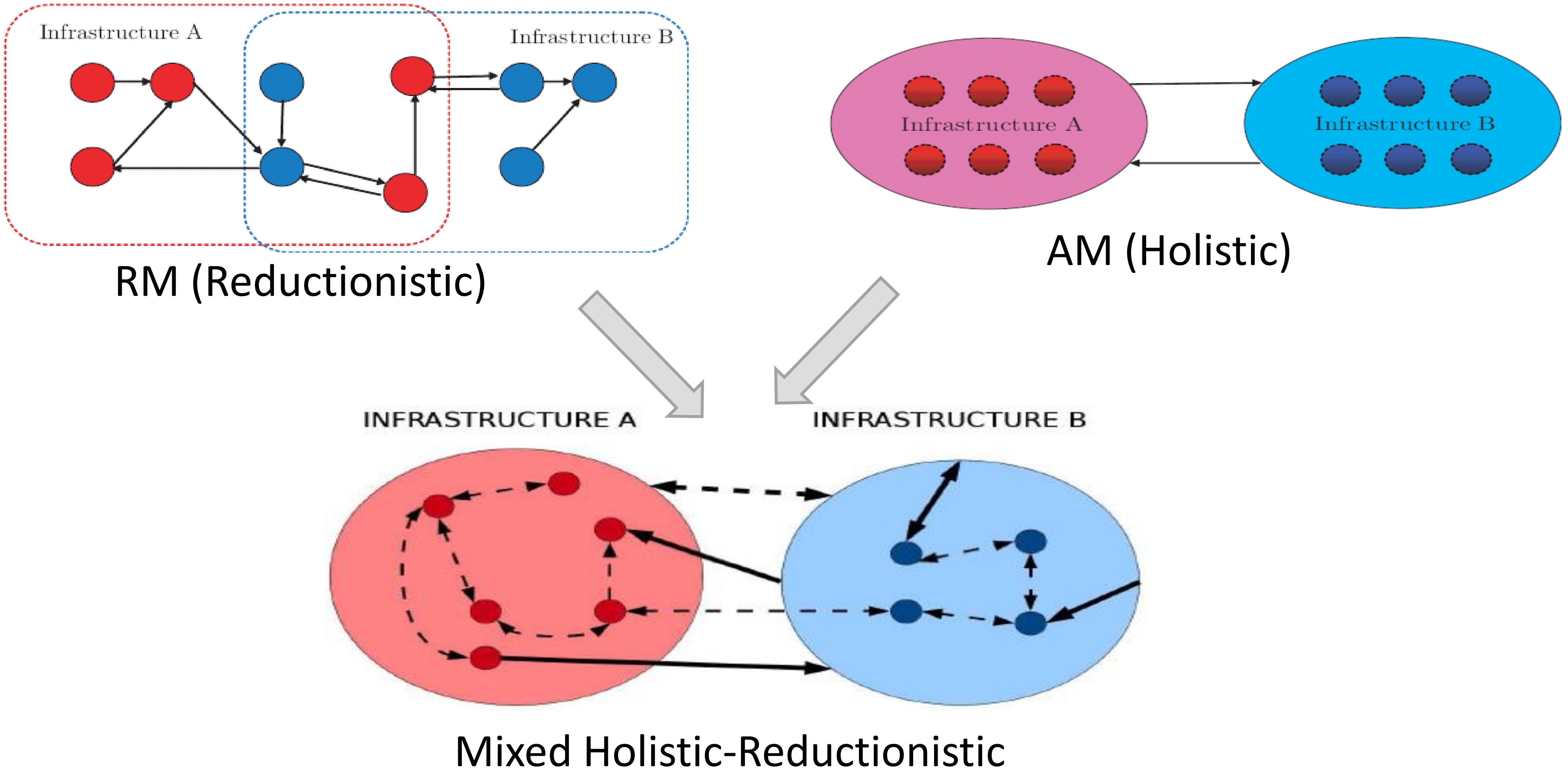
Vertical simulators = **re-use** of well tested and validated software packages. “intra-domain dependency” links are described inside each vertical simulator while the simulation environment has to manage “only” the inter-domains dependency links

Horizontal simulators = provide a single conceptual and formal instrument to represent the characteristics of heterogeneous infrastructures belonging to different domains



R. Setola, S. Bologna, E. Casalicchio and V. Masucci, “An Integrated Approach for Simulating Interdependencies” in *Critical Infrastructure Protection II*, M. Papa and S. Shenoi (Eds.), Springer, Boston, Massachusetts, pp. 221 – 231, 2008.

Multi-scale Models

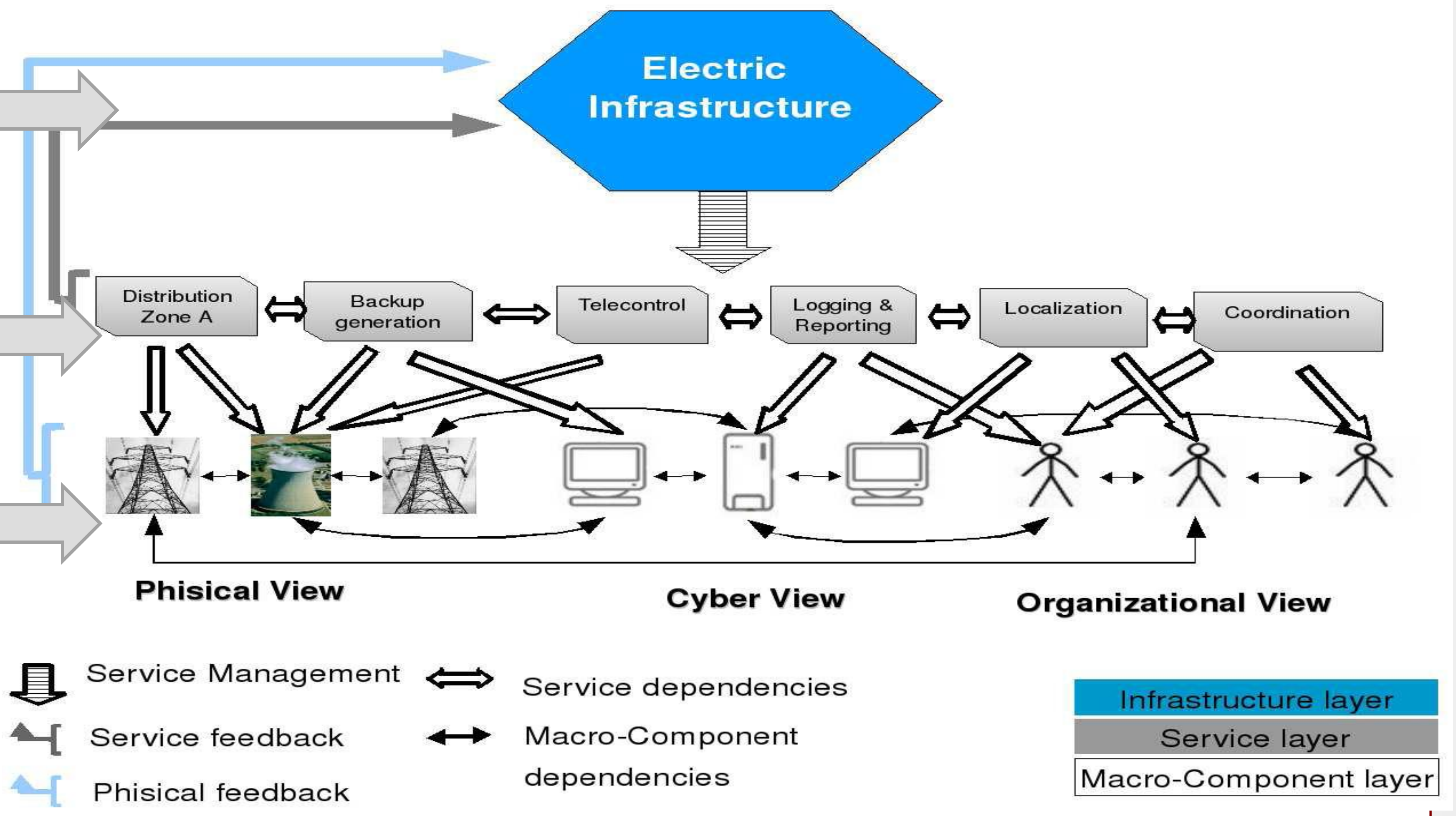


The HR model of an infrastructure

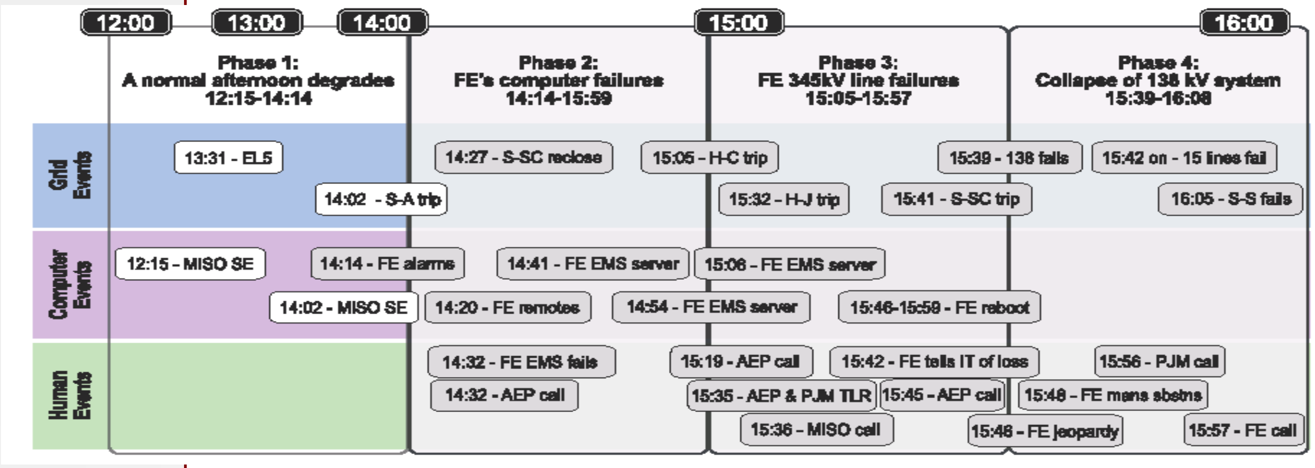
A business partner or a customer sees this…

..which is controlled via these…

…based (also) on the existence of them



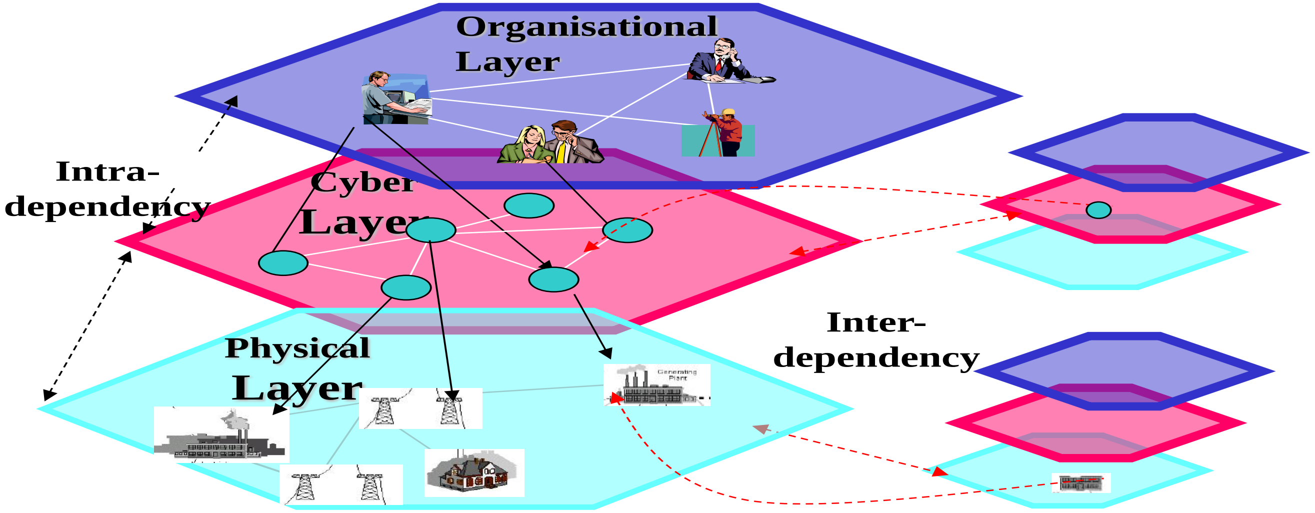
MHR3



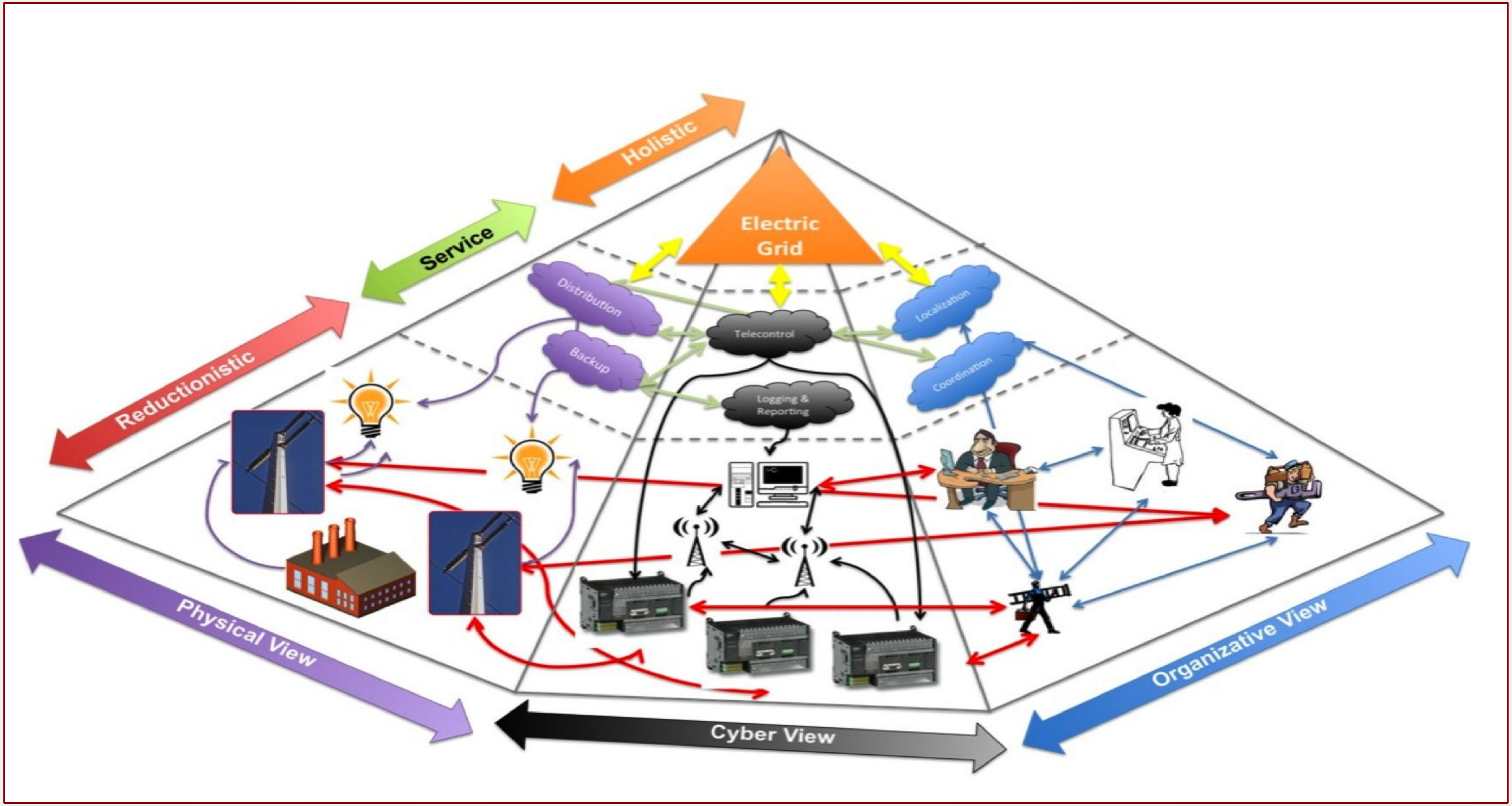
To correctly capture the complexity of the phenomena, it is mandatory to have an holistic vision able to agregate the different vision.

- Physical
- Logic
- Organization

Each layer is characterized by its own component, resource, fault and link



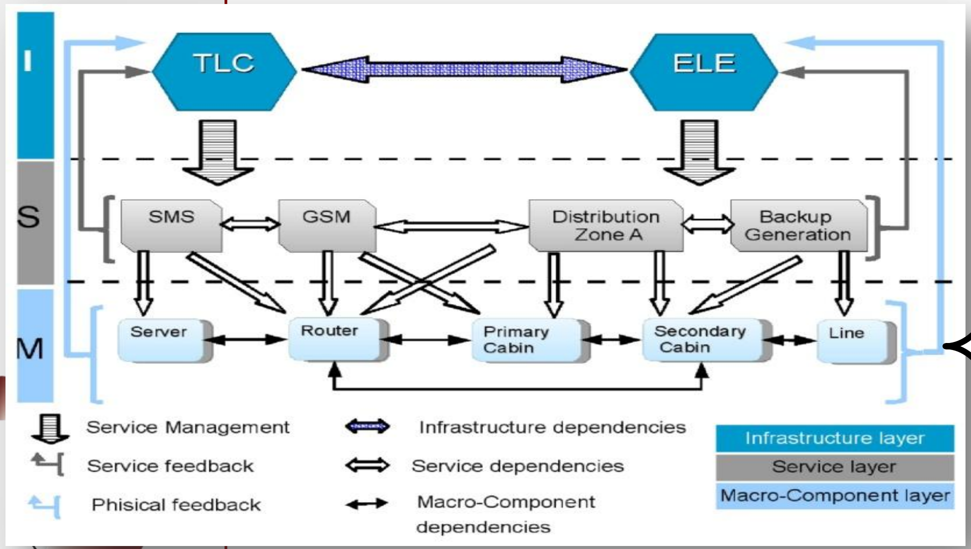
MHR^3

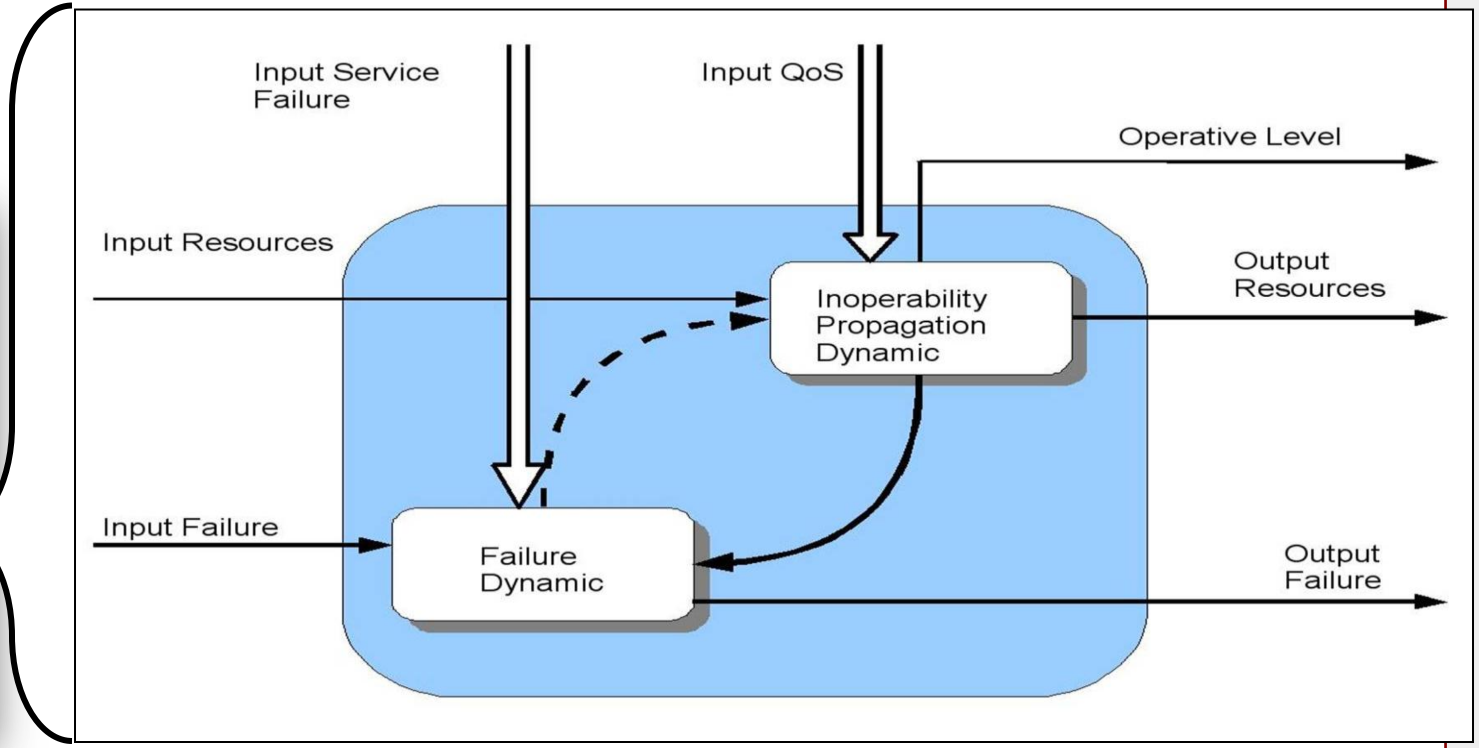

Holistic
Service
Reductionistic
Electric Grid
Distribution
Backup
Telecontrol
Logging & Reporting
Localization
Coordination
Physical View
Cyber View
Organizative View

r.setola@unicampus.it

MHR – COMPONENT LAYER

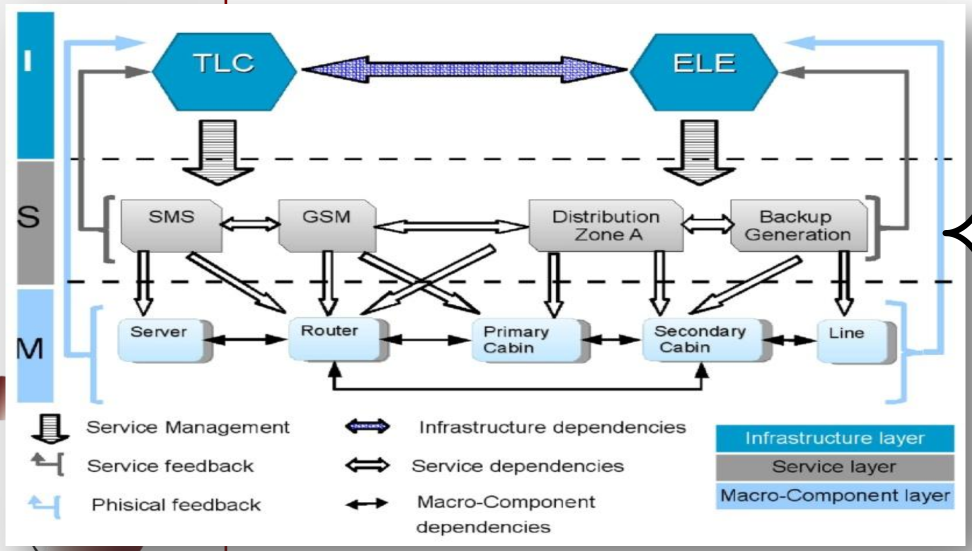
Components are representative of 'small' parts or elements of the infrastructure, with a recognizable functional, phisical or sociologic individuality.

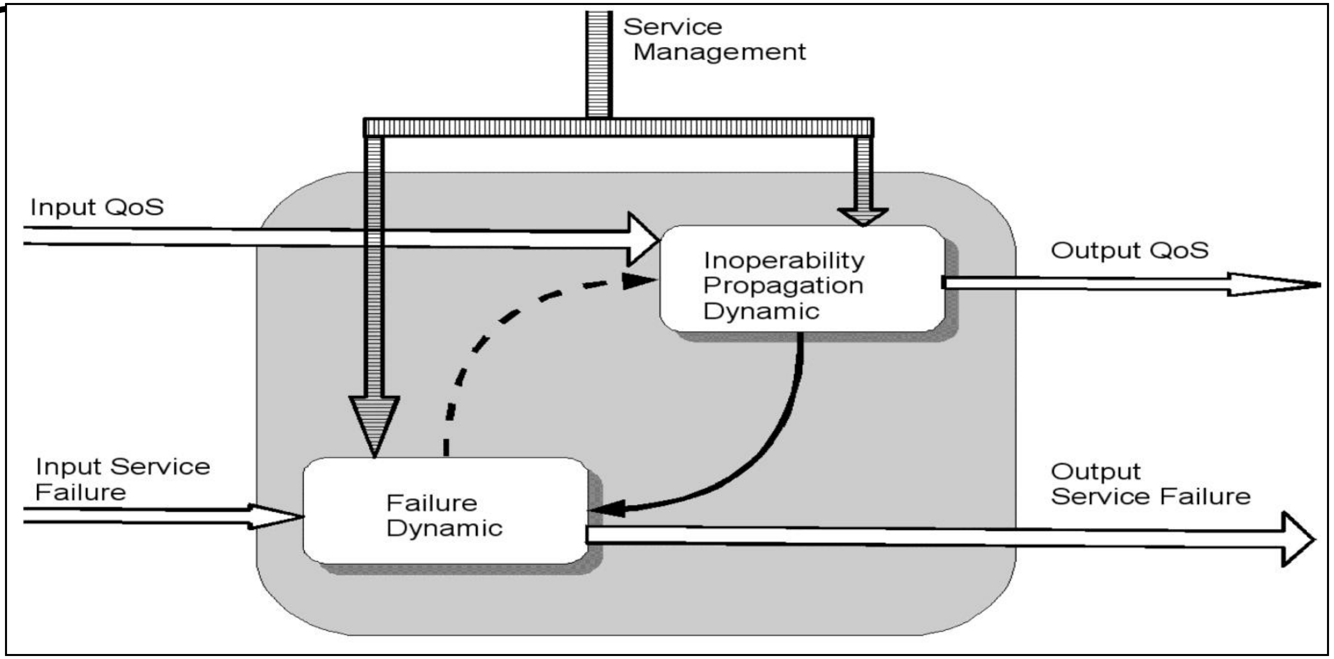




MHR – SERVICE LAYER

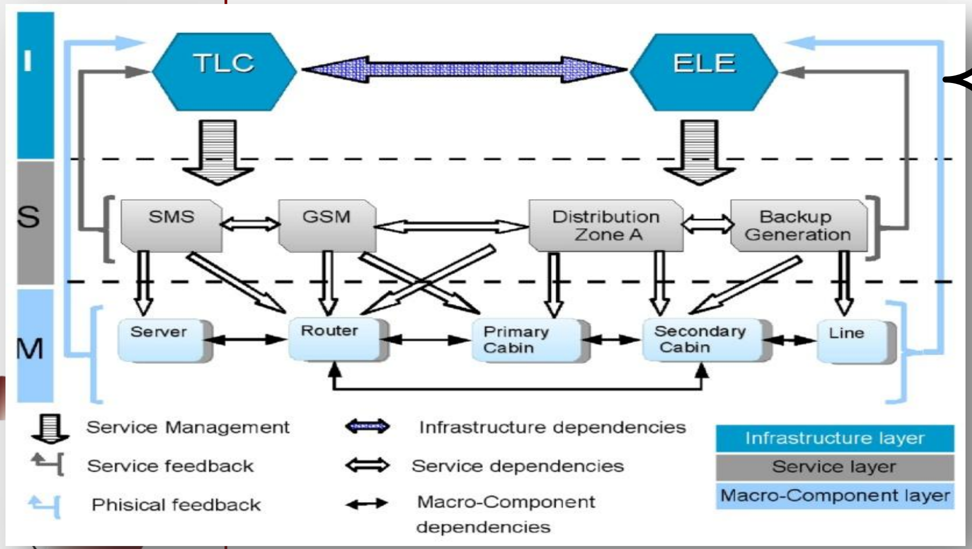
An element in the ‘**service**’ (or functional) layer represent a (logical, organizative or real) element which provides an **aggregate** resource (like a VoIP service or telecontrol).

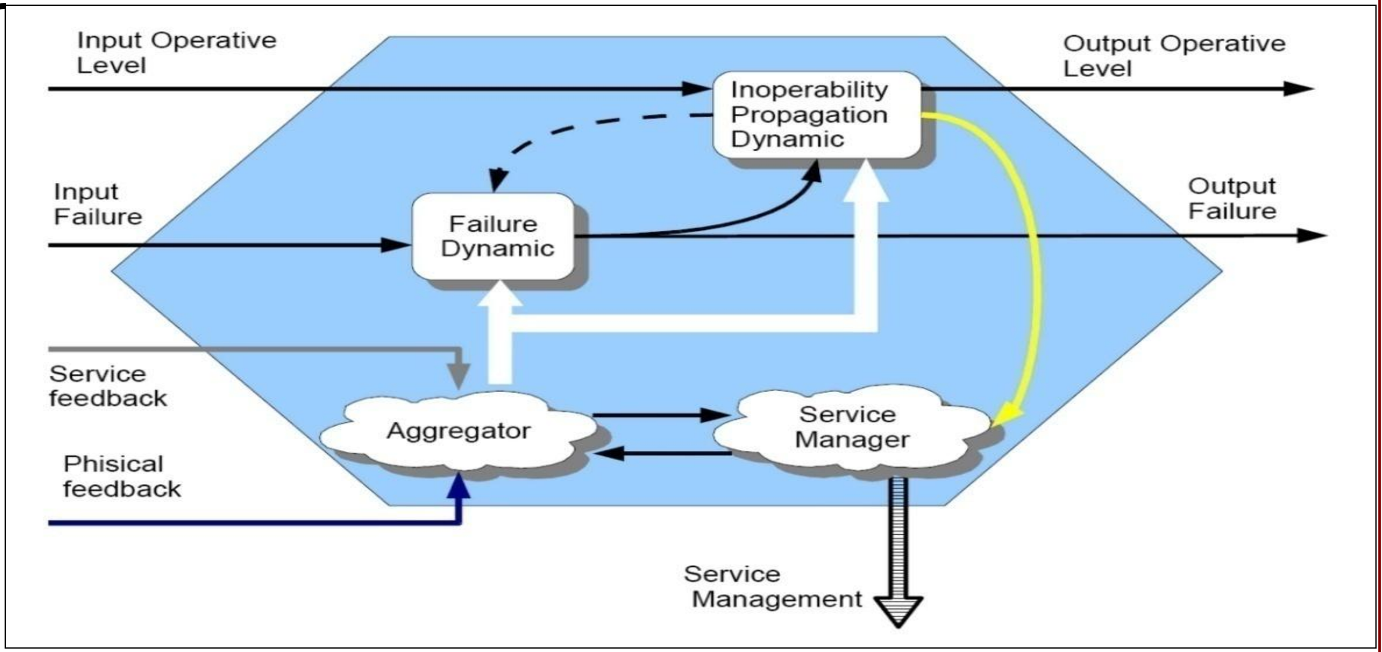




MHR- INFRASTRUCTURE LAYER

The upmost layer should represent the infrastrcture **as a whole** (or its general organizative divisions), in order to have a model which can take into account the **global dynamcs** of the infrastructure (and, possibly, the behaviours related to policies, strategies, etc.).





CIPRNet

Critical Infrastructure Preparedness and Resilience Research Network

www.ciprnet.eu

Holistic modelling

Roberto Setola (UCBM)

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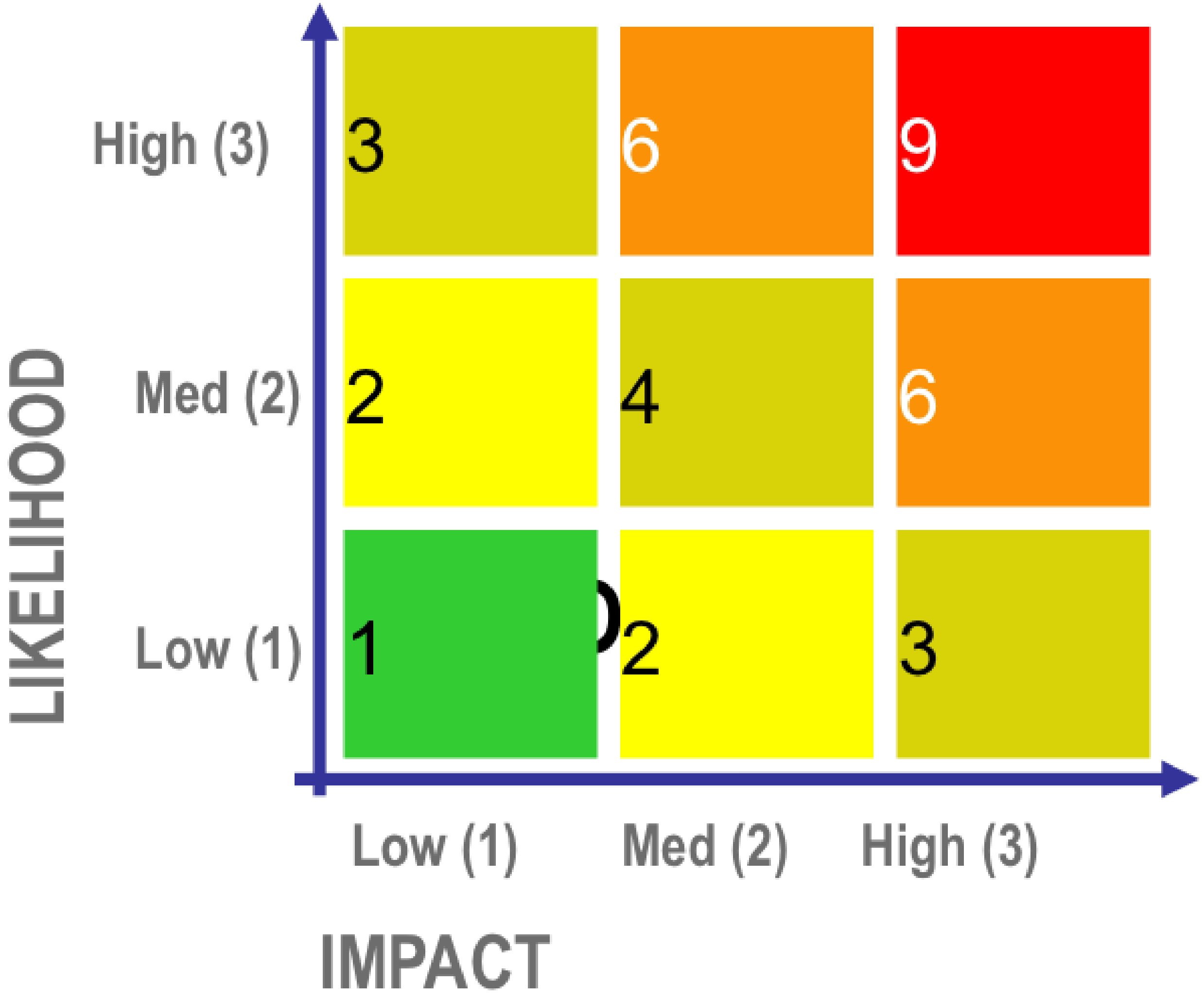
Modelling, Simulation and Analysis of Critical Infrastructure Training School (Edition 0)

Deltares Headquarters – Delft (The Netherlands) – 3-4 February 2014

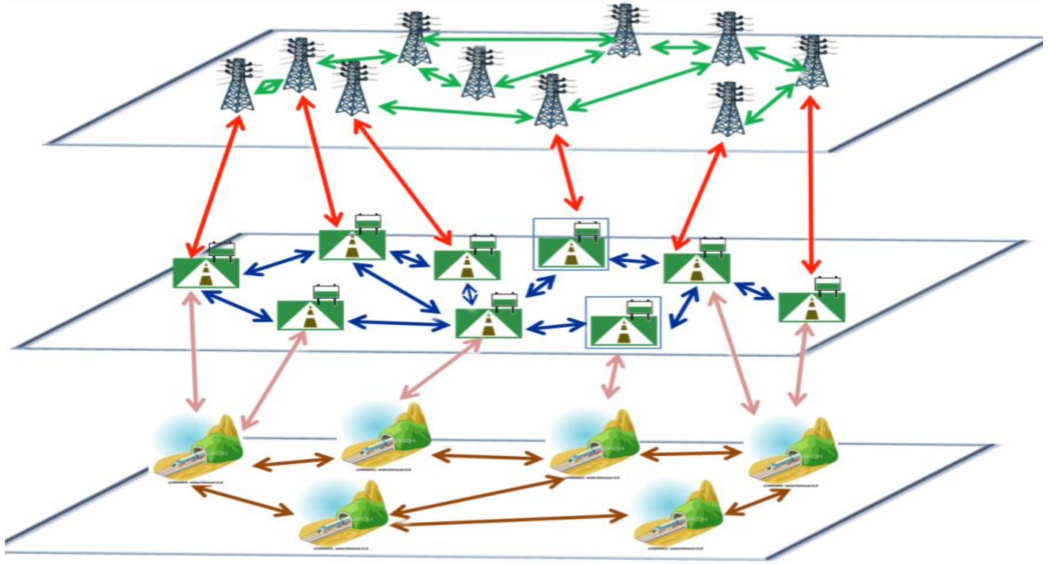
Operational Risk Matrices



Input-output Models

Infrastructures are modeled as black boxes

The emphasis is on interaction (input and output)



Which inputs are needed ?

What is the effect of a lack of resources?

Input-Output Inoperability Model

Based on the economic equilibrium theory of W. Leontief

Each infrastructure has an **inoperability** q (% of malfunctioning)

The model considers constant external perturbations and analyzes the domino effects

W. Leontief, Input-Output Economics, Oxford University Press, 1966.

Y. Haimes et al., Inoperability input-output model for *interdependent* infrastructure sectors I: Theory and methodology, Journal of Infrastructure Systems, vol. 11(2), pp. 67-79, 2005.

Characteristics

Represent the effects of an adverse event on coupled critical infrastructures

Highlight domino effects and intrinsic vulnerabilities

Economic Origin: interdependency is proportional to economic interaction

***Assumption**: after an external perturbation the infrastructures reach an equilibrium*

Economic model of Leontief

$$x = Ax + c \quad \Rightarrow \quad x = (I - A)^{-1} c$$

x is the difference among the planned (x_p) and the actual (x_r) production due to the presence of a negative event

c is the difference among the planned (c_p) and the actual (c_r) demand

A is the matrix of Leontief coefficients (a_{ij} is the fraction of the overall demand of the j-th infrastructure provided by i-th infrastructure).

The solution is a new **equilibrium** condition

Inoperability

Inability (in %) of an infrastructure to provide its intended function/services.

It is obtained normalizing x in the range tra 0 e 1:

$$q = Px$$

$$P = \begin{bmatrix} x_{1p} & 0 & 0 \\ 0 & \ddots & 0 \\ 0 & 0 & x_{np} \end{bmatrix}$$

It is a quite abstract indicator of the infrastructure status

Input-Output Inoperability Model

Using the P

$$q = A^* q + c^*$$

where

$$A^* = PAP^{-1}; c^* = Pc$$

Consequently the effect of a perturbation are described by

$$q = (I - A^*)^{-1} c^*$$

Dynamic IIM

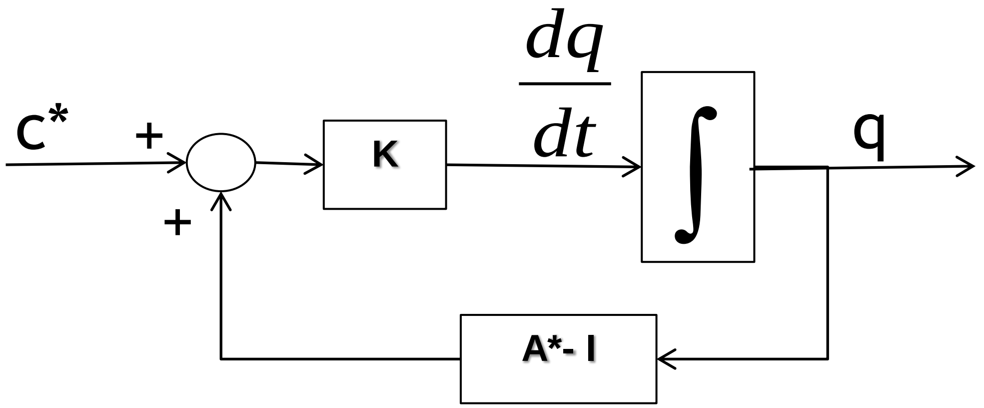
To model the evolution of the system to reach the equilibribium

$$q(t) = A^{*} q(t) + c^{*}(t) + B \frac{d[q(t)]}{dt}$$

Assumed $B = -K^{-1}$ con K>0 diagonale:

$$\frac{d[q(t)]}{dt} = K(A^{*} - I)\ q(t) + Kc^{*}(t)$$

Meaning of the matrix K



K is the resilience matrix

k_{ii} represents the “recovery-speed” of the i-th infrastructure.

Implementing counter-measurement and mitigation strategies amplify k_{ii}

hence the recovery time is reduced

It is a “gain” for the schema

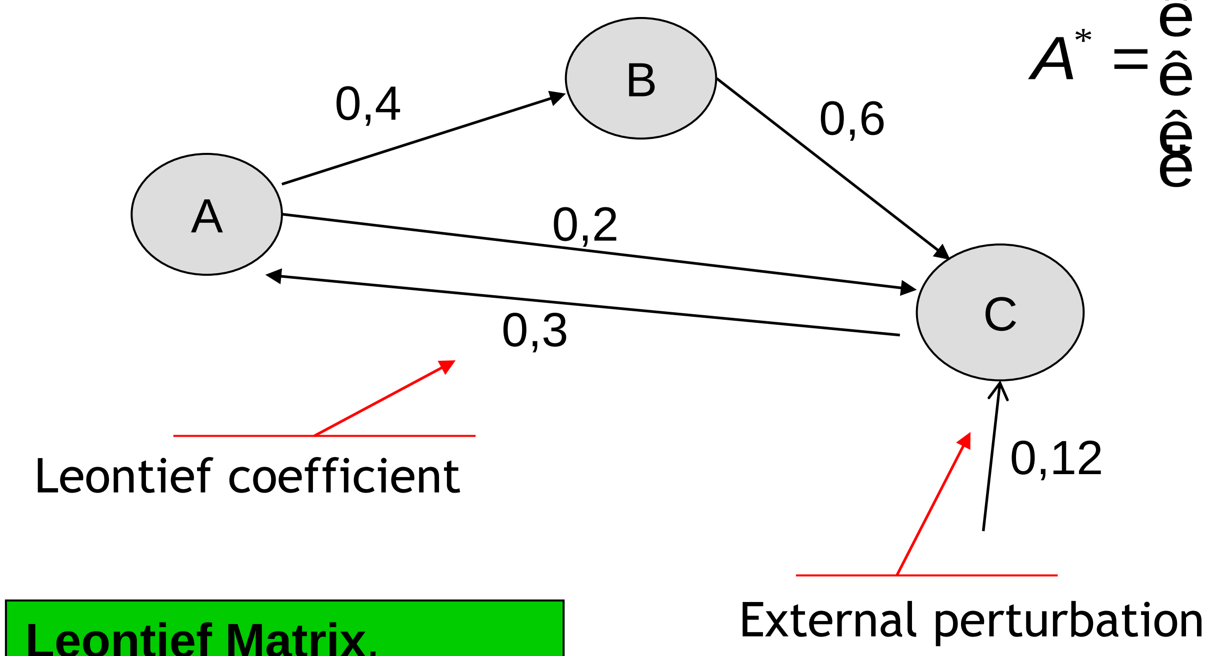
IIM Discrete Time

$$\dot{\mathbf{q}}(t) \simeq \frac{\mathbf{q}(t+T_s)-\mathbf{q}(t)}{T_s}$$

$$\mathbf{q}(k+1) = [T_s K A - T_s K + I]\mathbf{q}(k) + T_s K \mathbf{c}$$

$$\mathbf{q}(k+1) = A^d \mathbf{q}(k) + \mathbf{c}^d$$

IIM - Example



$$A^* = \begin{bmatrix} 0 & 0 & 0.3 \\ 0.4 & 0 & 0 \\ 0.2 & 0.6 & 0 \end{bmatrix}; \quad c^* = \begin{bmatrix} 0 \\ 0 \\ 0.12 \end{bmatrix}$$

Leontief Matrix.
Coefficients are the fraction of transmitted inoperability

$$q(k+1) = A^* q(k) + c^*$$

Example (2)

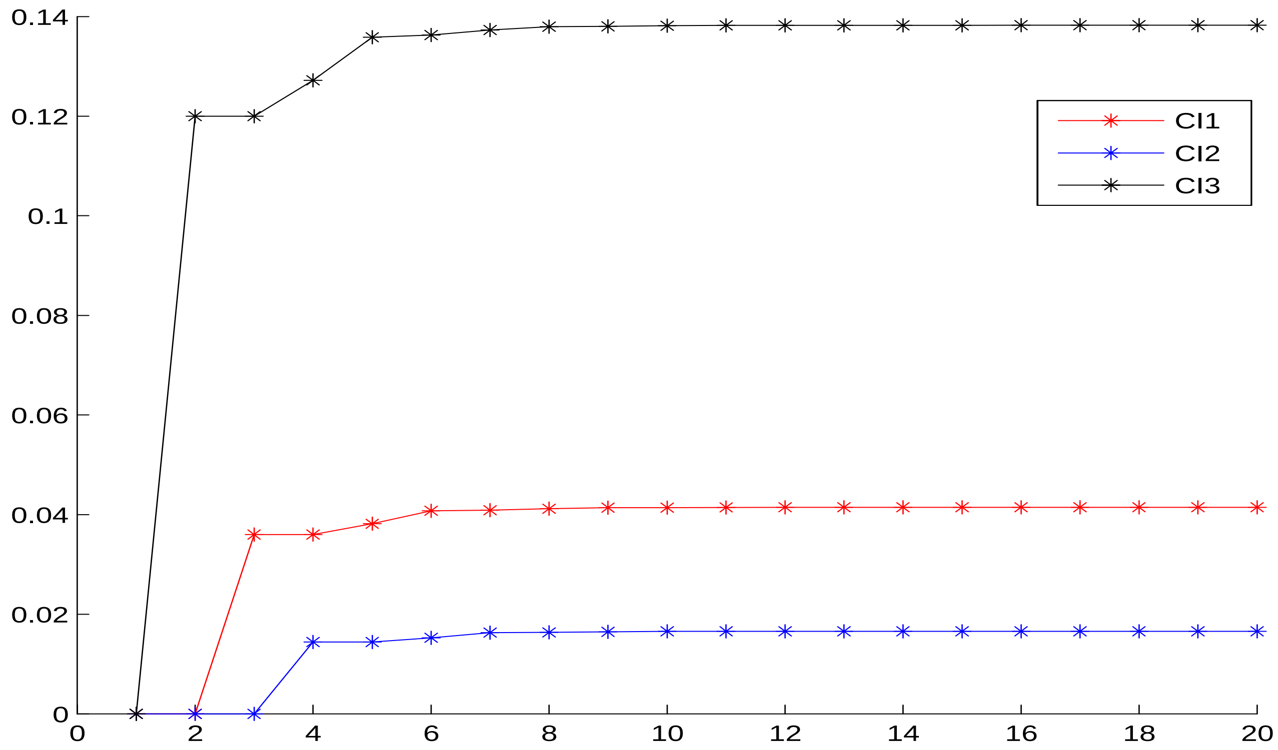
$$q(0)=\begin{bmatrix}0\\0\\0\end{bmatrix}$$

$$q(1)=A^{*}q(0)+c^{*}=\begin{bmatrix}0&0&0.3\\0.4&0&0\\0.2&0.6&0\end{bmatrix}\begin{bmatrix}0\\0\\0\end{bmatrix}+\begin{bmatrix}0\\0\\0.12\end{bmatrix}=\begin{bmatrix}0\\0\\0\end{bmatrix}+\begin{bmatrix}0\\0\\0.12\end{bmatrix}=\begin{bmatrix}0\\0\\0.12\end{bmatrix}$$

$$q(2)=A^{*}q(1)+c^{*}=\begin{bmatrix}0&0&0.3\\0.4&0&0\\0.2&0.6&0\end{bmatrix}\begin{bmatrix}0\\0\\0.12\end{bmatrix}+\begin{bmatrix}0\\0\\0.12\end{bmatrix}=\begin{bmatrix}0.036\\0\\0\end{bmatrix}+\begin{bmatrix}0\\0\\0.12\end{bmatrix}=\begin{bmatrix}0.036\\0\\0.12\end{bmatrix}$$

$$q(n)=(A^{*})^{n}q(0)+\sum_{i=1}^{n}(A^{*})^{i-1}c^{*}$$

IIM example (3)



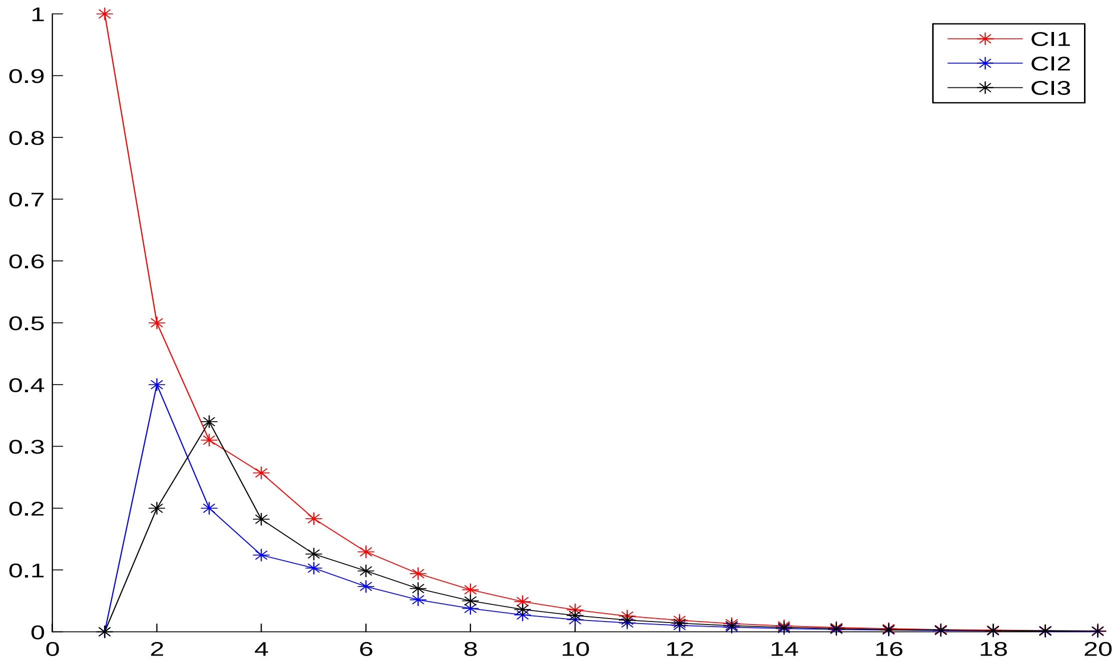
$$A^d = \begin{bmatrix} 0 & 0 & 0.3 \\ 0.4 & 0 & 0 \\ 0.2 & 0.6 & 0 \end{bmatrix}; c^d = \begin{bmatrix} 0 \\ 0 \\ 0.12 \end{bmatrix}; q(0) = \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix}$$

Infrastructure #1 is affected by a failure of 12%

This induces degradation in #2 and #3

This exacerbates the consequences on # up to 14%

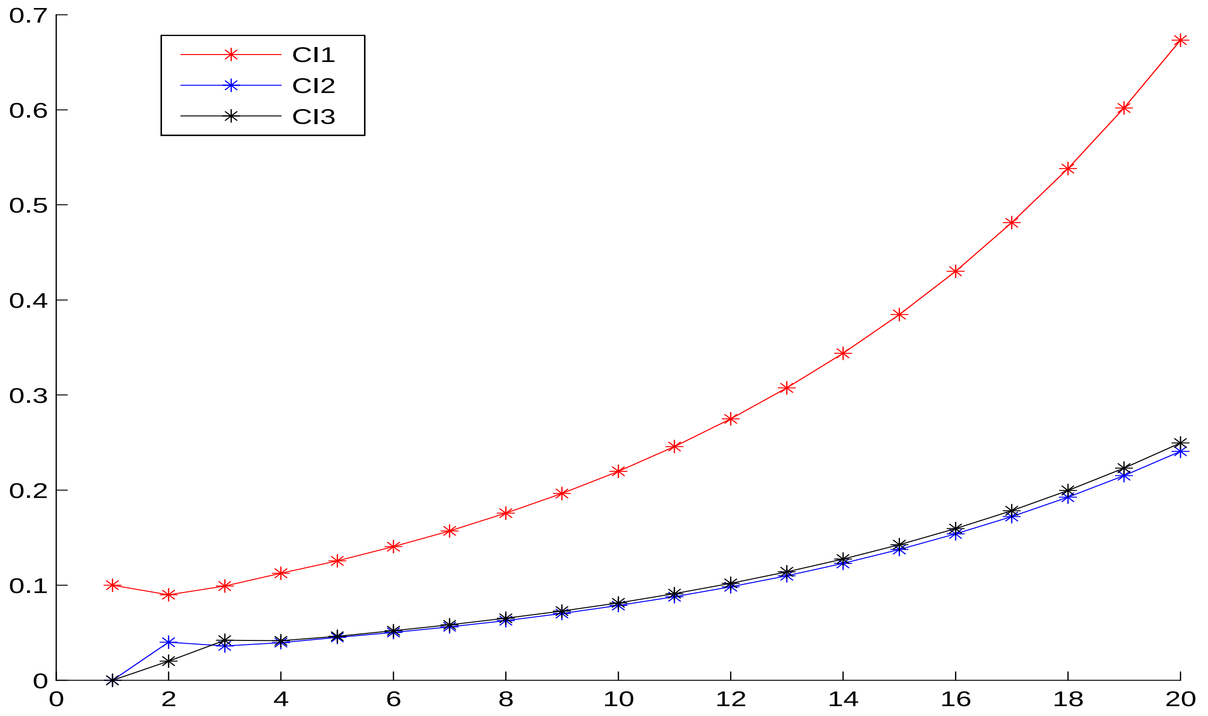
Example (absence of external perturbation)



No external persistent perturbation (c=0) and assuming that the first infrastructure is totally inoperable at the time 0, i.e. $q_1(0)=1$

$$A^d = \begin{bmatrix} 0.5 & 0 & 0.3 \\ 0.4 & 0 & 0 \\ 0.2 & 0.6 & 0 \end{bmatrix} \quad c^d = \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix} \quad q(0) = \begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix}$$

Example (absence of external perturbation 2)



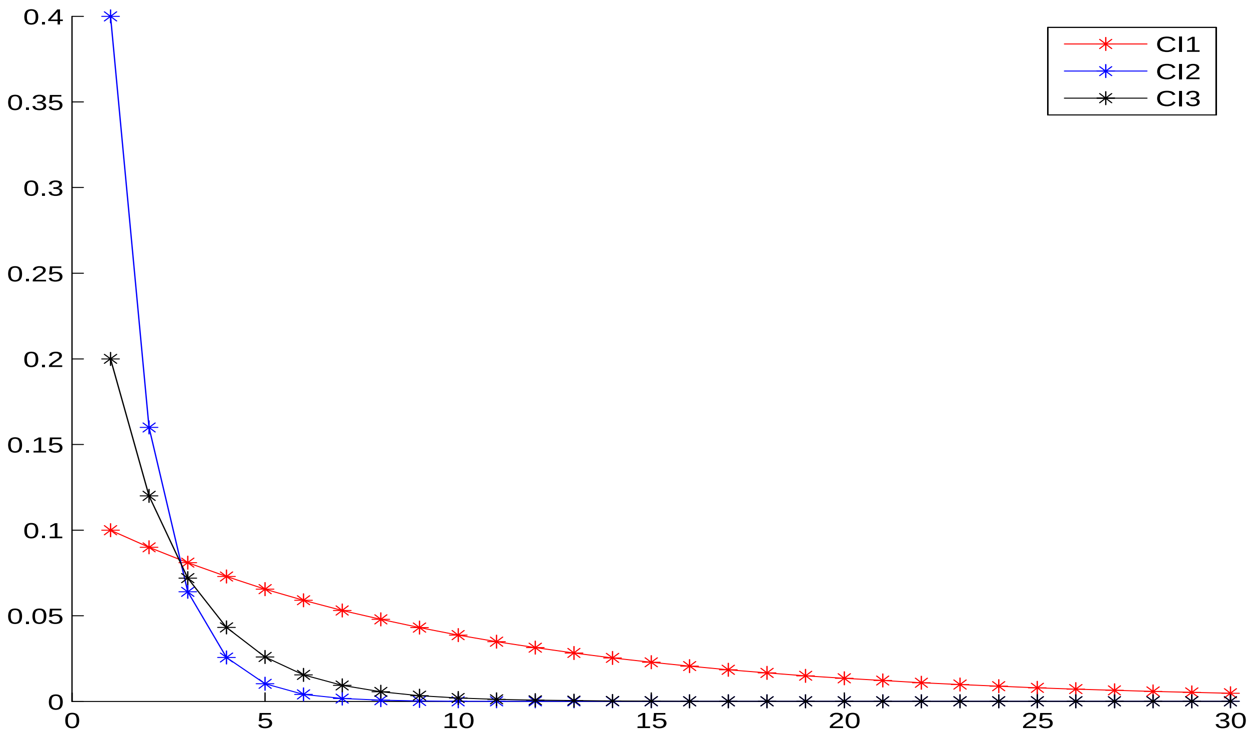
The situation should not normalize

It depended on the stability of the matrix A^d

The elements on the diagonal of A^d represent a "memory"

$$A^d = \begin{bmatrix} 0.9 & 0.3 & 0.3 \\ 0.4 & 0 & 0 \\ 0.2 & 0.6 & 0 \end{bmatrix};\ c^d = \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix};\ q(0) = \begin{bmatrix} 0.1 \\ 0 \\ 0 \end{bmatrix}$$

IIM example

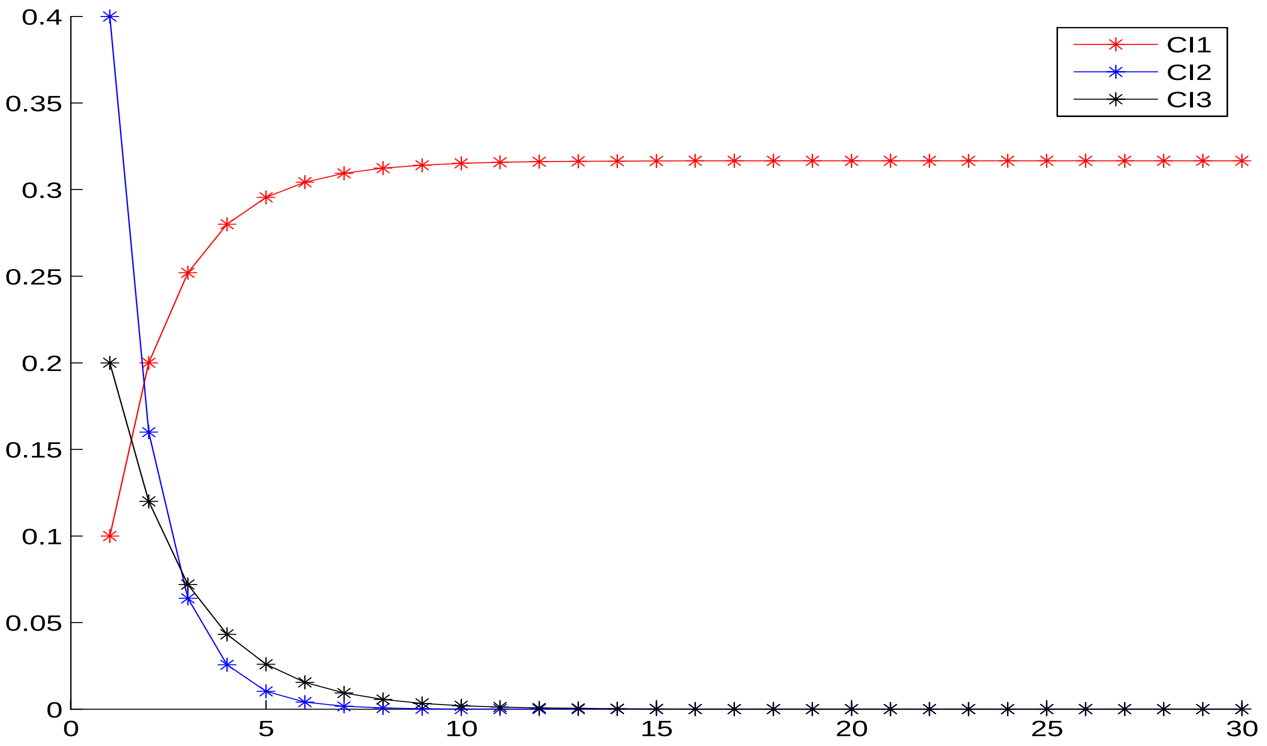


$$A^d = \begin{bmatrix} 0.9 & 0 & 0 \\ 0 & 0.4 & 0 \\ 0 & 0 & 0.6 \end{bmatrix}; c^d = \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix}; q(0) = \begin{bmatrix} 0.1 \\ 0.4 \\ 0.2 \end{bmatrix}$$

In this case the inoperability decrease with a speed that is inversely proportional to the a_{ii} coefficient.

We can assume a_{ii} as a measure of the restoration capability of the infrastructure

Simulazione IIM: accumulo



$$A^d = \begin{bmatrix} 1 & 0.1 & 0.3 \\ 0 & 0.4 & 0 \\ 0 & 0 & 0.6 \end{bmatrix};\ c^d = \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix};\ q(0) = \begin{bmatrix} 0.1 \\ 0.4 \\ 0.2 \end{bmatrix}$$

High order dependency

Being A^d a no-negative matrix, if it is stable

The closed loop solution can be calculated as

$$(I - A^d)^{-1} = \sum_{i=0}^{\infty} (A^d)^i = I + A^d + (A^d)^2 + \ldots$$

I represent the initial condition

A^d the direct dependency (X > Y)

$(A^d)^2$ the second order dependency (X > A > Y)

$(A^d)^3$ the thirdorder dependency (X > A > B >Y)

…And so on

Dependency index & Influnce gain

$$\mathbf{A} = \begin{pmatrix} 0 & * & * & * \\ * & 0 & * & * \\ * & * & 0 & * \\ * & * & * & 0 \end{pmatrix}$$

dependency index

$$\delta_i = \sum_j a_{ij}$$

Is a measurement of the robustness with respect to the transmitted inoperability

$$\rho_j = \sum_i a_{ij}$$

influence gain

Is a measurement of the influence that a specific infrastructure has on the global system

Steady-state solution

$$\bar{\mathbf{x}} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{c} = \mathbf{S}\,\mathbf{c}$$

If A is positive and stable, then

$$\mathbf{S} = [\mathbf{I} - \mathbf{A}]^{-1} = \mathbf{I} + \mathbf{A} + \mathbf{A}^2 + \mathbf{A}^3 + \cdots$$

Overall depencey index and influence gain

$$\bar{\rho}_j = \frac{1}{n-1}\sum_{i \neq j} s_{ij} \qquad \bar{\delta}_i = \frac{1}{n-1}\sum_{j \neq i} s_{ij}$$

R. Setola and S. De Porcellinis, “A Methodology to Estimate Input-output Inoperability Model Parameters”, *Critical Information Infrastructures Security 2007*, Lecture Notes in Computer Science, Springer-Verlag, Berlin, pp. 149 – 160, 2008.

$$A^d = \begin{pmatrix} 0 & 0.1 & 0.2 & 0.1 \\ 0.2 & 0 & 0.1 & 0.3 \\ 0.4 & 0.1 & 0 & 0.1 \\ 0.4 & 0.3 & 0.3 & 0 \end{pmatrix}$$

$$(I - A^d)^{-1} = \begin{pmatrix} 1.28 & 0.23 & 0.34 & 0.23 \\ 0.58 & 1.23 & 0.38 & 0.46 \\ 0.65 & 0.27 & 1.24 & 0.27 \\ 0.88 & 0.54 & 0.62 & 1.31 \end{pmatrix} \quad d_4 = 3.37$$

$$r_1 = 3.41$$

The first infrastructure is those more influence

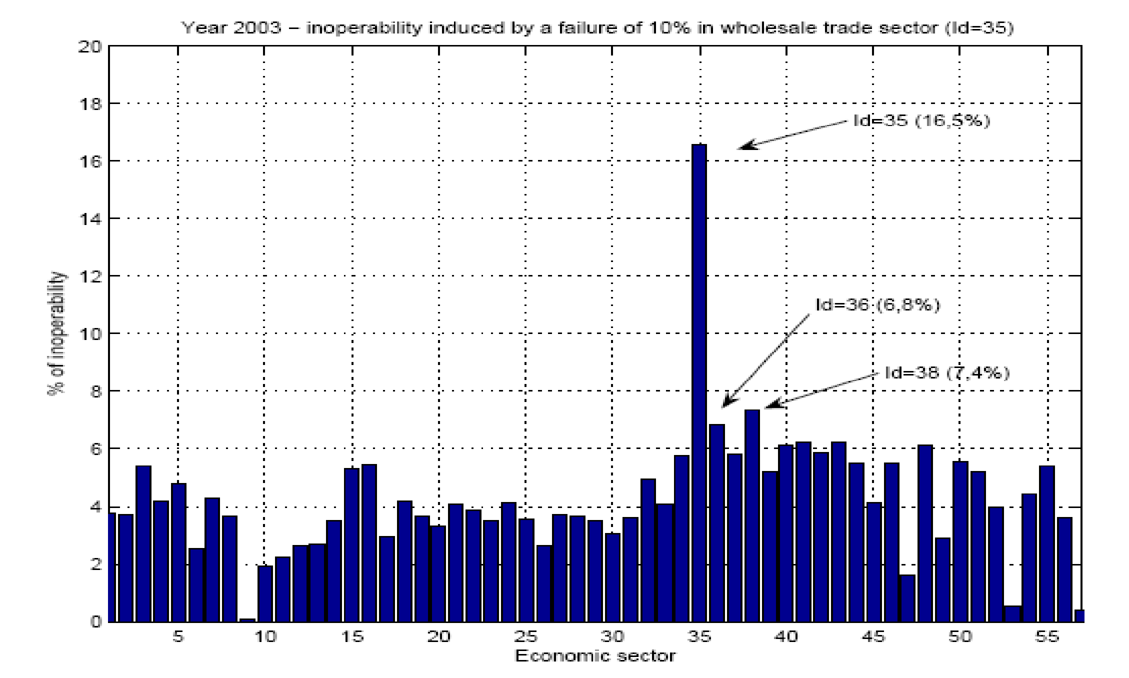
The 4-th the most fragile

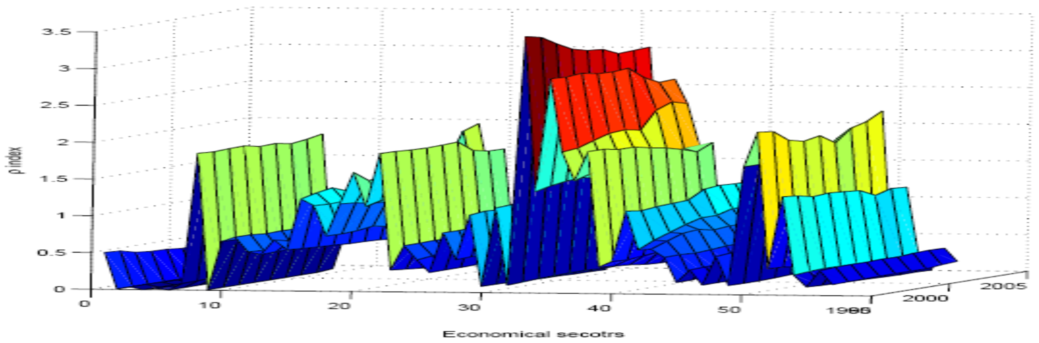
The indeces take into account first and high order dependencies

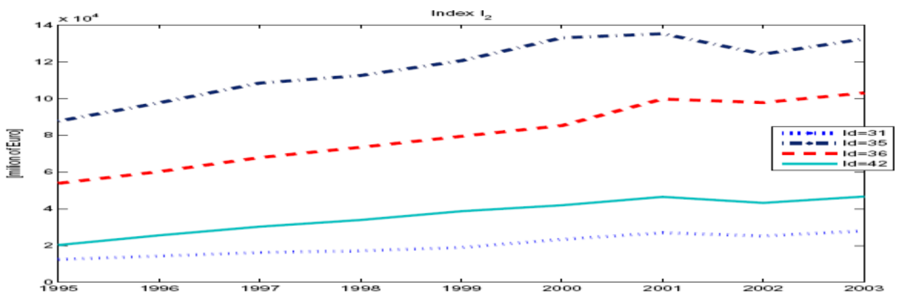
Application of IIM to Italy

ISTAT provides Input-Output table of Italian economy in the period from 1995 to 2007

These data are arranged in accordance with EU standard *Sec95* (59 sectors *but for our analysis only 57 are relevant*)







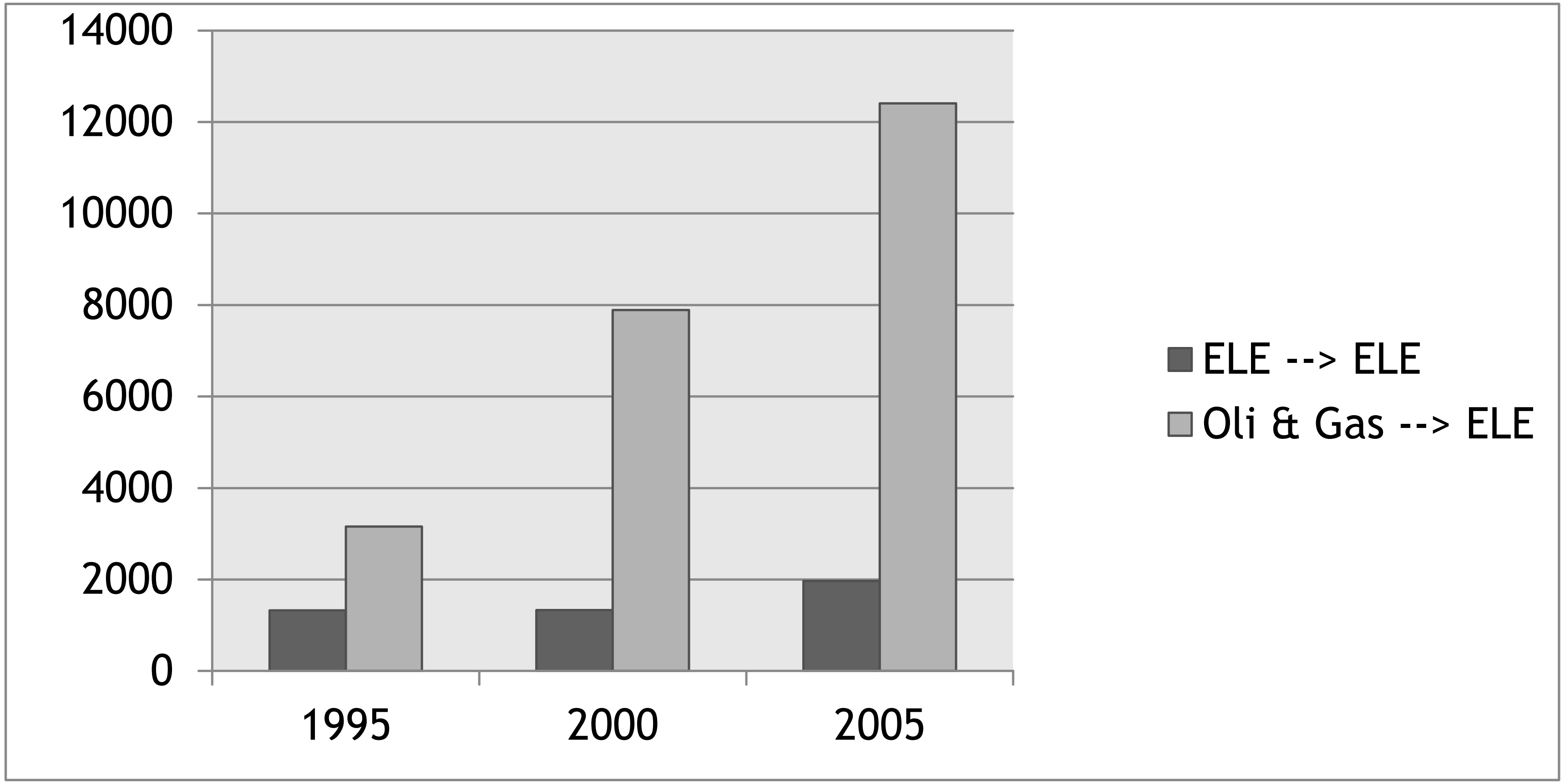
R. Setola, "Analysis of Interdependencies among Italian Economic Sectors via Input-Output Interoperability Model", in *Critical Infrastructure Protection: Issues and Solutions,* Lecture Notes in Computer Science, Springer, pp. 311 – 321, 2007.

Italian scenario

	Air tr.	Water tr.	Land tr.	Elec., gas, water	Post & TLC	Fin. interm.	Ins. and pens. funding	Act. auxiliary to fin. interm.	Coke, petr. products, nuclear fuels	δ
Air tr.	0.008	0.007	0.015	0.002	0.027	0.016	0.001	0.007	0.001	0.076
Water tr.	0.000	0.004	0.021	0.024	0.001	0.000	0.000	0.001	0.015	0.062
Land tr.	0.003	0.002	0.064	**0.007**	0.010	0.002	0.001	0.002	0.005	0.031
Elec., gas, water	0.000	0.000	0.013	0.138	0.010	0.004	0.000	0.002	0.007	0.037
Post & TLC	0.003	0.001	0.032	0.014	0.022	**0.035**	0.005	0.011	0.005	0.107
Fin. interm.	0.001	0.001	0.036	0.010	0.014	0.081	0.028	0.019	0.006	0.069
Ins. and pens. funding	0.004	0.002	0.025	0.002	0.005	0.021	0.001	0.002	0.002	0.041
Act. auxiliary to fin. interm.	0.000	0.000	0.003	0.001	0.004	0.301	0.353	0.155	0.000	0.009
Coke, petr. products, nuclear fuels	0.023	0.003	**0.109**	0.027	0.004	0.001	0.000	0.002	0.059	0.171
ρ	0.035	0.017	0.255	0.088	0.076	0.058	0.007	0.025	0.042	

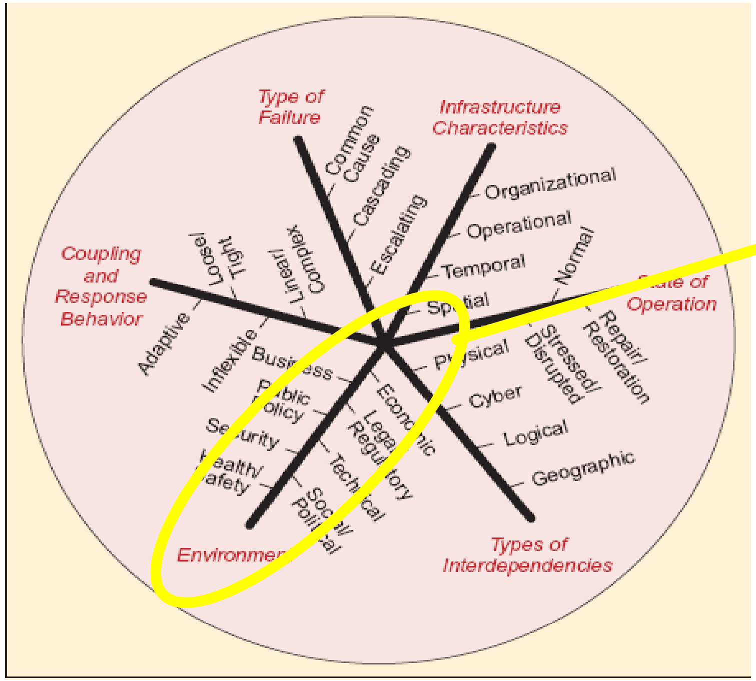
Dependency coefficients derived from a subset of Italian Infrastructures for year 2008, source EUROSTAT

Evolution of Italian Scenario



The amount of inter-sectors economic exchanged grow largely than those of intra sector (main diagonal)

IIM Operational vs Economic



Economic (business) links represent just one of the dimension of dependency

Fukushima Nuclear plant

To capture (other) depedency we have to consider also ooperational dimension

IIM with Technician point of view

Identify IIM parameters on the base of operative technicians' expertise (operators' perceptions)

Ask to experts the follow question

Which is the impact on *your* infrastructure of the complete absence of services provided by *yyy* infrastructure for a time period of *zzz*

In this way we try to acquire directly from their expertise an estimation about the dependency parameters to set-up a technical oriented IIM

R. Setola, S. De Porcellinis, and M. Sforna "Critical Infrastructure Dependency Assessment Using Input-output Inoperability Model", *Int. J. Critical Infrastructure Protection (IJCIP)*, pp. 170 - 178, 2009.

The scenario

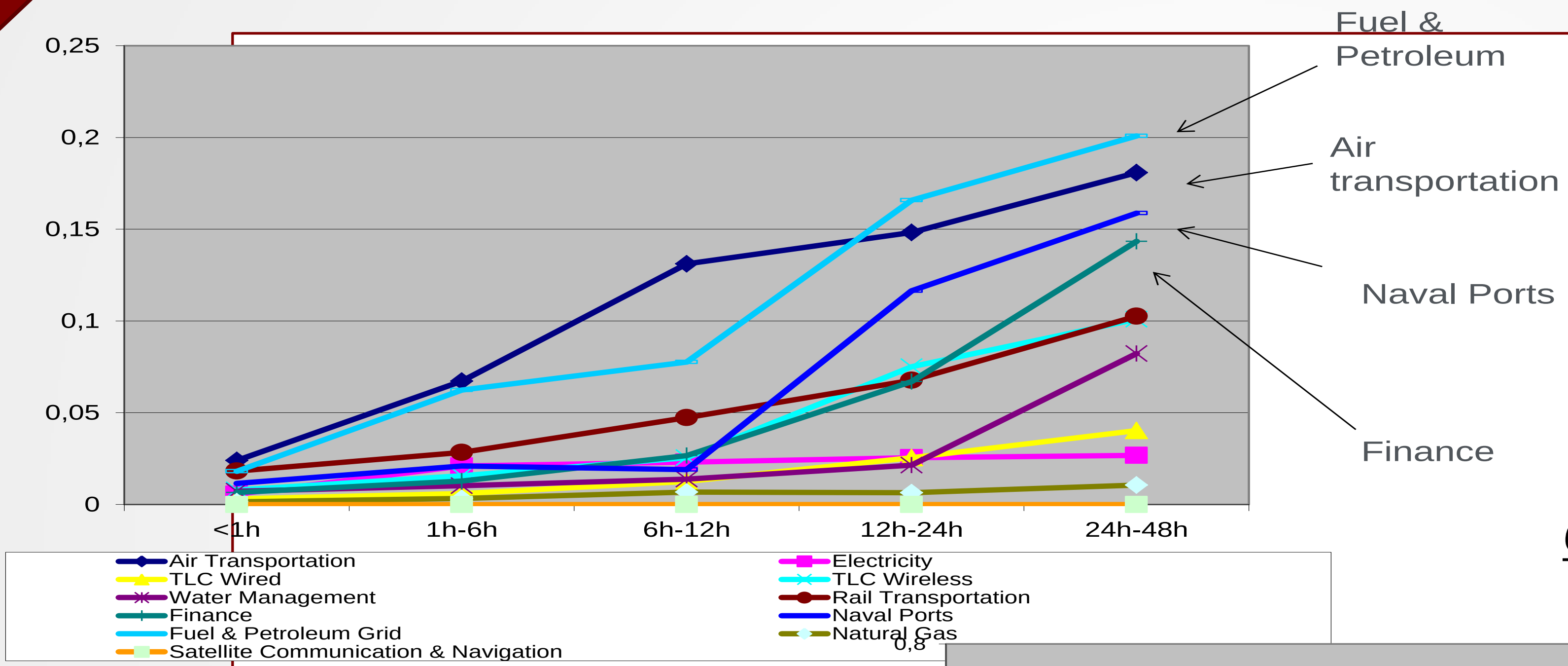
In our case study we consider 11 critical sectors

Id	*Sector*
1	Air transportation
2	Electricity
3	Wired Telecommunication (TLC wired)
4	Wireless Telecommunication (TLC wireless)
5	Water management
6	Rail transportation
7	Finance
8	Naval Ports
9	Fuel & petroleum grid
10	Natural Gas
11	Satellite Communication & Navigation

and 5 time slot

a) less than 1 h
b) from 1 to 6 h
c) from 6 to 12 h
d) from 12 to 24 h
e) from 24 to 48 h

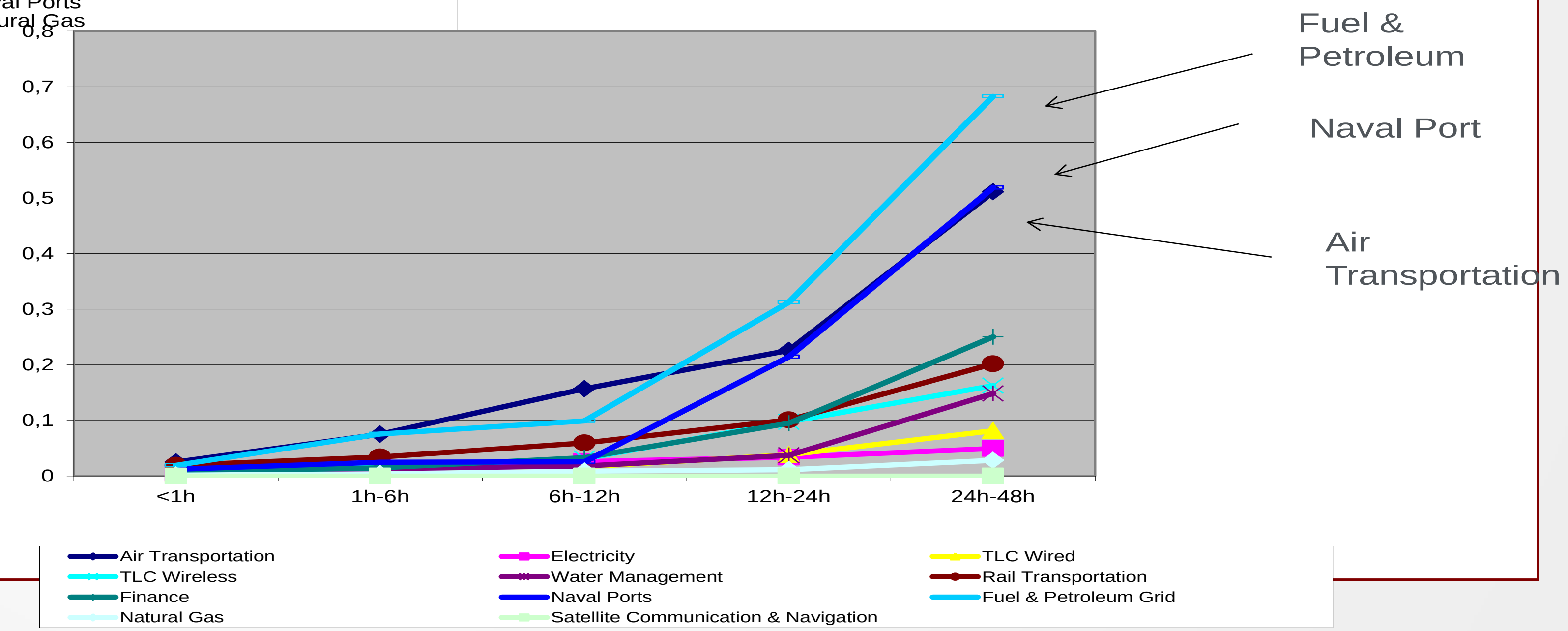
The results



Normalised dependency index

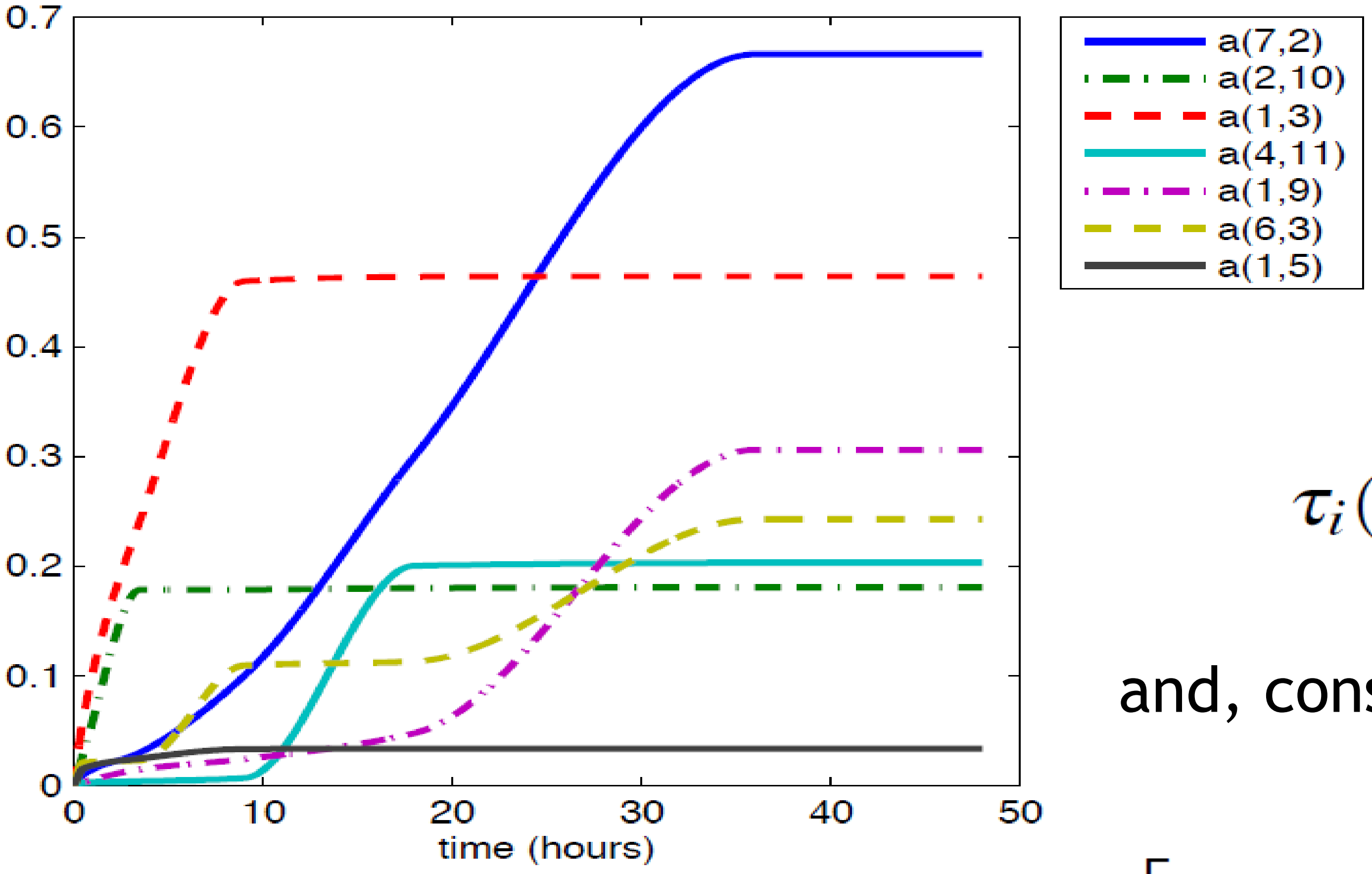
The curves cross each others, i.e. they relevance/fragility varies with the outage time

Overall normalised dependency index



This phenomana should be considered when emergency plan are designed

Time varying IIM



Time-outage coefficients

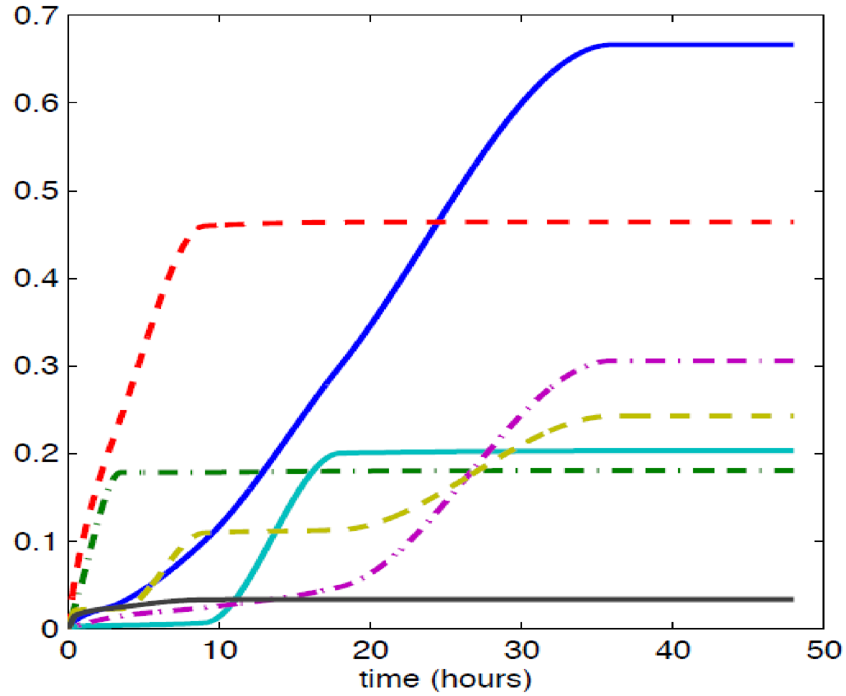
To manage the variation of the Leontief coefficient with the outage time, we introduce the «unavilibility time»

$$\tau_i(k+1) = T_s q_i(k) + \tau_i(k)$$

and, consequently, expand the model

$$\begin{bmatrix} q(k+1) \\ \tau(k+1) \end{bmatrix} = \begin{bmatrix} A^d(\tau) & 0 \\ T_s I & I \end{bmatrix} \begin{bmatrix} q(k) \\ \tau(k) \end{bmatrix} + \begin{bmatrix} I \\ 0 \end{bmatrix} c^d$$

Time Varying IIM



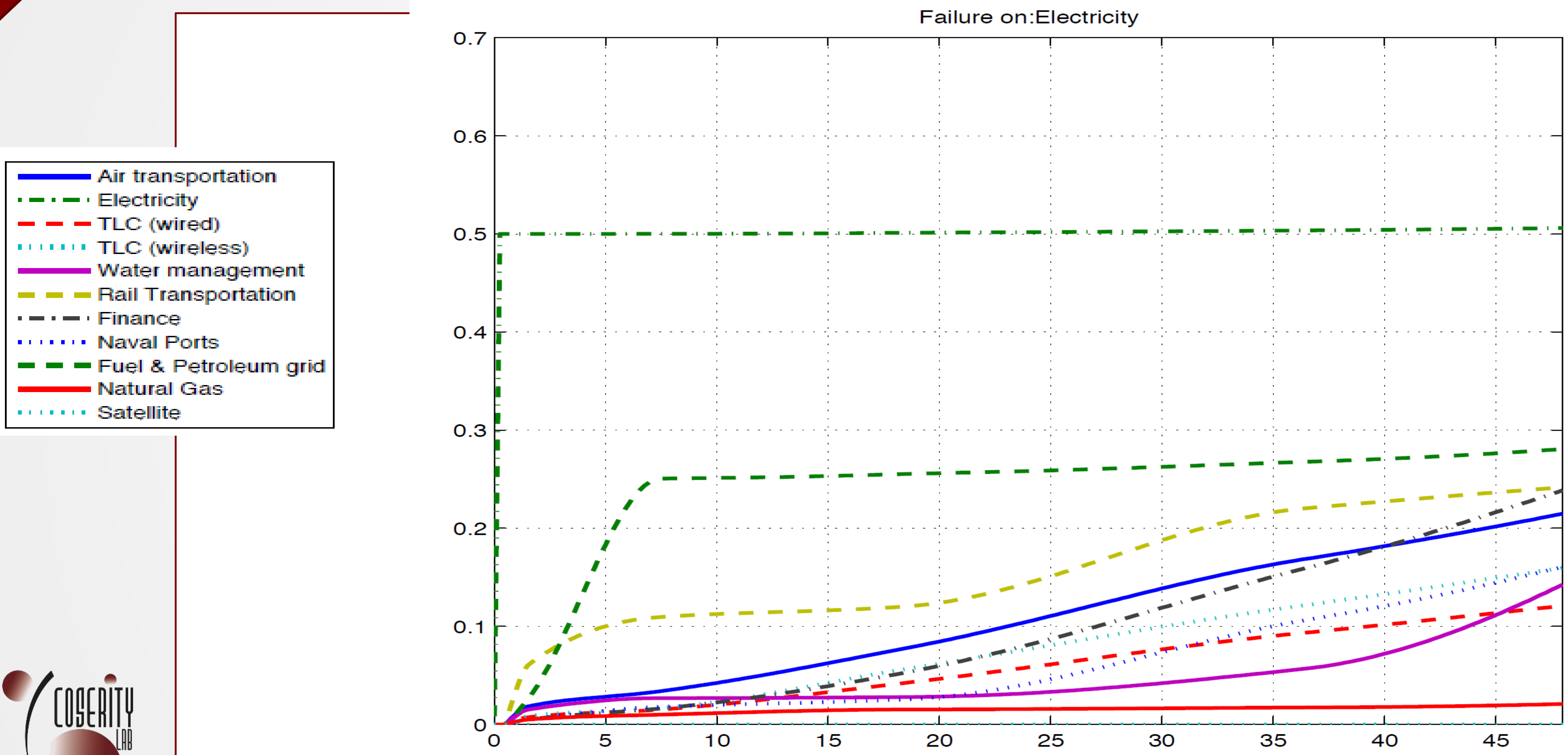
Constant: it does not change with outage period, i.e. direct link (no buffer or bck)

Linear + constant: buffer absorb partially the inoperability until expire

S-Shape: buffer absorb quite completely inoperability for a while but when expire there is a rapid degradation (no graceful degradation)

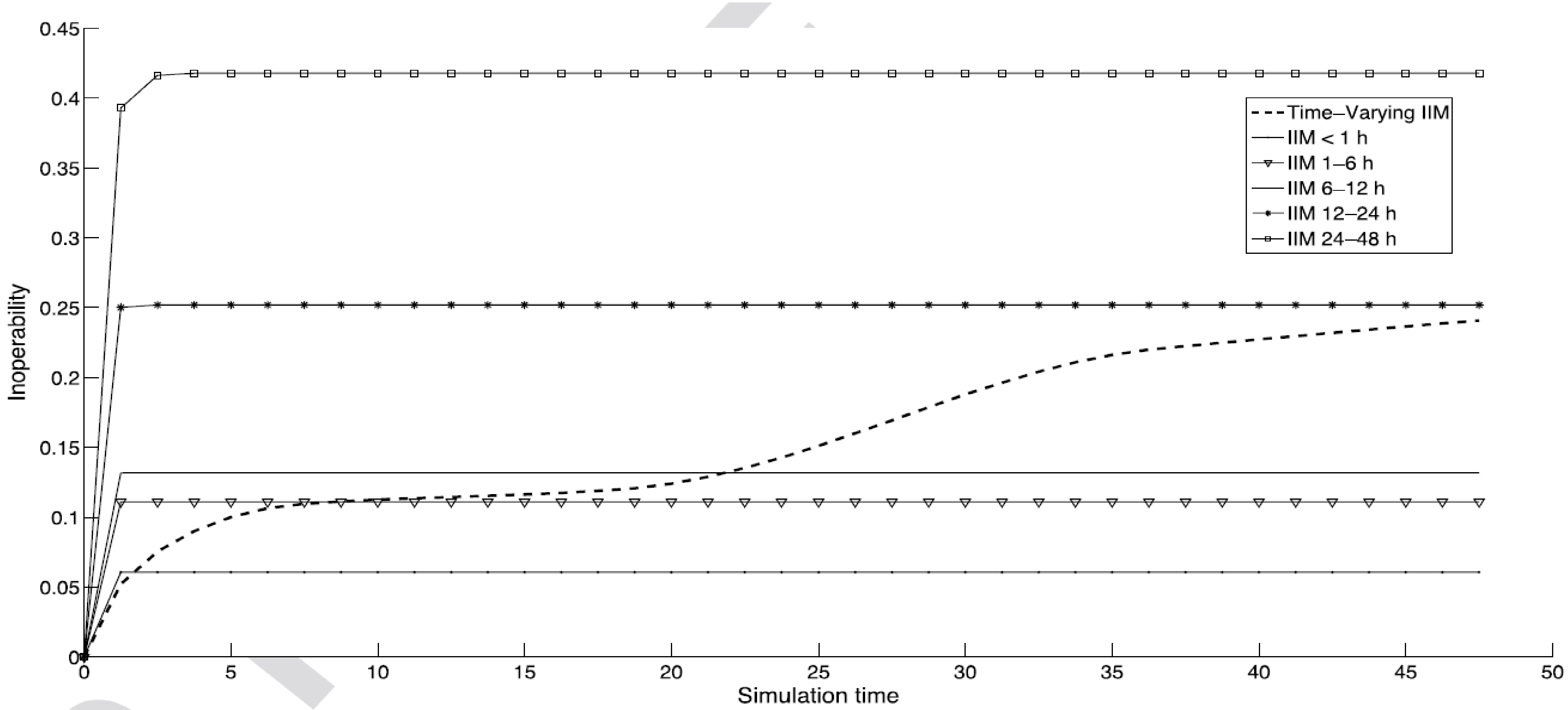
Double S-Shape: there are two type of buffers which designed to support general and prioritary aspects

Results



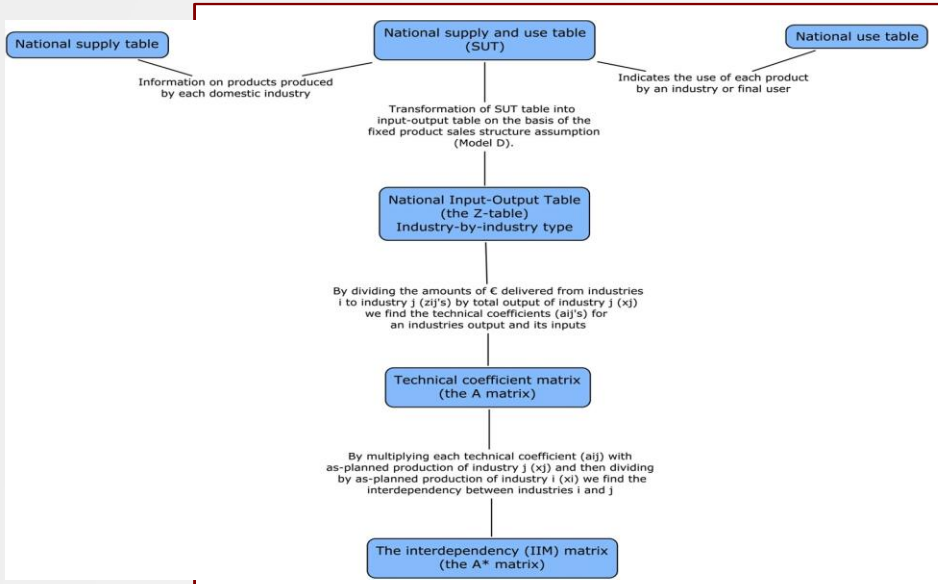
F. Conte, G. Oliva and R. Setola, Time varying Input-Output inoperability model, *International Journal on Infrastructure Systems*, 2013.

Time Varing IIM vs constaant IIM

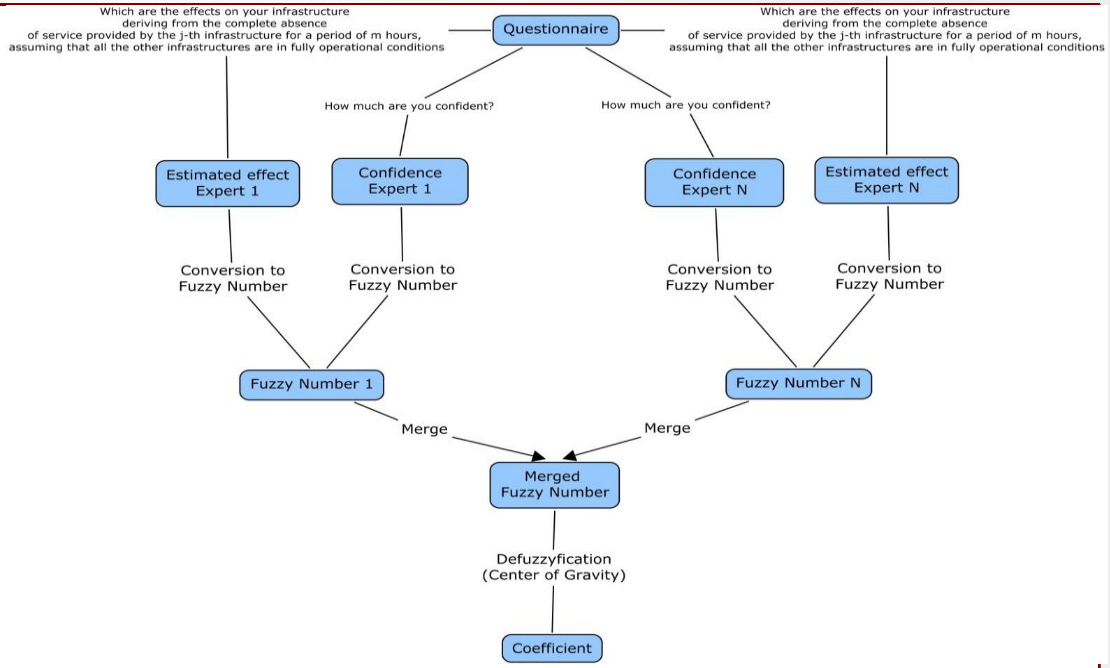


Neglecting the variation of the dependency coefficients can drive to large error

Economic vs Expericence IIM



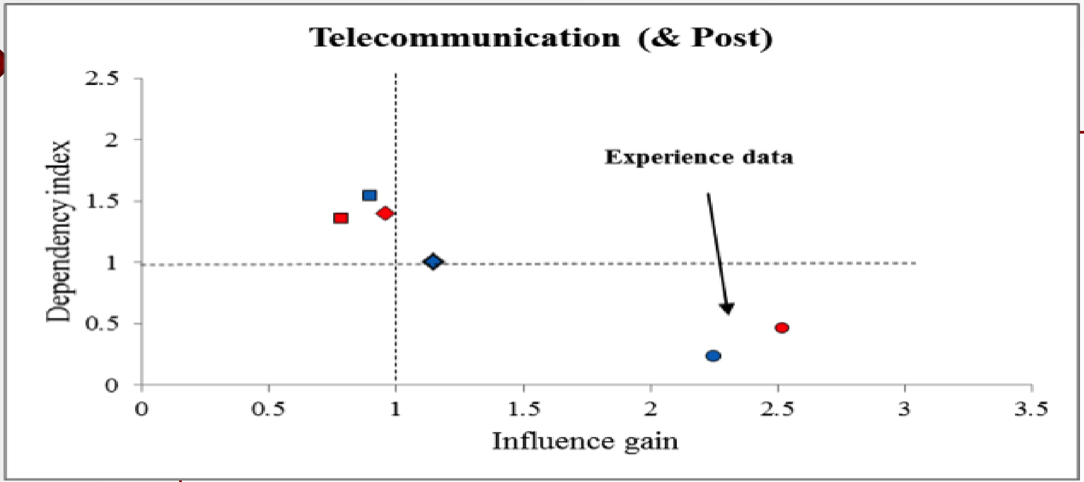
Economic IIM coefficients are elaborated on IO tables produced by national statistic body

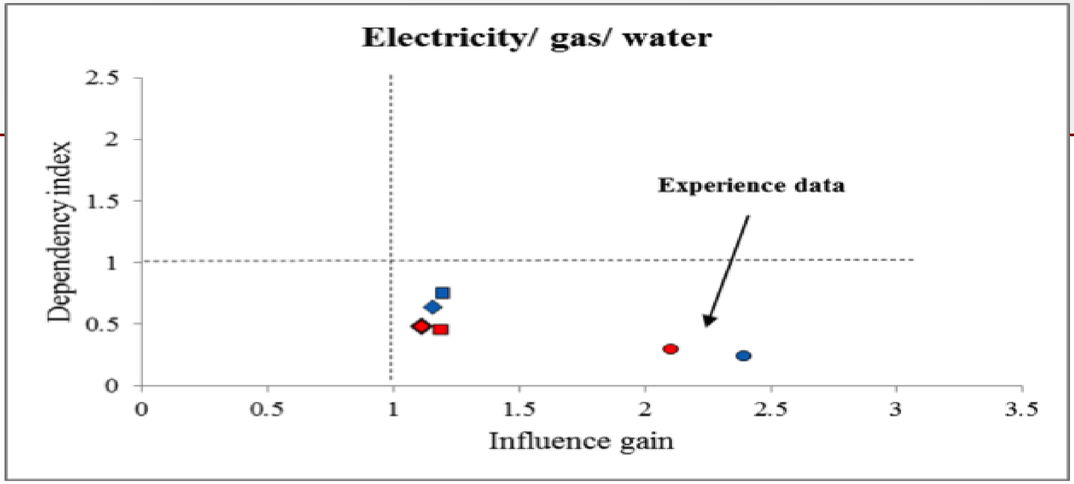


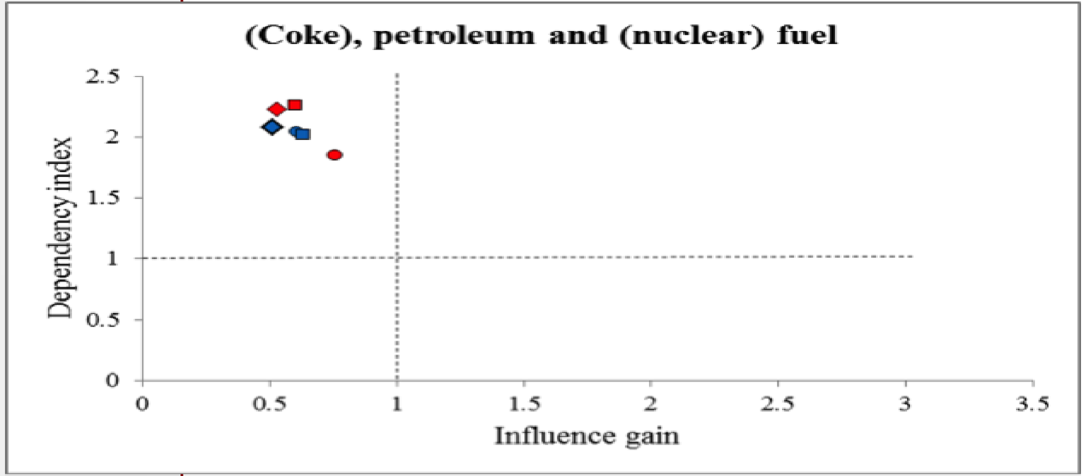
Operational IIM coefficients are elicit from expert knowledge collected via questionnaires

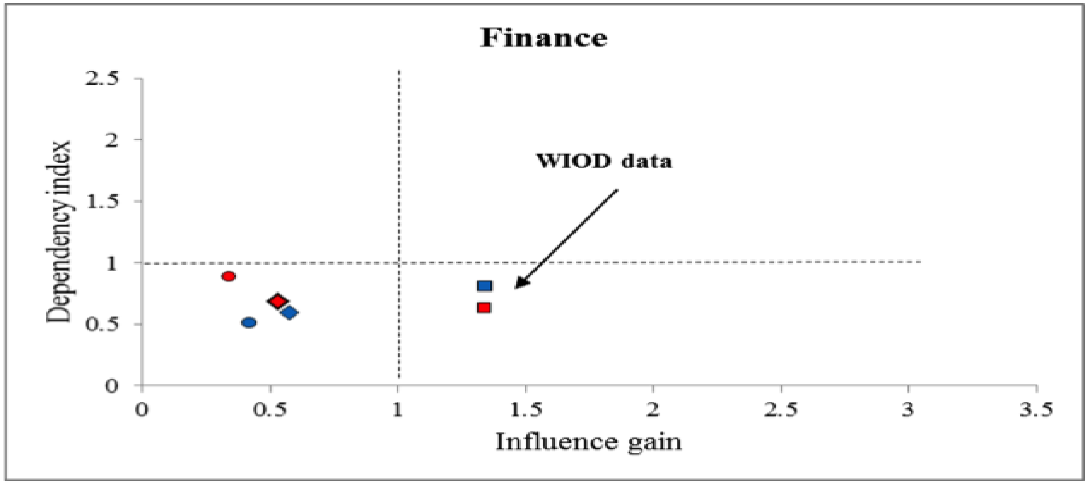
They provide comparable results ?

G. Oliva, R. Setola, D. Ward and O. Jonkeren, “Validating Economic and Experi- ence based Data for estimating Infrastructure Interdependencies”, ASCE Journal of Infrastructure Sytems, Submitted.









squares = WIOD data, diamonds = Eurostat data, circles = Experience data. Red = normalized values, blue = eigenvector values

How to answer

Impact	*Description*	*Value*
nothing	the event does not induce any effect on the infrastructure	0
negligible	the event induces some very limited and geographically bounded consequences on services that have no direct impact on the infrastructure's operativeness	0,05
very limited	the event induces some geographically bounded consequences on services that have no direct impact on the infrastructure's operativeness	0,08
limited	the event induces consequences only on services that have no direct impact on the infrastructure's operativeness	0,10
some degradations	the event induces limited and geographically bounded consequences on the capability of the infrastructure to provide its services	0,20
circumscribed degradation	the event induces geographically bounded consequences on the capability of the infrastructure to provide its services	0,30
significant degradation	the event significantly degrades the capability of the infrastructure to provide its services	0,50
provided only some services	the impact is such that the infrastructure is able to provide national-wide only some essential services	0,70
quit complete stop	the impact is such that the infrast… provide, in some geographically ar… sential servicese	
stop	the infrastructure is unable to prov…	

The experts have to use linguistic value extracted from a predefined scale

They have also to express a **grade of confidence** (accuracy) about each one of their estimation

Confidence	*Description*	*Value*
+	Good confidence	0
++	Relative confidence	$\pm 0,05$
+++	Limited confidence	$\pm 0,10$
++++	Uncertain	$\pm 0,15$
+++++	Strongly uncertain	$\pm 0,20$

The answers

A snapshot of filled questionnaires

Fiumicino/Ciampino

in presenza di una paralisi completa nelle seguenti infrastrutture
che tipo di degradazione presenta

	Per un tempo inferiore ad 1 ora		Per un tempo compreso fra 1 e 6 ore		Per un tempo compresa fra le 6 e le 12 ore		Per un tempo compresa fra le 12 e le 24 ore		Per un tempo compresa fra le 24 e le 48 ore	
	Livello di degradazione	*incertezza*	*Livello di degradazione*	*incertezza*	*Livello di degradazione*	*incertezza*	*Livello di degradazione*	*incertezza*	*Livello di degradazione*	*incertezza*
Rete di distribuzione carburante	per nulla	+	per nulla	++	per nulla	++	per nulla	+++	degradazioni significative	++++
Rete Elettrica	per nulla	+	per nulla	+	per nulla	++	per nulla	++	per nulla	++
Rete trasporto Gas	per nulla	+	per nulla	+	per nulla	+	per nulla	+	per nulla	+
Comuncazione satellitare e GPS	alcune degradazioni	+	alcune degradazioni	+	alcune degradazioni	+	alcune degradazioni	+	alcune degradazioni	+
Rete Autostradale	molto limitato	+	alcune degradazioni	+	degradazioni circoscritte	+	degradazioni circoscritte	+	degradazioni significative	+
Approviggionamento alimentare	per nulla	++	quasi insignificante	+++	molto limitato	+++	alcune degradazioni	++++	degradazioni circoscritte	+++++
Trasporto pubblico locale	quasi insignificante	+	molto limitato	+	limitato	++	limitato	++	degradazioni circoscritte	+++
Rete ferroviaria	quasi insignificante	+	quasi insignificante	+	molto limitato	+	molto limitato	++	limitato	++
Sistema Idrico (acqua potabile)	quasi insignificante	+++	molto limitato	+++	molto limitato	+++	limitato	+++	limitato	+++
Fornitura servizi di TLC fissi	limitato	++	degradazioni circoscritte	++	degradazioni circoscritte	+++	degradazioni significative	+++	degradazioni significative	++++
Fornitura servizi di TLC mobili	quasi insignificante	+++	quasi insignificante	+++	quasi insignificante	++++	quasi insignificante	++++	quasi insignificante	+++++
Servizi TLC [illegible] mobili (contempor	limitato	++	degradazioni circoscritte	++	degradazioni circoscritte	+++	degradazioni significative	+++	degradazioni significative	++++
Circuiti Bancari (transazione e cash)	per nulla	+++++	quasi insignificante	+++++	molto limitato	+++++	alcune degradazioni	+++++	degradazioni circoscritte	+++++
Sistema portuale	per nulla	+	per nulla	+	per nulla	+	per nulla	+	per nulla	+
							molto limitato	+++++	limitato	+++++
							alcune degradazioni	+++	degradazioni circoscritte	++
							paralisi	+	paralisi	+
							paralisi	+	paralisi	+

degradazioni circoscritte	++	degradazioni circoscritte	+++
quasi insignificante	+++	quasi insignificante	++++

Perceived Severity	Description	Value
nothing	the event does not induce any effect on the infrastructure/land	0
negligible	the event induces some very limited and geographically bounded consequences that have no direct impact on the infrastructure's or land's operativeness	0.025
very limited	the event induces some geographically bounded consequences that have no direct impact on the infrastructure's or land's operativeness	0.05
limited	the event induces consequences only on subsystems/zones that have no direct impact on the infrastructure's or land's operativeness	0.1
circumscribed degradation	the event induces geographically bounded consequences	0.2
significant degradation	the event significantly degrades the operativeness of the infrastructure/land	0.30
severe degradation	the impact on the infrastructure/land is severe	0.500
quite complete stop	the impact is quite catastrophic	0.700
stop	total disruption	1

Criticality Scale

Confidence	Description	Value (severity)	Value (growth)
*	Perfect Knowledge (no uncertainty)	0	0
* *	Excellent confidence	±0.005	±0.0005
* * *	Good confidence	±0.050	±0.0050
* * * *	Relative Confidence	±0.100	±0.0100
* * * * *	Uncertain	±0.200	±0.0200

Confidence Scale

Data collected via questionnaire have also information about the quality of data

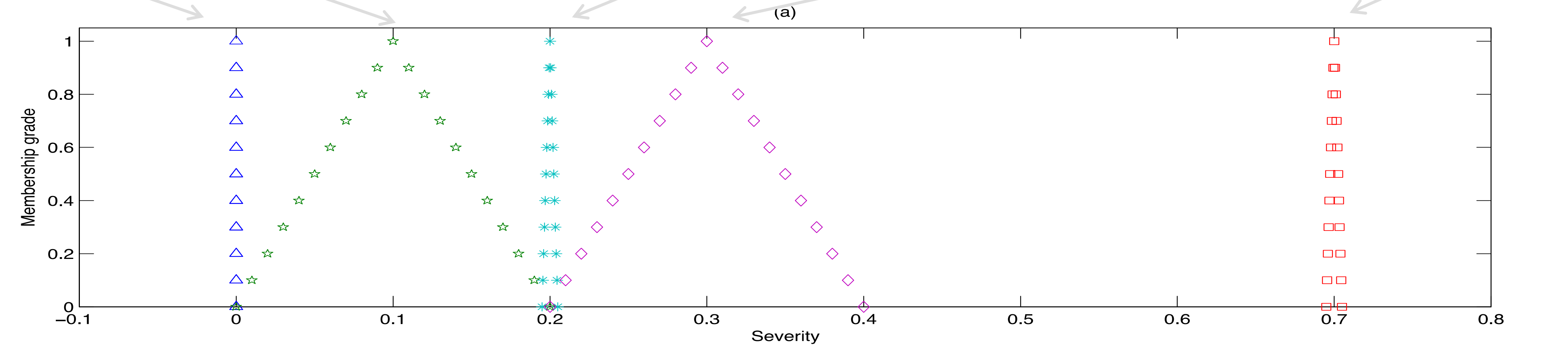
Nothing (Certain)

Limited (Relative Confidence)

Circumscribed (Excellent Confidence)

Significant (Relative Confidence)

Quite Catastrophic (Excellent Confidence)



Complex Syste

Fuzzy IIM

ID	# 1	# 2	# 3	# 4	# 5	# 6	# 7	# 8	# 9	# 10	# 11
# 1	0.0000 **0.0000** 0.0000	0.0000 **0.0000** 0.0000	0.0056 **0.0056** 0.0064	0.0010 **0.0010** 0.0035	0.0050 **0.0050** 0.0050	0.0000 **0.0000** 0.0033	0.0000 **0.0000** 0.0000	0.0000 **0.0035** 0.0120	0.0080 **0.0080** 0.0080	0.0000 **0.0000** 0.0050	0.0000 **0.0000** 0.0000
# 2	0.1321 **0.1339** 0.1368	0.0000 **0.0000** 0.0000	0.0779 **0.0821** 0.0873	0.1054 **0.1094** 0.1134	0.0500 0.0500 0.0500	0.2317 0.2333 0.2350	0.0900 **0.1000** 0.1100	0.0300 **0.036** 0.0420	0.5000 **0.5000** 0.5000	0.0150 **0.0300** 0.0450	0.0000 **0.0000** 0.0000
# 3	0.3936 **0.3993** 0.5800	0.0233 **0.0233** 0.0233	0.0000 **0.0000** 0.0000	0.1149 **0.1203** 0.1258	0.0100 **0.0200** 0.0300	0.1060 **0.1093** 0.1127	0.0900 **0.1000** 0.1100	0.0355 **0.0390** 0.0425	0.0500 **0.0500** 0.0500	0.0050 **0.0050** 0.0050	0.0000 **0.0000** 0.0000
# 4	0.2283 **0.2339** 0.4552	0.0070 **0.0098** 0.0127	0.0085 **0.0128** 0.0179	0.0000 **0.0000** 0.0000	0.0000 **0.0080** 0.0180	0.0993 **0.1027** 0.1093	0.0250 **0.0300** 0.0350	0.0355 **0.0390** 0.0425	0.1000 **0.1000** 0.1000	0.0000 **0.0080** 0.0180	0.0000 **0.0000** 0.0000
# 5	0.0235 **0.0330** 0.0430	0.0015 **0.0015** 0.0015	0.0010 **0.0025** 0.0065	0.0010 **0.0010** 0.0035	0.0000 **0.0000** 0.0000	0.0017 **0.0043** 0.0077	0.0000 **0.0050** 0.0150	0.0200 **0.0260** 0.0320	0.0500 **0.0500** 0.0500	0.0050 **0.0050** 0.0050	0.0000 **0.0000** 0.0000
# 6	0.0169 **0.0243** 0.0317	0.0013 **0.0028** 0.0043	0.0016 **0.0016** 0.0056	0.0016 **0.0046** 0.0086	0.0000 **0.0050** 0.0100	0.0000 **0.0000** 0.0000	0.0000 **0.0000** 0.0100	0.0175 **0.0235** 0.0295	0.0200 **0.0200** 0.0200	0.0000 **0.0000** 0.0000	0.0000 **0.0000** 0.0000
# 7	0.0000 **0.0089** 0.0215	0.0000 **0.0000** 0.0000	0.0025 **0.0040** 0.0065	0.0010 **0.0010** 0.0050	0.0030 **0.0080** 0.0130	0.0033 **0.0067** 0.0117	0.0000 **0.0000** 0.0000	0.0105 **0.0165** 0.0225	0.0200 **0.0200** 0.0200	0.0000 **0.0000** 0.0050	0.0000 **0.0000** 0.0000
# 8	0.0000 **0.0000** 0.0031	0.0080 **0.0080** 0.0080	0.0010 **0.0010** 0.0050	0.0010 **0.0010** 0.0035	0.0000 **0.0050** 0.0100	0.0000 **0.0000** 0.0050	0.0000 **0.0000** 0.0100	0.0000 **0.0000** 0.0000	0.0200 **0.0200** 0.0200	0.0000 **0.0050** 0.0100	0.0000 **0.0000** 0.0000
# 9	0.0204 **0.0234** 0.0275	0.0022 **0.0022** 0.0022	0.0010 **0.0010** 0.0021	0.0010 **0.0010** 0.0035	0.0080 **0.0080** 0.0080	0.0017 **0.0050** 0.0100	0.0000 **0.0000** 0.0100	0.0110 **0.0170** 0.0230	0.0000 **0.0000** 0.0000	0.0050 **0.0050** 0.0050	0.0000 **0.0000** 0.0000
# 10	0.0000 **0.0059** 0.0133	0.1785 **0.1785** 0.1785	0.0016 **0.0031** 0.0071	0.0016 **0.0031** 0.0071	0.0030 **0.0080** 0.0130	0.0000 **0.0000** 0.0033	0.0000 **0.0050** 0.0150	0.0120 **0.0180** 0.0240	0.0000 **0.0000** 0.0000	0.0000 **0.0000** 0.0000	0.0000 **0.0000** 0.0000
# 11	0.2313 **0.2378** 0.4552	0.0043 **0.0043** 0.0043	0.0015 **0.0044** 0.0094	0.0021 **0.0061** 0.0111	0.0150 **0.0200** 0.0250	0.0000 **0.0027** 0.0093	0.0030 **0.0080** 0.0130	0.0250 **0.0285** 0.0320	0.0080 **0.0080** 0.0080	0.0050 **0.0050** 0.0050	0.0000 **0.0000** 0.0000

ID	Infrastructure
1	Air Transportation
2	Electricity
3	Telecommunications (Wired)
4	Telecommunications (Wireless)
5	Water Management
6	Rail Transportation
7	Finance
8	Naval Ports
9	Fuel and Petroleum Grid
10	Natural Gas
11	Satellite Communications and Positioning

G. Oliva, S. Panzieri and R. Setola, Fuzzy Dynamic Input-Output Inoperability Model, international Journal on Critical Infrastructure Protection, 2011.

IIM Fuzzy (state) System

$$\mathbf{x}(k+1) = \mathbf{F}(\mathbf{x}(k), k); \quad \mathbf{x}(0) = \mathbf{x}_0$$

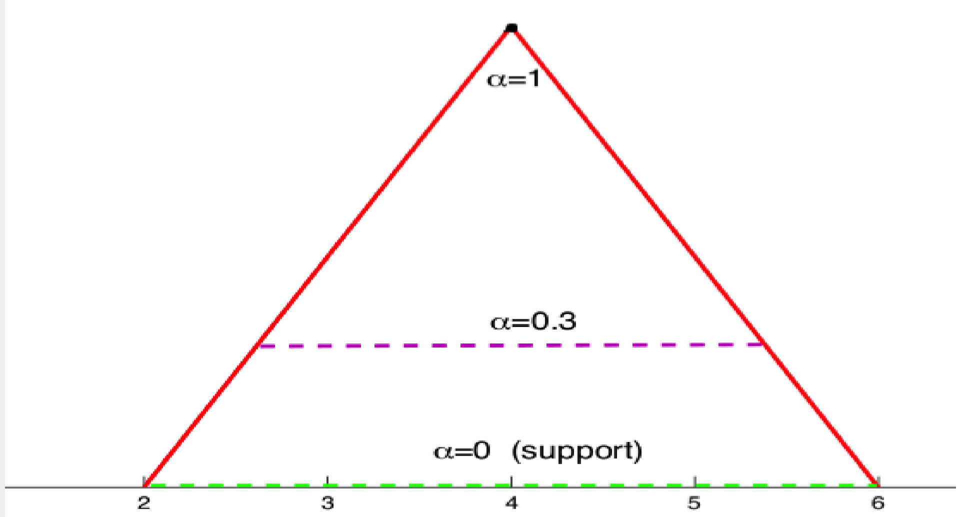
$$\mathbf{x}, \mathbf{x}_0 \in \mathbb{E}^N$$

We consider systems with fuzzy state and crisp parameters

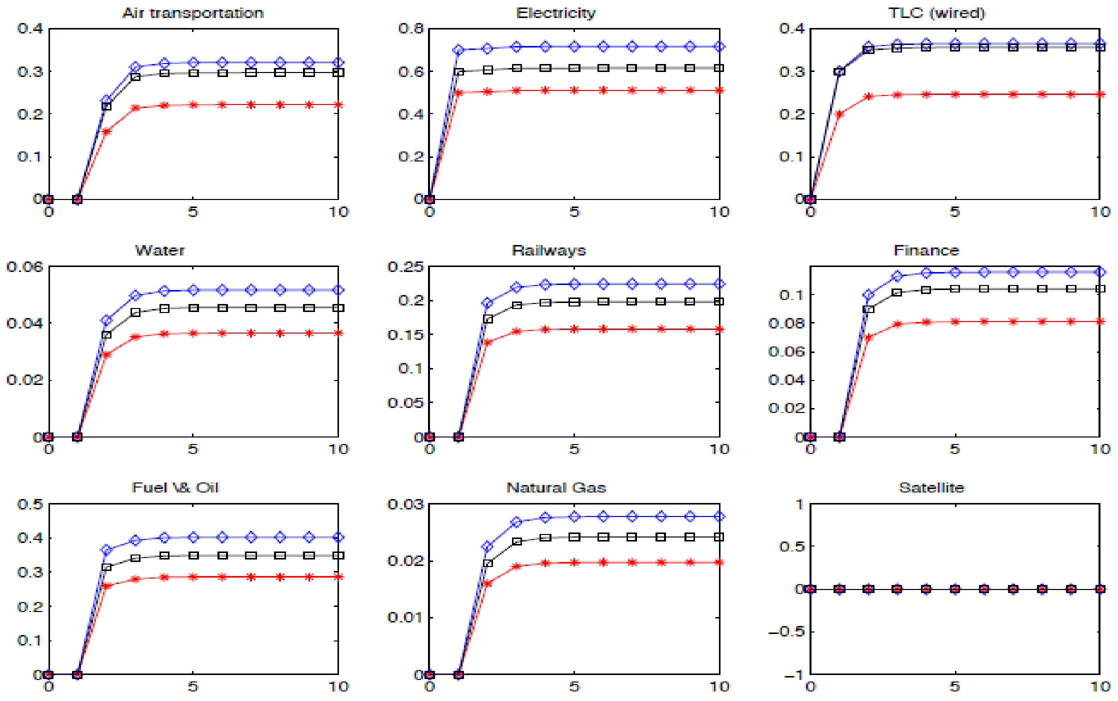
The state variables are represented by fuzzy sets

The α-level $[x]^\alpha$ of a fuzzy set is the subset of points with membership grade ≥α

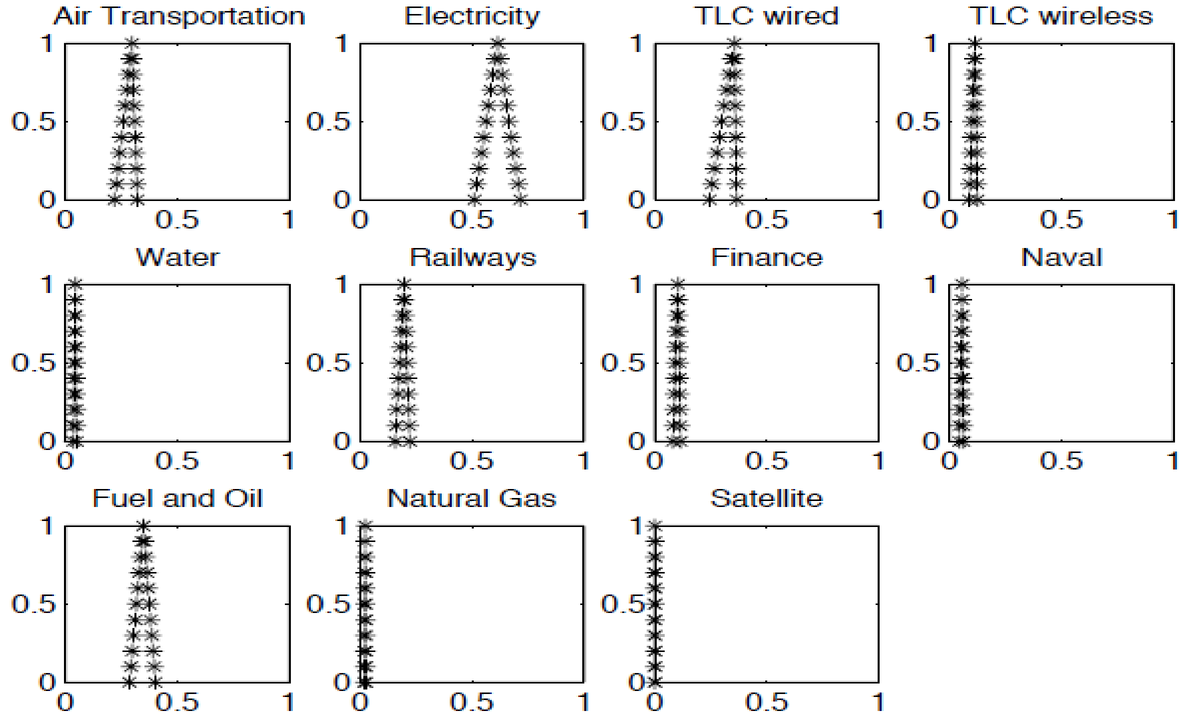
The distance is defined as the maximum difference in the membership grades



Results IIM Fuzzy

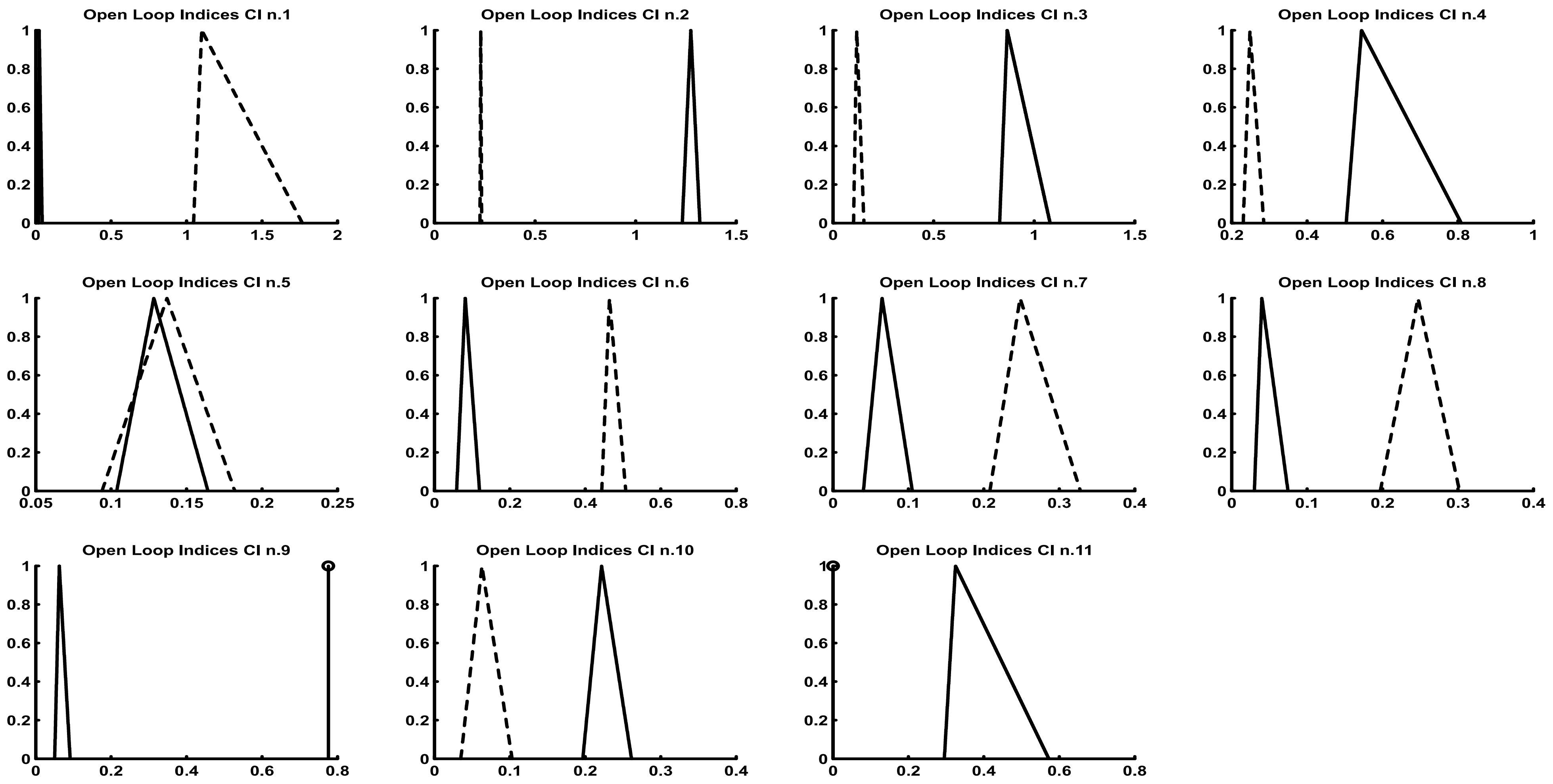


Provide best, worst and most beliveble solutions



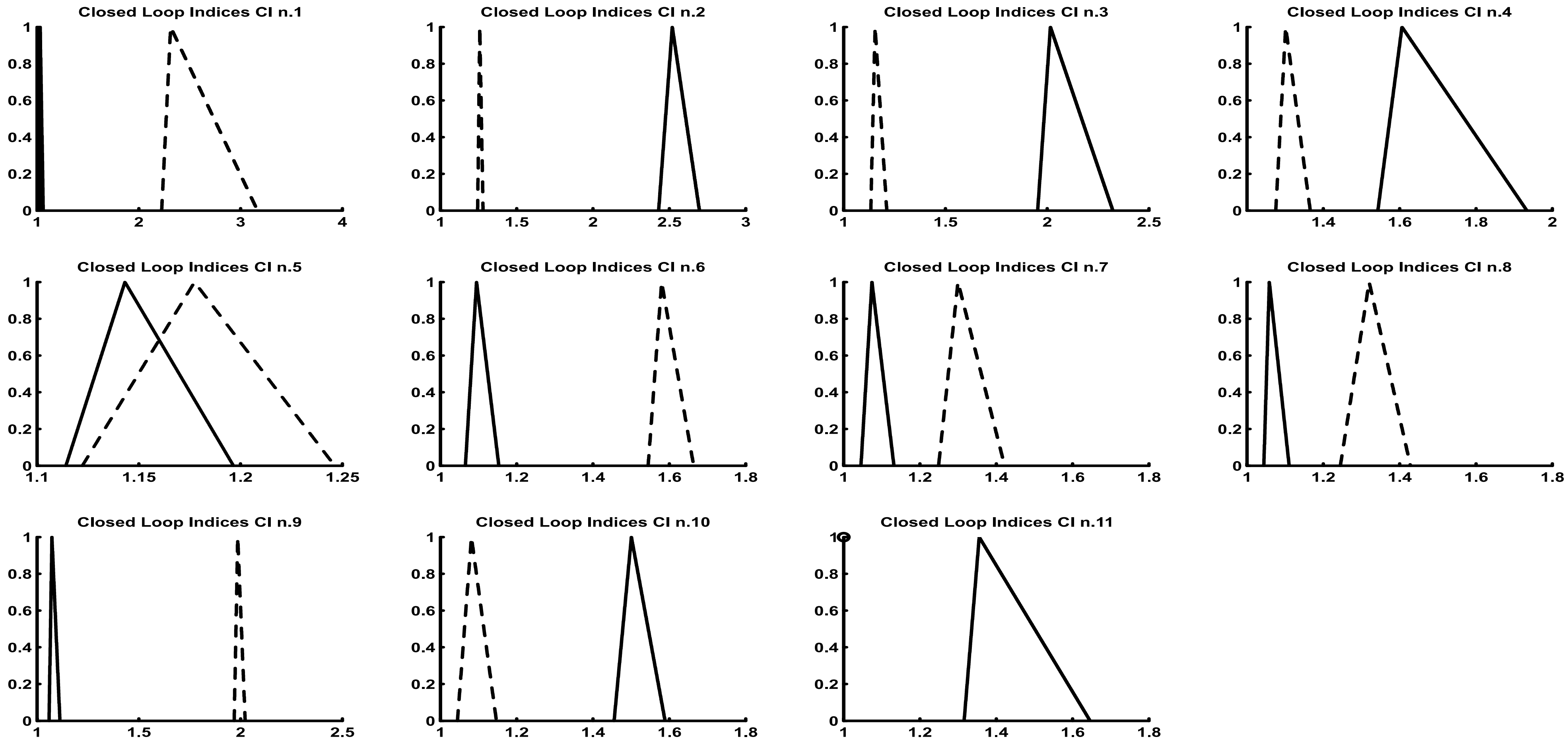
Consequences of a «severe failure» in the electric grid (c_2=[0,5, 0,6, 0,7]) in conjuction with a «moderate failure» in the wired TLC network (c_3=[0,2, 0,3, 0,35])

Open loop IIM fuzzy indicators



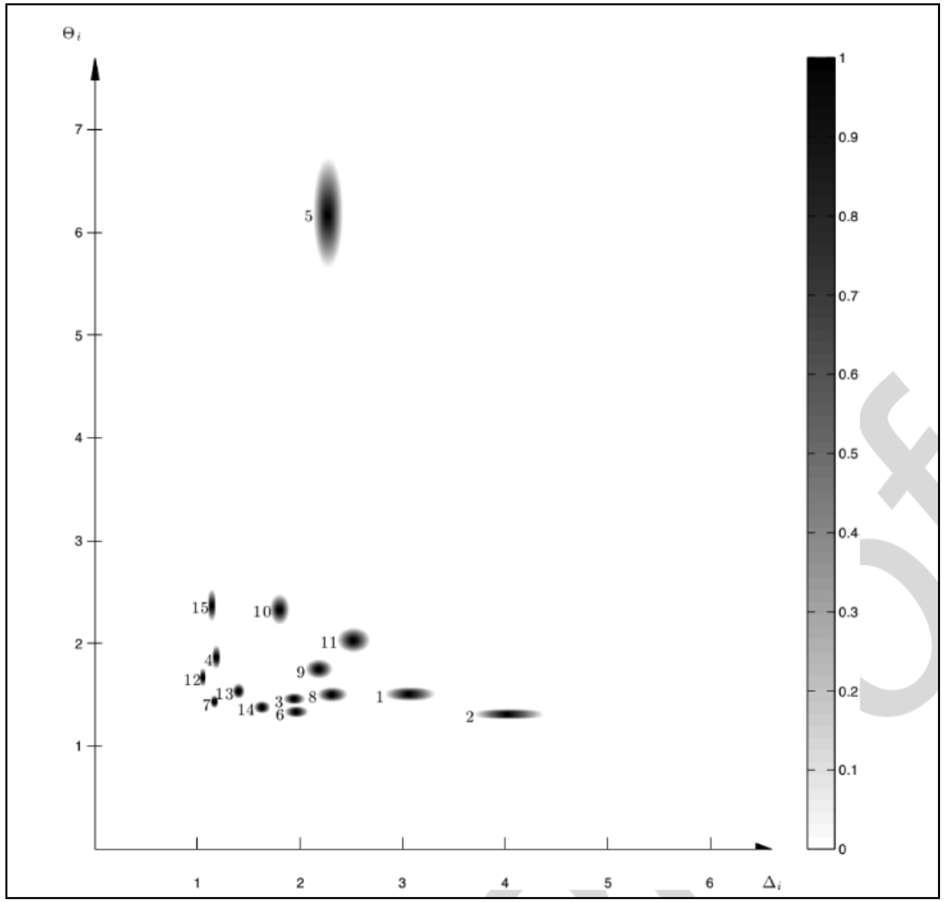
Solid line = dependency index; Dotted line = influence gain

Closed loop IIM fuzzy indicators

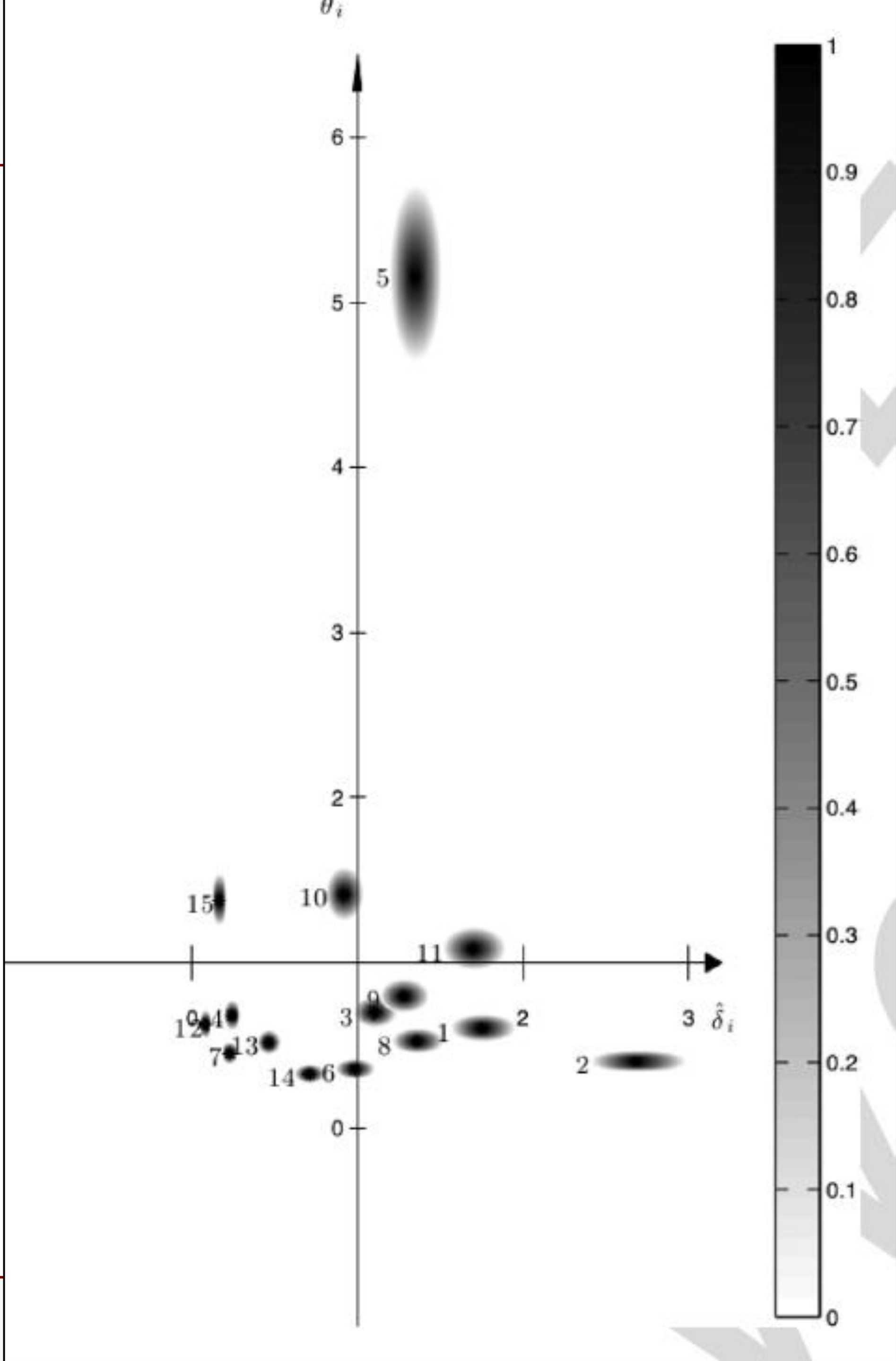


Solid line = dependency index; Dotted line = influence gain

Criticality map



(dependency index, influence gain) plan



Conclusion

IIM is an interesting tool for understand the (inter)dependency phenomena

It is (quite) easy to set-up and manage

Unfortunately it capture only some phenomena and it is useful for strategic analysis rather than operational consideration r.setola@unicampus.it

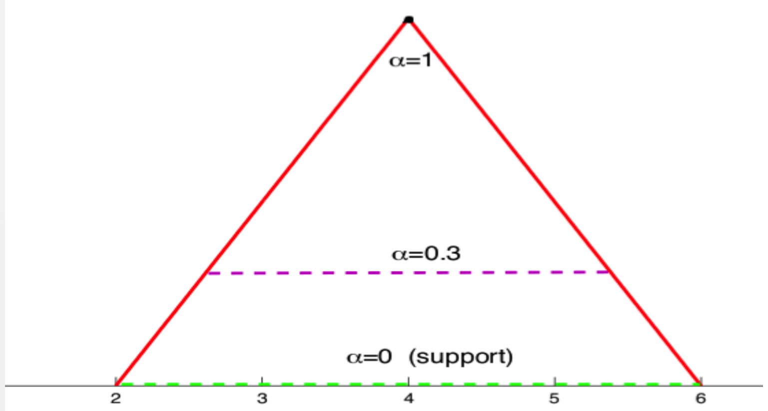
IIM Fuzzy System

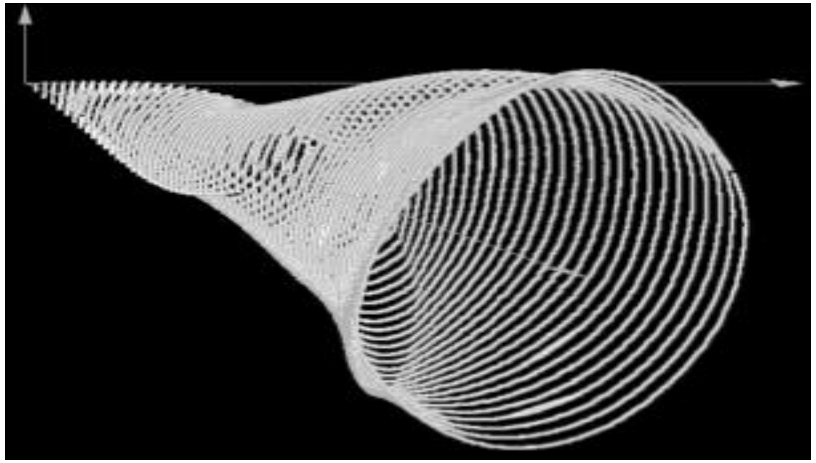
$$x(k+1) = Hx(k), \quad x(0) = X_0 \in E^n$$

H is a nxn fuzzy-value matrix, i.e. $h_{ij} \in \mathbb{E}$

To solve, we have to translate the fuzzy-equation into a family of discrete difference inclusions

$$[x]^\alpha(k+1) \in [H]^\alpha [x]^\alpha(k); \quad [x]^\alpha(0) = [X_0]^\alpha; \quad 0 \leq \alpha \leq 1$$





AGENZIA NAZIONALE PER LE NUOVE TECNOLOGIE, L'ENERGIA E LO SVILUPPO ECONOMICO SOSTENIBILE

Topological properties of complex networks and their relevance in functional and vulnerability assessments of Critical Infrastructures

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ENEA
Computing and Technological Infrastructures Lab.
Casaccia Research Center
Roma

CIPRNET Dissemination Lecture

Complex Systems - 0

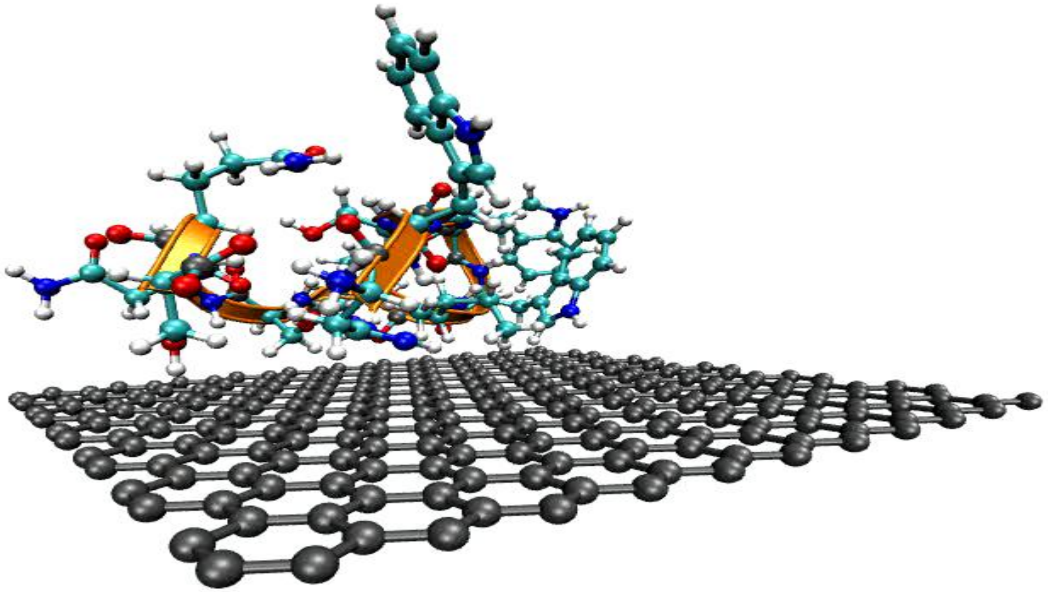
Objective of this lecture:

Show basic features of complex networks and the existence of a line of study allowing to extract a number of information from very basic data on complex infrastructures.

Such type of analysis (graph theory), coupled with simple dynamical model, can provide information on very complex properties.

Complex Systems - 1

- Physical self-assembled systems assume their “unavoidable” structure by minimizing a “known” free energy function.



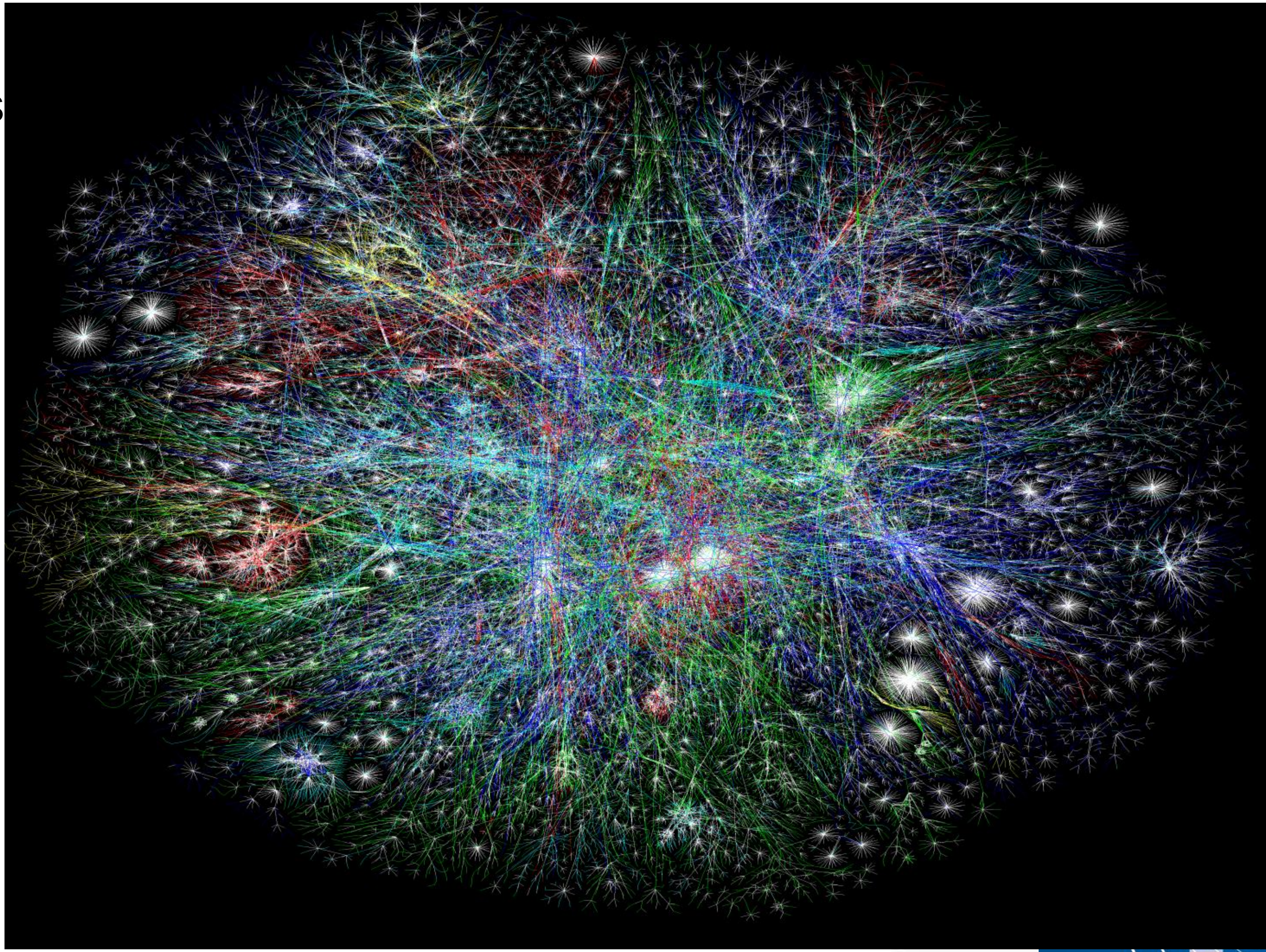
- Known laws control their time behavior
- Growth follows Free Energy minimization

Complex Systems - 2

•There are other types of N-component systems called “Complex Systems” as they cannot be represented by an hamiltonian description

•Unknown growth rules (if any) control their growth and time behavior

•Structure and function are sometimes independent, sometimes tightly co-regulated.



Complex Systems - 3

Complexity stems in

- the intrinsic “non linearity” of growth and
- <u>the emergence of properties which cannot be simply explained on the bases of the properties and behavior of its components</u>.

These are main ingredients of complexity

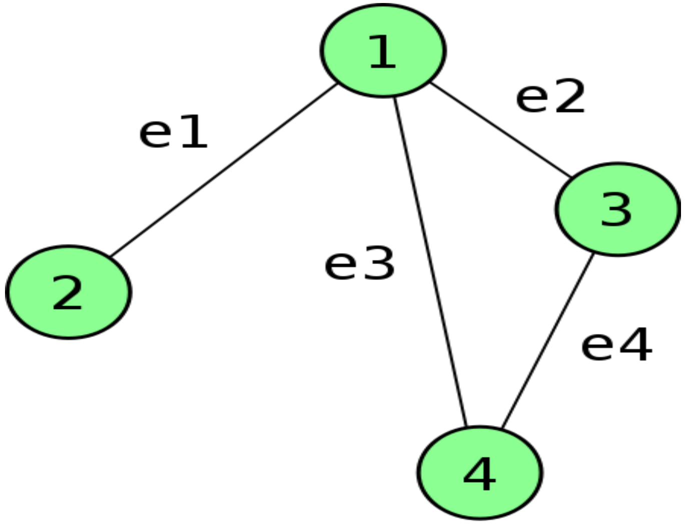
Some examples of complex systems

- ❑ The Internet
- ❑ A people community (social network)
- ❑ Roads and motorways
- ❑ Metabolic networks
- ❑ ……

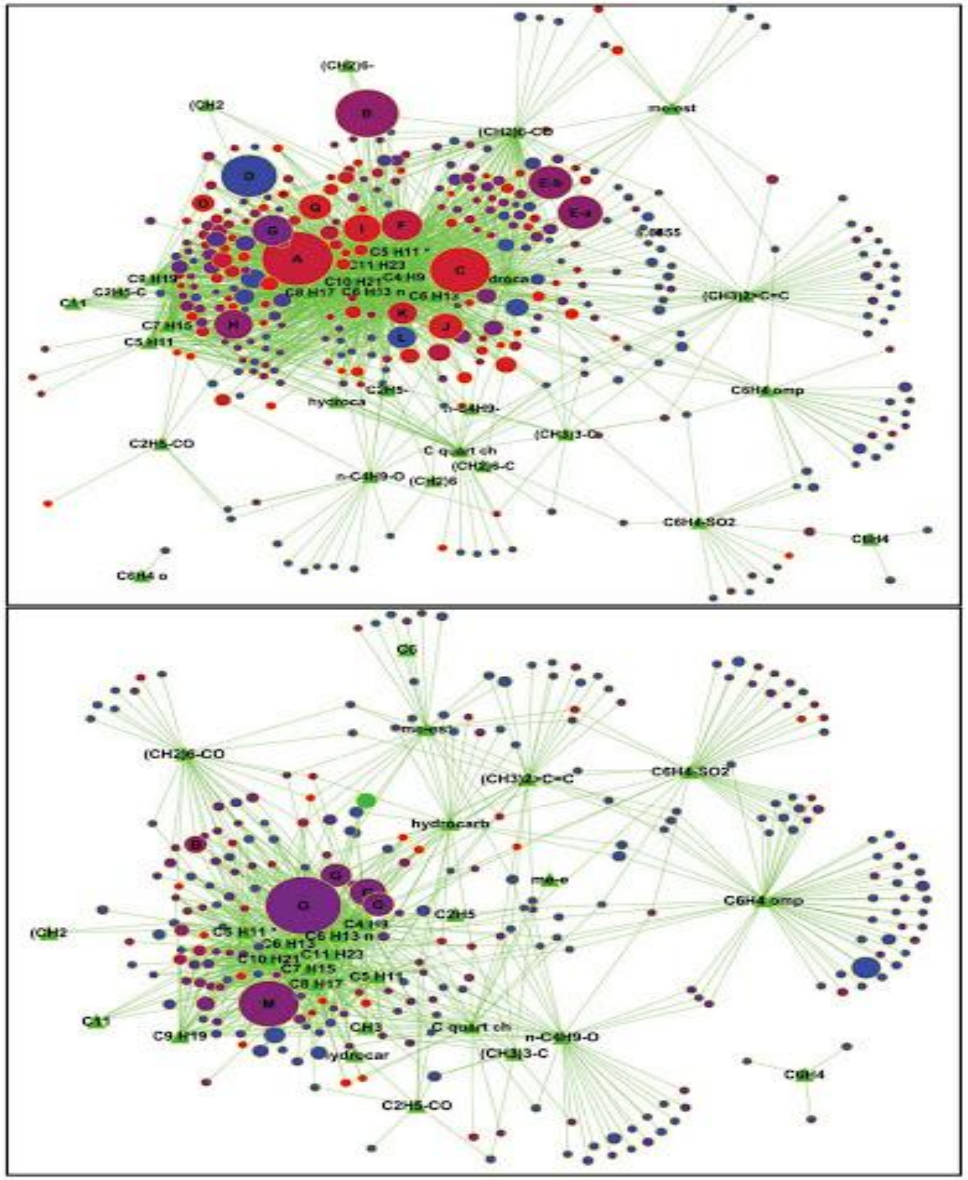
Complex Systems - 4

- Complex systems tend to have remarkably similar structures from the topological viewpoint
- This characteristics has triggered the analysis of their more abstract structure, i.e. the “network” they form.
- An aggregation of N-bodies could be, at the lowest level of description, represented by a graph where

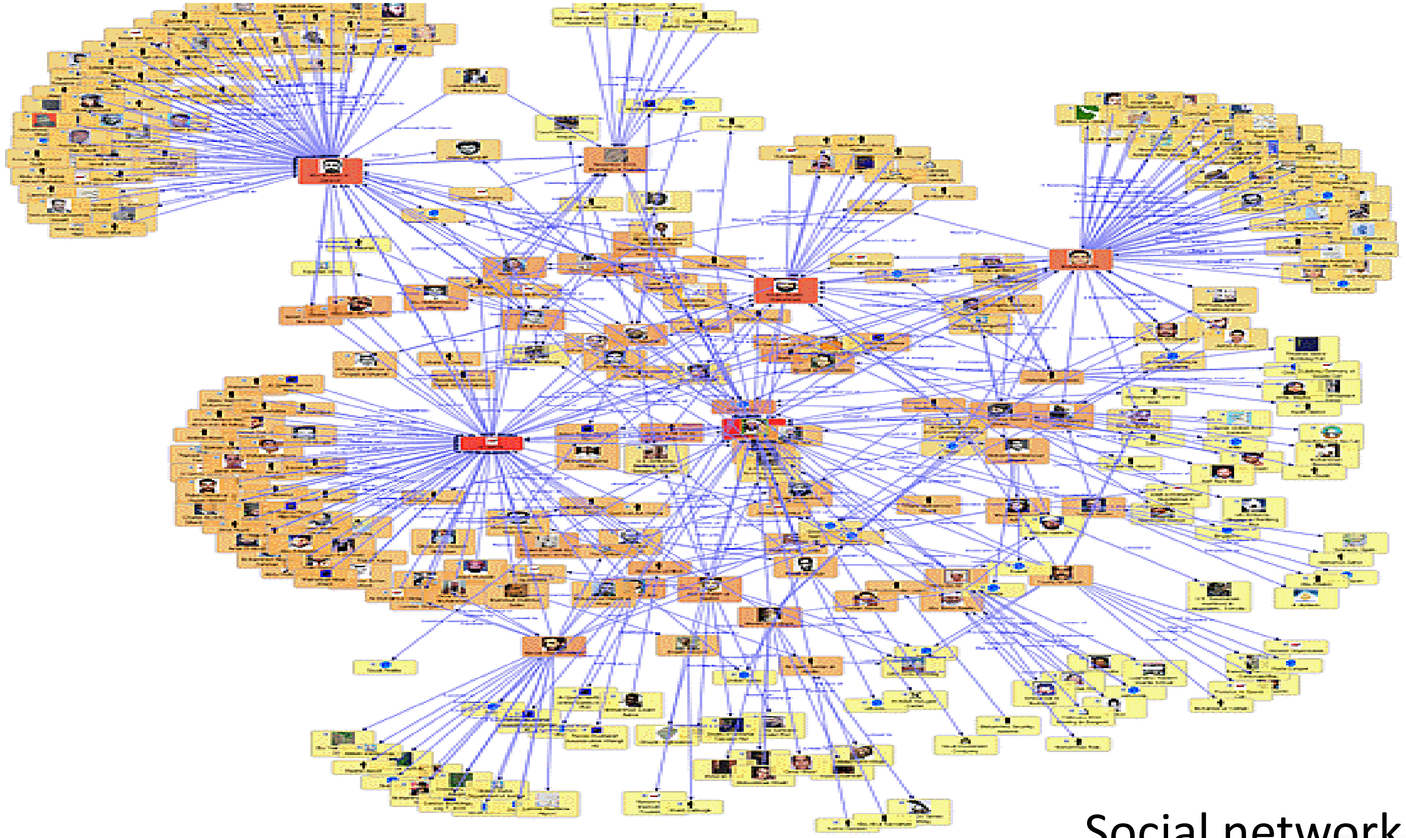
  - NODES are the connected elemental entities
  - LINKS are the physical (or functional) relations connecting them



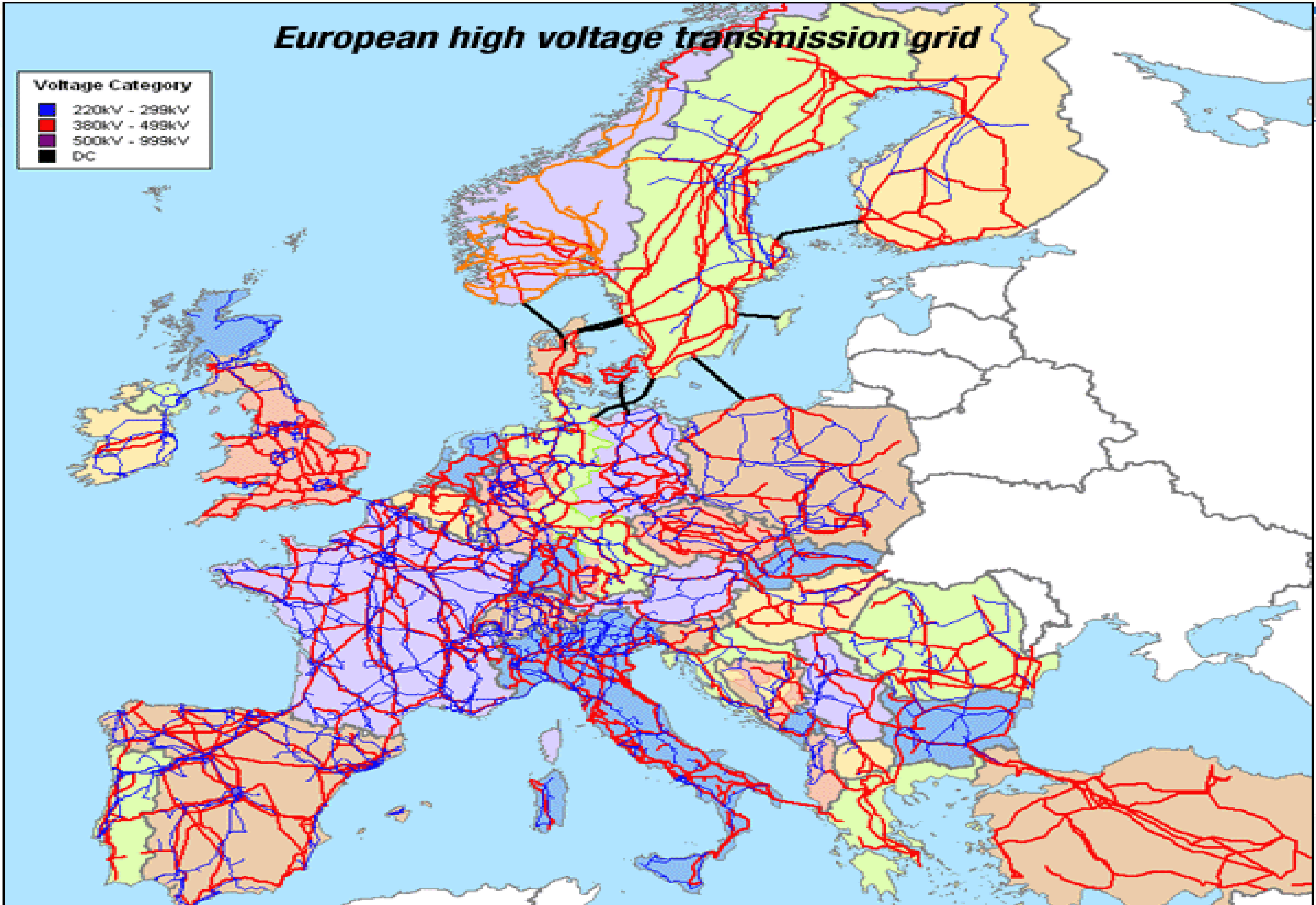
Complex Systems - 5



Protein networks



Social network


European high voltage transmission grid
Voltage Category
220kV - 299kV
380kV - 499kV
500kV - 999kV
DC

Complex Systems - 6

The analysis of Complex Systems has revealed that:

- CS's tend to assume a "robust" structure (minimize perturbation upon faults)

- CS's tend to maximize their "functionality" (ability to perform specific tasks)

R.Albert, A.-L. Barabasi, Rev. Mod. Phys. **74** (2002) 47

S.Boccaletti et al., Phys. Reports, **424** (2006) 175

Goals of the lecture

1. Show how self-assembly under "complexity" pressure allows systems to structure themselves in a way they can reach robustness AND functionality

1. Show that they gain advantages by assuming certain types of topological structures

2. Understand the intimate relationship between structure and function, allowing (in many cases) to gain insights on functional properties looking simply at their topological properties.

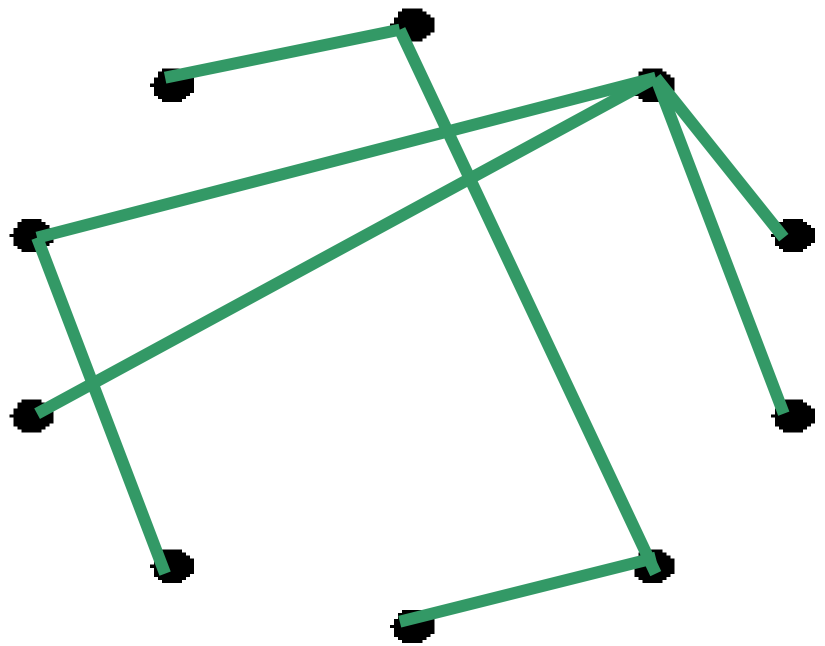
Goals of the lecture

4. With the use of simple dynamical models implementing the “traffic” on the networks, show how structures and functions are related one to the other.

5. Using these models, we could study either “physiological” and “pathological” conditions (i.e. upon damages created by threats) thus studying their vulnerability and the extent of their resilience

Better an approximate number than nothing at all….
(unknown physicists, 20th century)

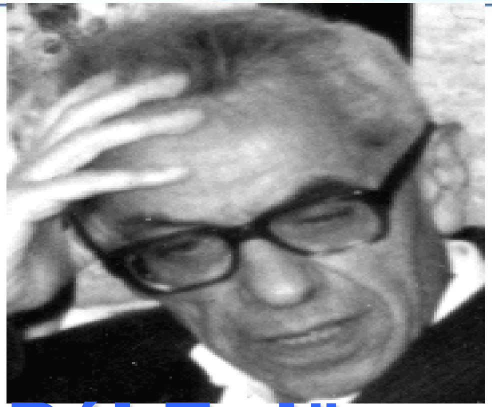
Random networks



Connect with probability p

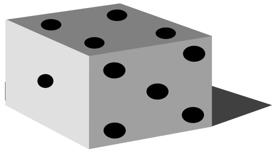
p=1/9

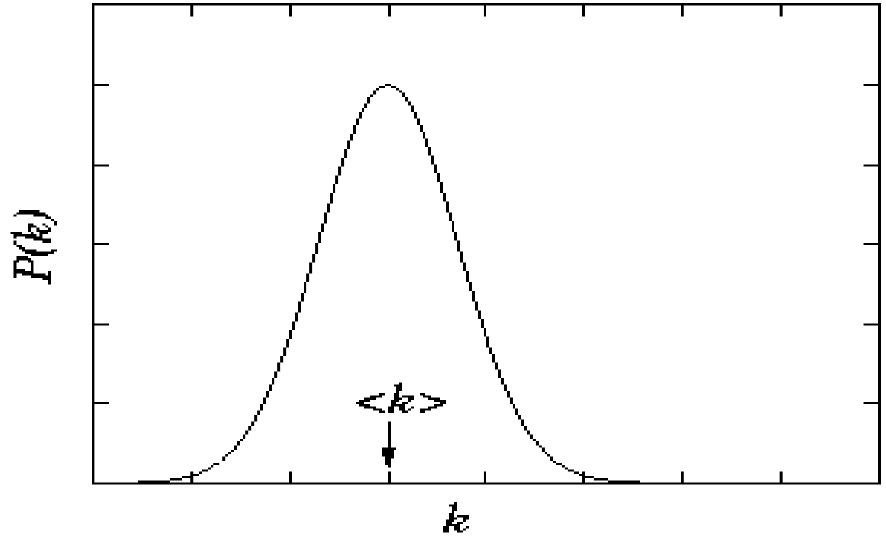
N=10 ⟨k⟩ ~ 1.5



Pál Erdös (1913-1996)

Poisson distribution



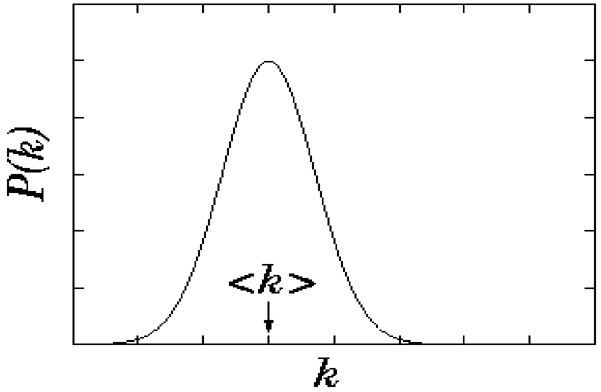


- Democratic

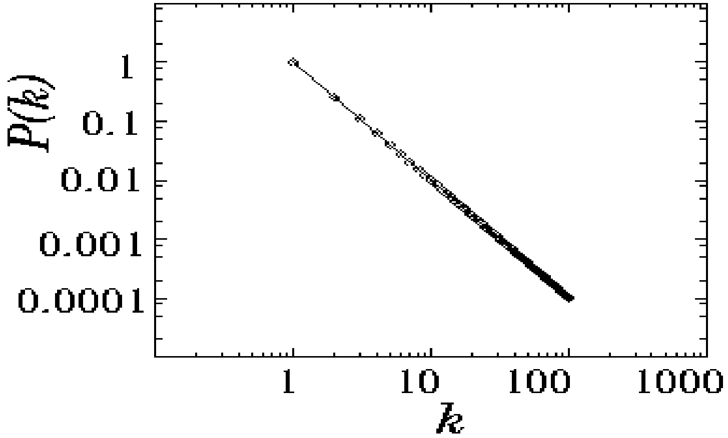
- Random

Types of network topologies

Poisson distribution

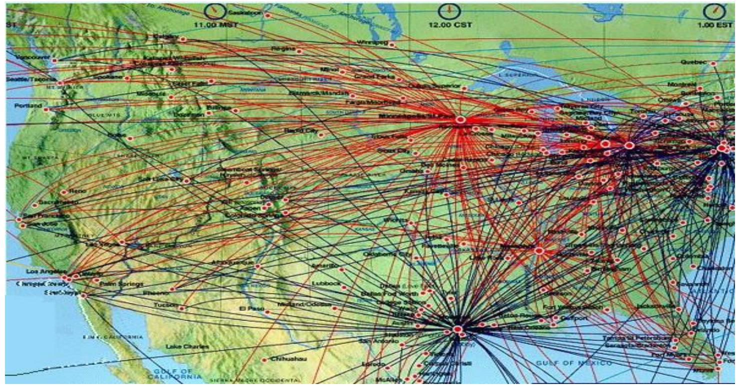


Power-law distribution



$P(k)=k^{-\gamma}$

Exponential Network



Scale-free Network

Why scale free network are “better” than random networks

A seminal paper (Nature, 2001), Barabasi et al. showed how in protein networks, “hubs” correspond to protein whose elimination brings the cell to death. The cell, in turn, is less vulnerable to the removal of nodes with lower k.

That means that scale free structure seems to be a relevant pre-requisite to ensure network robustness against random faults. In turn, this exposes the cell to be more vulnerable for “focussed” faults (attacks?)

brief communications

Lethality and centrality in protein networks

The most highly connected proteins in the cell are the most important for its survival.

Proteins are traditionally identified on the basis of their individual actions as catalysts, signalling molecules, or building blocks in cells and microorganisms. But our post-genomic view is expanding the protein's role into an element in a network of protein–protein interactions as well, in which it has a contextual or cellular function within functional modules[1,2]. Here we provide quantitative support for this idea by demonstrating that the phenotypic consequence of a single gene deletion in the yeast *Saccharomyces cerevisiae* is affected to a large extent by the topological position of its protein product in the complex hierarchical web of molecular interactions.

The *S. cerevisiae* protein–protein interaction network we investigate has 1,870 proteins as nodes, connected by 2,240 identified direct physical interactions, and is derived from combined, non-overlapping data[3,4], obtained mostly by systematic two-hybrid analyses[3]. Owing to its size, a complete map of the network (Fig. 1a), although informative, in itself offers little insight into its large-scale characteristics. Our first goal was therefore to identify the architecture of this network, determining whether it is best described by an inherently uniform exponential topology, with proteins on average possessing the same number of links, or by a highly heterogeneous scale-free topology, in which proteins have widely different connectivities[5].

As we show in Fig. 1b, the probability that a given yeast protein interacts with k other yeast proteins follows a power law[5] with an exponential cut-off[6] at $k_c = 20$, a topology that is also shared by the protein–protein interaction network of the bacterium *Helicobacter pylori*[7]. This indicates that the network of protein interactions in two separate organisms forms a highly inhomogeneous scale-free network in which a few highly connected proteins play a central role in mediating interactions among numerous, less connected proteins.

An important known consequence of the inhomogeneous structure is the network's simultaneous tolerance to random errors, coupled with fragility against the removal of the most connected nodes[8]. We find that random mutations in the genome of *S. cerevisiae*, modelled by the removal of randomly selected yeast proteins, do not affect the overall topology of the network. By contrast, when the most connected proteins are computationally eliminated, the network diameter increases rapidly. This simulated tolerance against random mutation is in agreement with results from systematic mutagenesis experiments, which identified a striking capacity of yeast to tolerate the deletion of a substantial number of individual proteins from its proteome[9,10]. However, if this is indeed due to a topological component to error tolerance, then, on average, less connected proteins should prove to be less essential than highly connected ones.

To test this, we rank-ordered all interacting proteins based on the number of links they have, and correlated this with the phenotypic effect of their individual removal from the yeast proteome. As shown in Fig. 1c, the likelihood that removal of a protein will prove lethal correlates with the number of interactions the protein has. For example, although proteins with five or fewer links constitute about 93% of the total number of proteins, we find that only about 21% of them are essential. By contrast, only some 0.7% of the yeast proteins with known phenotypic profiles have more than 15 links, but single deletion of 62% or so of these proves lethal. This implies that highly connected proteins with a central role in the network's architecture are three times more likely to be essential than proteins with only a small number of links to other proteins.

The simultaneous emergence of an inhomogeneous structure in both metabolic[5,11] and protein interaction networks suggests that there has been evolutionary selection of a common large-scale structure of biological networks and indicates that future systematic protein–protein interaction studies in other organisms will uncover an essentially identical protein-network topology. The correlation between the connectivity and indispensability of a given protein confirms that, despite the importance of individual biochemical function and genetic redundancy, the robustness against mutations in yeast is also derived from the organization of interactions and the topological positions of individual proteins[12]. A better understanding of cell dynamics and robustness will be obtained from an integrated approach that simultaneously incorporates the individual and contextual properties of all constituents in complex cellular networks.

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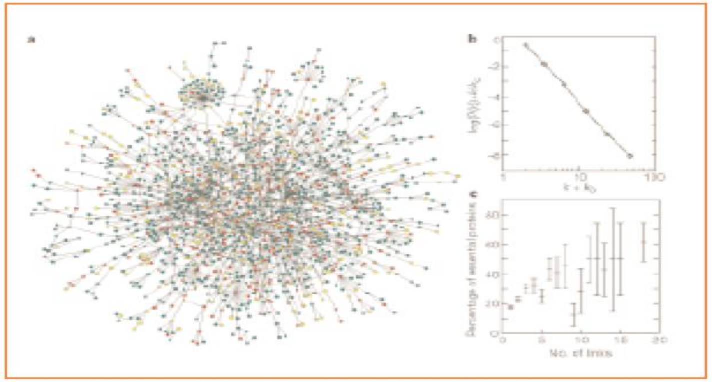


Figure 1 Characteristics of the yeast proteome. **a**, Map of protein–protein interactions. The largest cluster, which contains ~78% of all proteins, is shown. The colour of a node signifies the phenotypic effect of removing the corresponding protein (red, lethal; green, non-lethal; orange, slow growth; yellow, unknown). **b**, Connectivity distribution $P(k)$ of interacting yeast proteins, giving the probability that a given protein interacts with k other proteins. The exponential cut-off[6] indicates that the number of proteins with more than 20 interactions is slightly less than expected for pure scale-free networks. In the absence of data on the link directions, all interactions have been considered as bidirectional. The parameter controlling the short-length scale correction has value $k_0 = 1$. **c**, The fraction of essential proteins with exactly k links versus their connectivity, k, in the yeast proteome. The list of 1,572 mutants with known phenotypic profile was obtained from the Proteome database[13]. Detailed statistical analysis, including $r = 0.75$ for Pearson's linear correlation coefficient, demonstrates a positive correlation between lethality and connectivity. For additional details, see http://www.nd.edu/~networks/cell.

Analysis of graph data

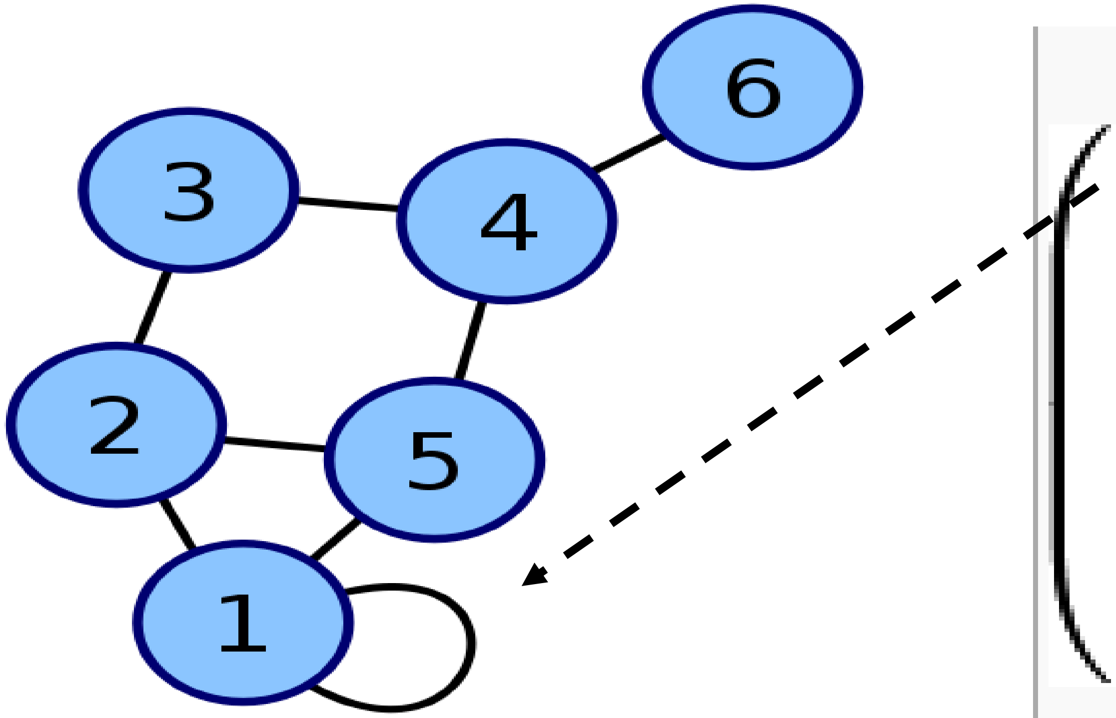
Graph data can be analysed in order to gain insight on network's properties.

We will focus on
-topological properties
-spectral properties

Through the analysis of these properties we will try to infer information on
- resilience to faults
- efficiency
- topological "critical" points

Topological properties

A graph can be fully represented by an Adjacency matrix a_{ij}



$$\begin{pmatrix} 1 & 1 & 0 & 0 & 1 & 0 \\ 1 & 0 & 1 & 0 & 1 & 0 \\ 0 & 1 & 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 & 1 & 1 \\ 1 & 1 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \end{pmatrix}$$

A-matrix elements can also be non-unitary if links are weighted

Topological properties

-Degree distribution $$k_i = \sum_{j=1}^{N} a_{ij}$$

-Clustering $$C = \frac{1}{N}\sum_{i=1}^{N} c_i = \sum_{j,m \in n_i} \frac{a_{ij}a_{jm}a_{mi}}{n_i(n_i-1)/2}$$

-betweennees centrality $$b_i = \frac{1}{(N-1)(N-2)} \sum_{j,k \in N, j \neq k} \frac{n_{jk}(i)}{n_{jk}}$$

- topological efficiency $$E[G] = \frac{1}{N(N-1)} \sum_{i,j \in N, i \neq j} \frac{1}{d_{ij}}$$

-information centrality $$I_i = \frac{E[G] - E[G_i]}{E[G]}$$

Spectral properties

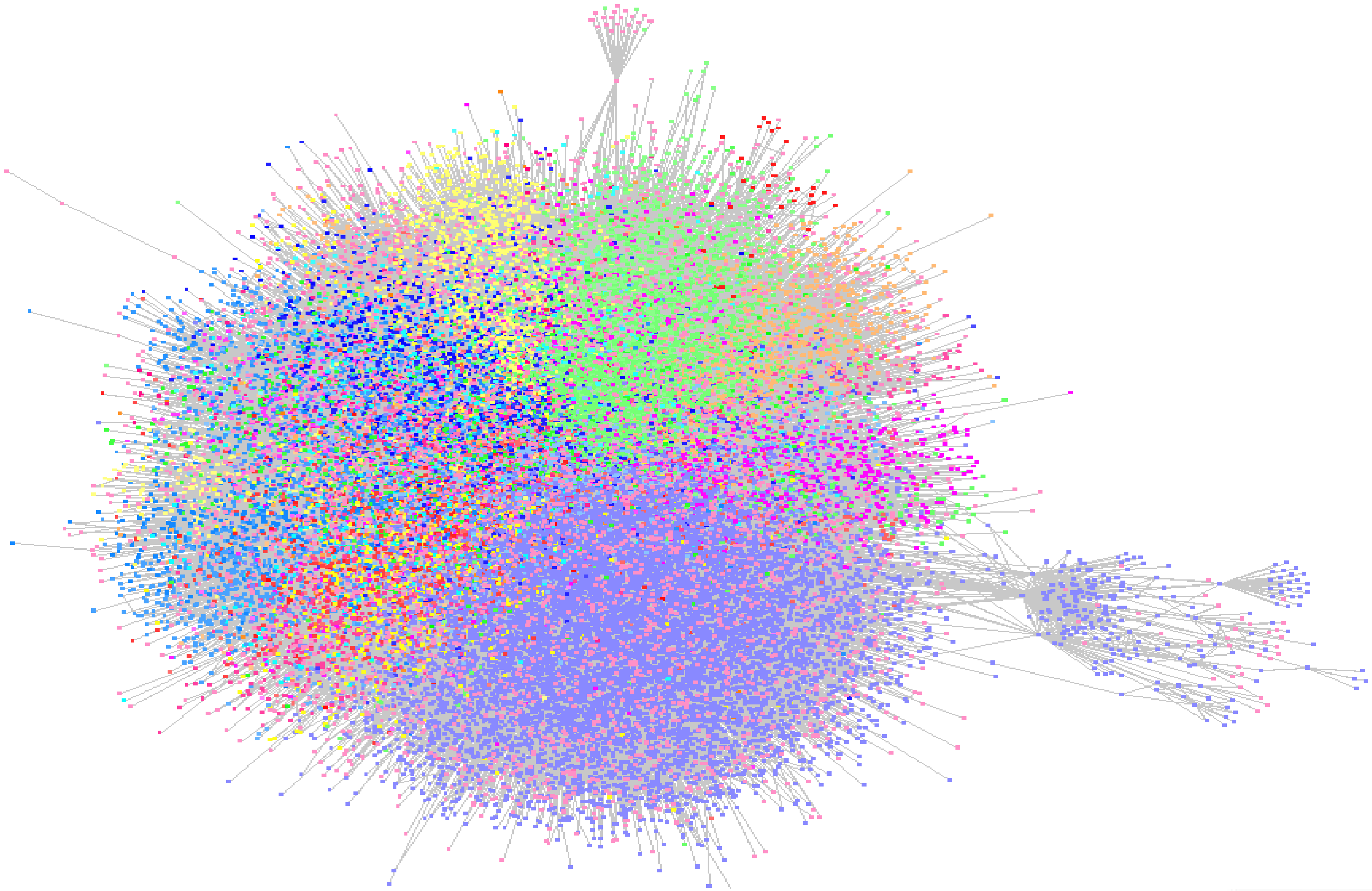
The Laplacian matrix L_{ij} is defined as

$$A = \begin{pmatrix} 0 & 1 & 1 & 0 & 1 & 0 \\ 1 & 0 & 0 & 1 & 0 & 1 \\ 1 & 0 & 0 & 1 & 1 & 0 \\ 0 & 1 & 1 & 0 & 0 & 1 \\ 1 & 0 & 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 1 & 0 & 0 \end{pmatrix} \qquad L = \begin{pmatrix} 3 & -1 & -1 & 0 & -1 & 0 \\ -1 & 3 & 0 & -1 & 0 & -1 \\ -1 & 0 & 3 & -1 & -1 & 0 \\ 0 & -1 & -1 & 3 & 0 & -1 \\ -1 & 0 & -1 & 0 & 2 & 0 \\ 0 & -1 & 0 & -1 & 0 & 2 \end{pmatrix}$$

The L structure ensures that its lowest eigenvalue is zero.
The sign of the elements of the eigenvector associated to the first non vanishing eigenvalue divides the network in two sub-networks (nodes with positive eigenvectors and node with negative eigenvectors) such as the value of S is minimum

$$S = L_{12} / N_1 \bullet N_2$$

The Internet (AS-level routers)



"Complex" growth

ENEA
AGENZIA NAZIONALE PER LE NUOVE TECNOLOGIE, L'ENERGIA E LO SVILUPPO ECONOMICO SOSTENIBILE

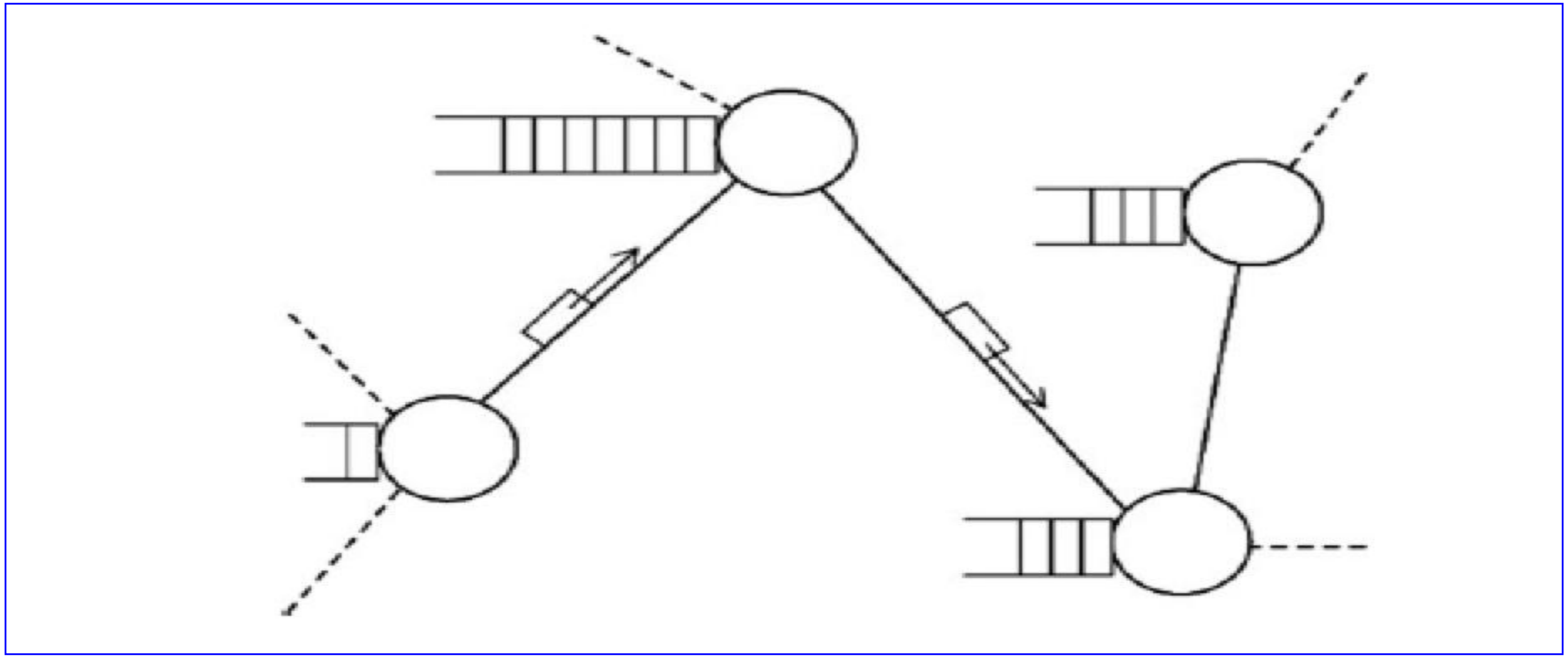
date	*N*	*L*	〈	*c*	©	*MaxD*	*diam*	n_{cut}
1998	3459	6137	$1.02 \cdot 10^{-3}$	0.194	2.35	734	10	11
1998	4107	7571	$8.98 \cdot 10^{-4}$	0.221	2.51	855	11	97
1999	4788	8990	$7.84 \cdot 10^{-4}$	0.237	2.41	1083	11	378
2000	6474	12572	$6.00 \cdot 10^{-4}$	0.252	2.46	1458	9	493
2007	17144	46621	$3.17 \cdot 10^{-4}$	0.422	2.25	2346	8	1962
2008	23015	74182	$2.80 \cdot 10^{-4}$	0.446	2.08	3592	8	2083
2011	33673	333437	$2.94 \cdot 10^{-4}$	0.581	1.97	5904	7	2115

- ***diam*** decreases as ***N*** and ***L*** increase
- ***clustering*** increases
- ***ncut*** increases

CIPRNet

Structure vs function

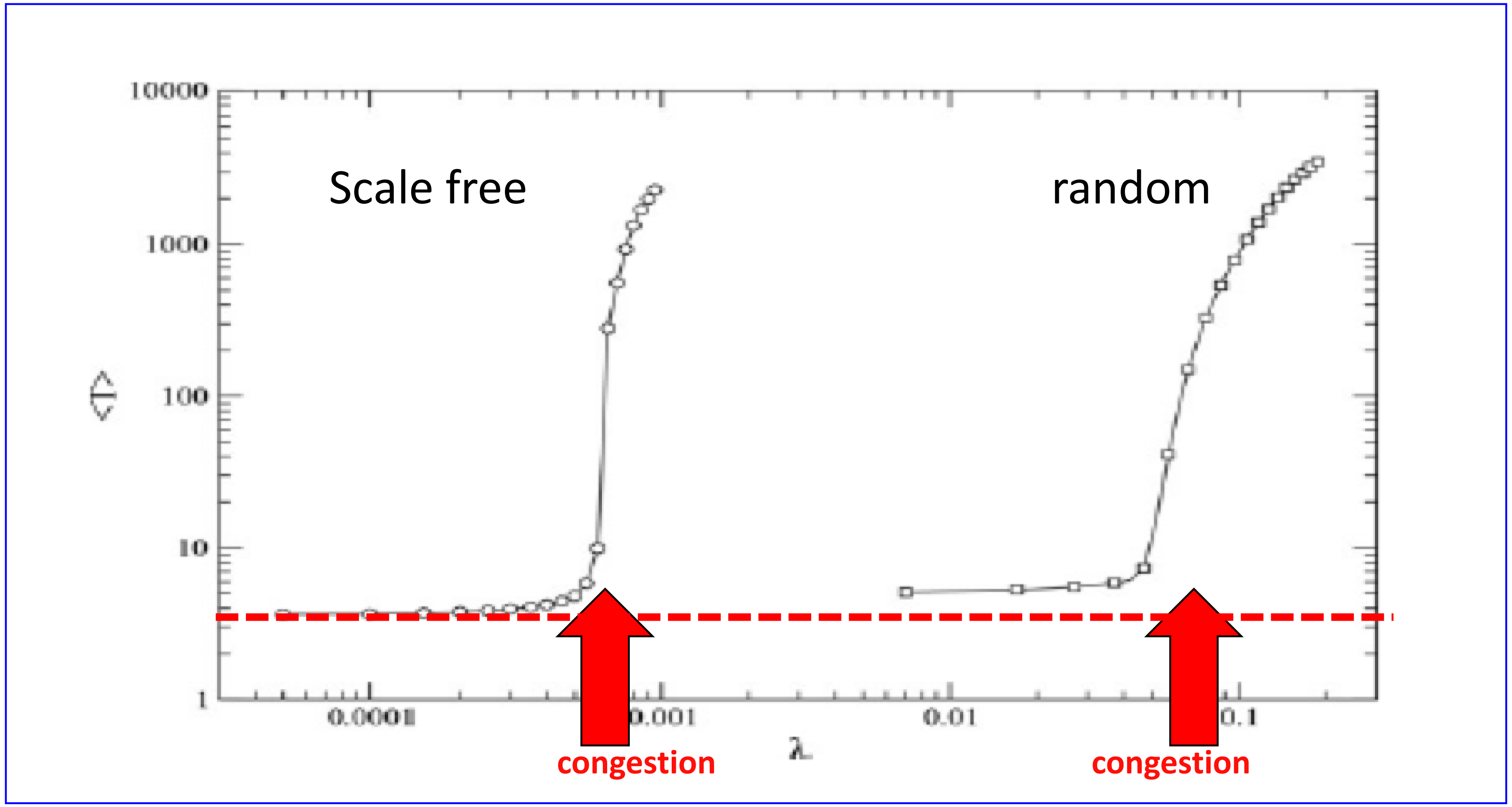
why the Internet has advantages of not being a random network



- Synthetic communication protocol
- Nodes have buffer (whose size might be set to be proportional to their k)
- They emit (or absorb) a number of 1kb packets
- Routing is deterministic along shortest paths

Structure vs function

why the Internet has advantages to not being a random network



Emitting packets randomly
Equal nodes buffer
Generating traffic λ

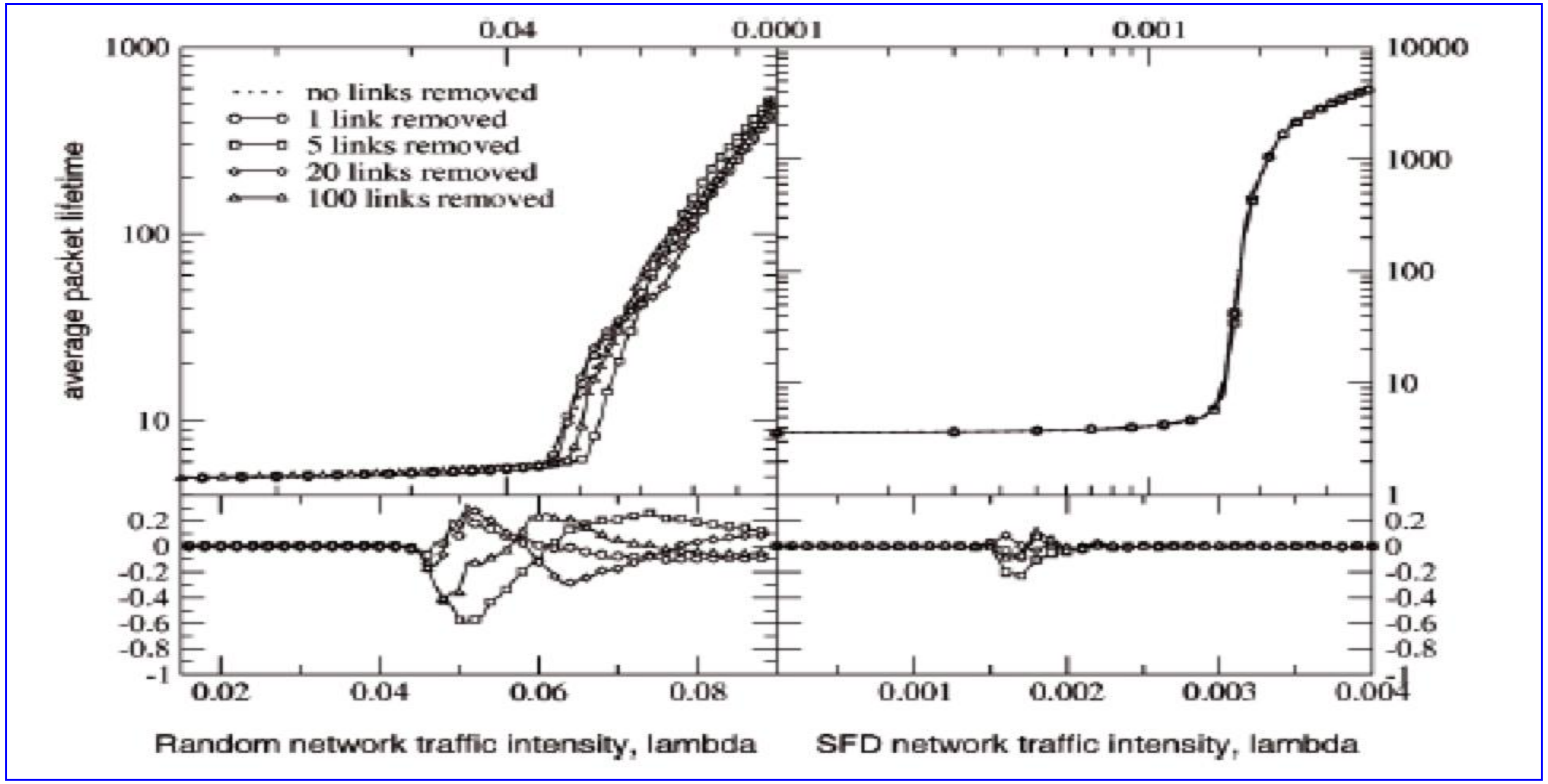
<T> average time for packets delivery

Congestion in random nets appears at higher traffic values !

Performance in normal conditions are better for scale free net !

Structure vs function

why the Internet has advantages to not being a random network

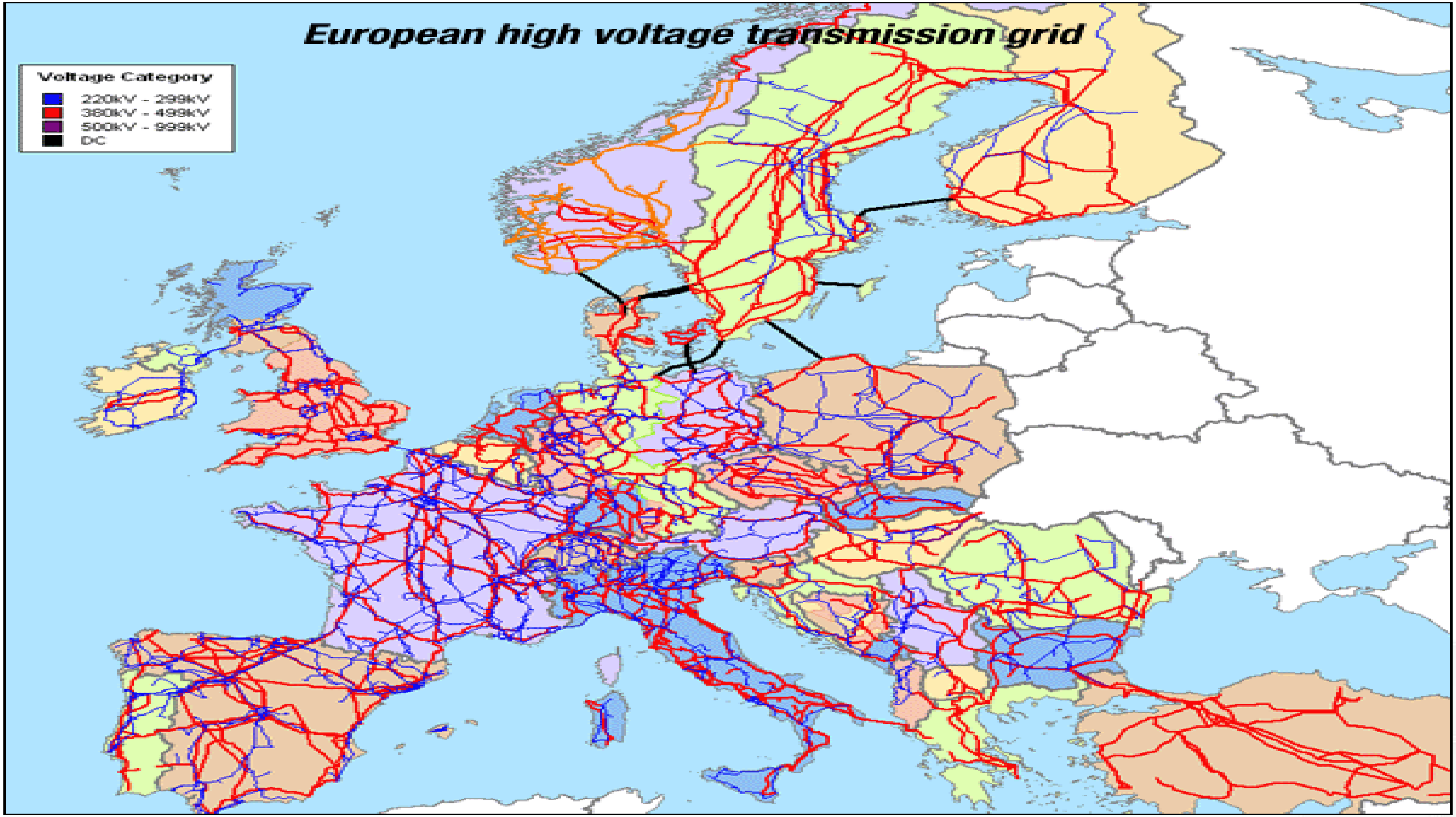


Links removal produces perturbations in the communications

Random links removal perturbs random network more that scale free

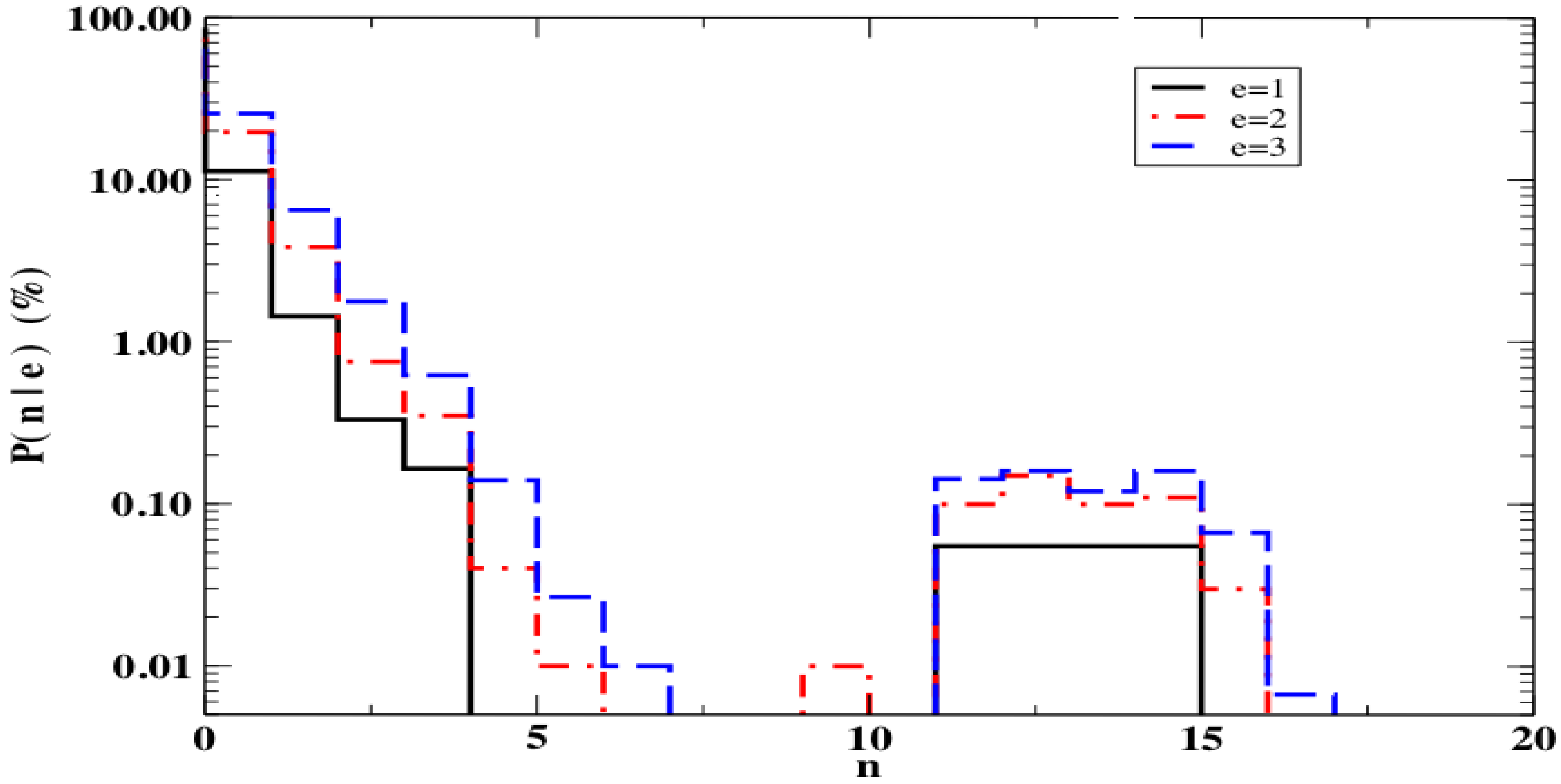
V.Rosato et al. Physica 387 (2008) 1689

The electrical transimssion network



Vulnerability assessment

Use of graph analysis to estimate structural vulnerability



Source data:

UCTE network data

N=1254 nodes

L= 1812 lines

Conditional probability P(**n** | **e**) of disconnecting **n** nodes if **e** links are simultaneously removed.

Using spectral properties for islanding

The UCTE network has been min-cut (i.e. the optimal bisection of the N nodes into two groups, N1 and N2, such that, if L12 are the links joining nodes of subset N1 with nodes of subset N2, the quantity S is minimized).

$$S = L12/ N1 \cdot N2$$

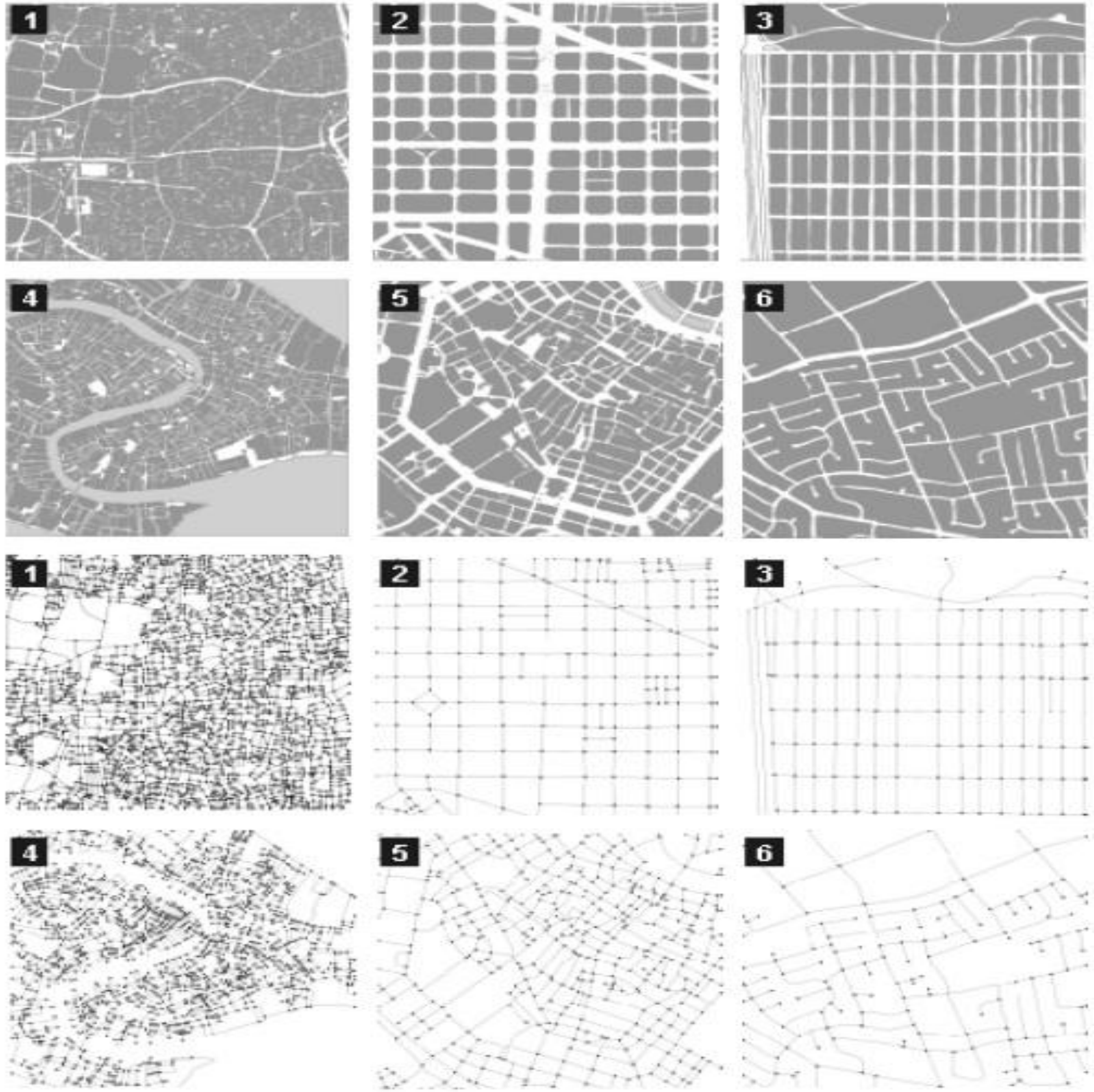
Procedure can be iterated for structural “islanding” definition.
Procedure can be also generalized to weighted network (weight=power-flow on the link).

Results on UCTE (unweighted):

Min-cut with L12 = 16 links joining two subsets (N1=492, N2=762)

233	<--->	224	F-17lonn <---> F-24	404	<--->	407	F-Cornie1/2 <---> F-195
243	<--->	262	F-27 <---> F-46/47	423	<--->	407	F-211 <---> F-195
278	<--->	283	F-63 <---> F-68	423	<--->	414	F-211 <---> F-202
287	<--->	311	F-72 <---> F-96	423	<--->	434	F-211 <---> F-223
298	<--->	302	F-83 <---> F-87	536	<--->	545	B-3 <---> B-12Avel
325	<--->	311	F-17lonn <---> F-24	589	<--->	397	CH -33 <---> F-BoisTo
356	<--->	407	F-Mambel <---> F-195	589	<--->	602	CH -33 <---> CH - VerboBoisTo
381	<--->	407	F-168 <---> F-195	711	<--->	715	I-Campochi1 <---> I-Carnposo

Cities and urban networks



Urban maps can be transformed into graphs.

Direct maps

- roads are links and intersections are nodes

Indirect maps

- Roads are nodes, intersections are links

Analysis of graph properties could reveal many relevant features, either on city historical development and on their functional use (also in relation to traffic)

Topological properties of city networks

Topological indices can be used to "qualify" cities

$$C_i^{\mathrm{D}} = \frac{k_i}{N-1} = \frac{\sum_{j \in N} a_{ij}}{N-1}.$$

degree centrality

$$C_i^{\mathrm{C}} = L_i^{-1} = \frac{N-1}{\sum_{j \in N;\, j \neq i} d_{ij}}$$

closeness centrality

$$C_i^{\mathrm{B}} = \frac{1}{(N-1)(N-2)} \sum_{j,\, k \in N;\; j \neq k;\; j,\, k \neq i} \frac{n_{jk}(i)}{n_{jk}}$$

centrality

$$C_i^{\mathrm{S}} = \left(\sum_{j \in N;\, j \neq i} \frac{d_{ij}^{\mathrm{Eucl}}}{d_{ij}} \right) \Big/ (N-1)$$

aightness centrality

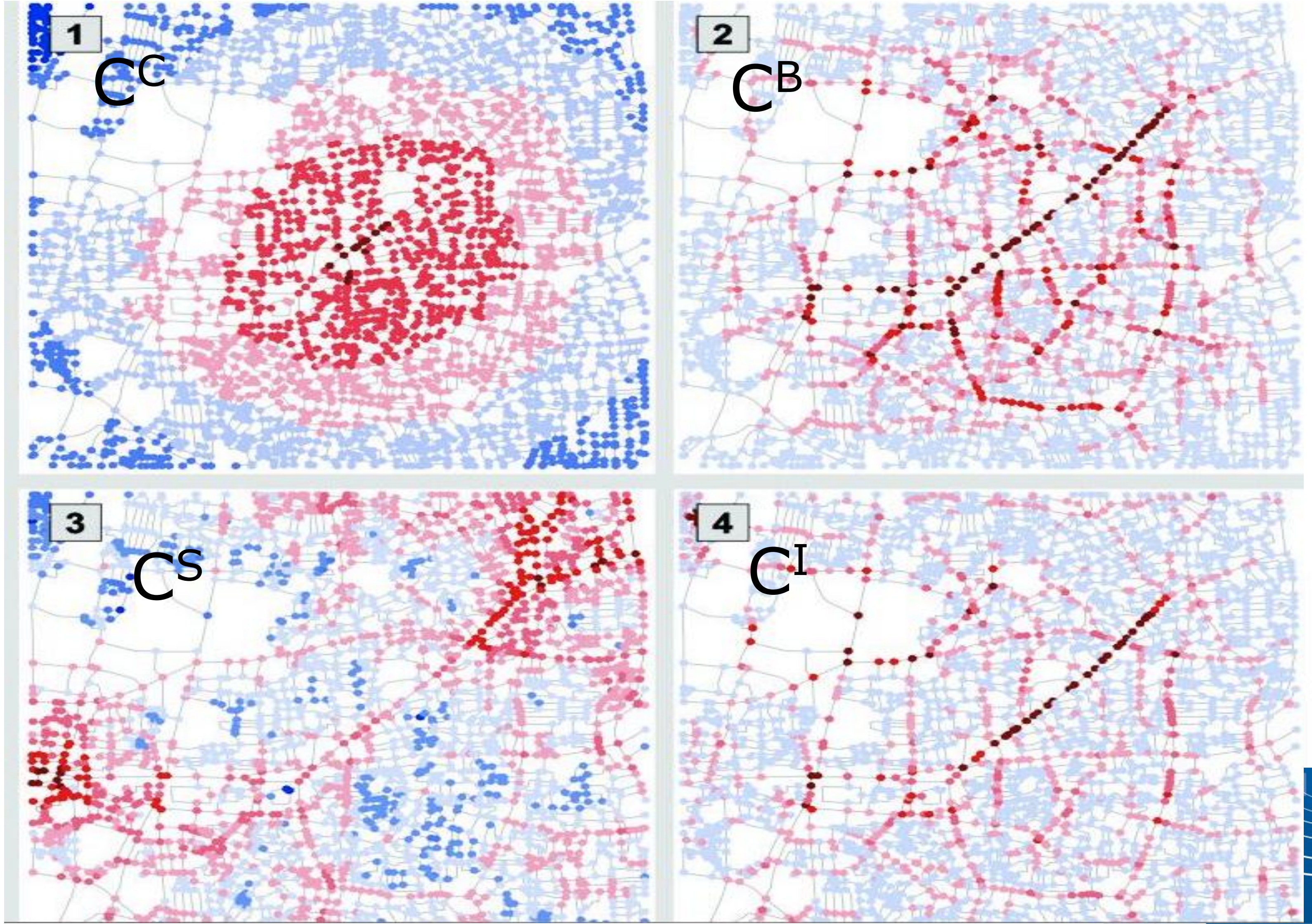
$$C_i^{I} = \frac{\Delta E_2^{\mathrm{glob}}}{E_2^{\mathrm{glob}}} = \frac{E_2^{\mathrm{glob}}(\mathrm{G}) - E_2^{\mathrm{glob}}(\mathrm{G}')}{E_2^{\mathrm{glob}}(\mathrm{G})}$$

n centrality

Centrality measures in urban's networks

Ahmedabad

(self-grown)

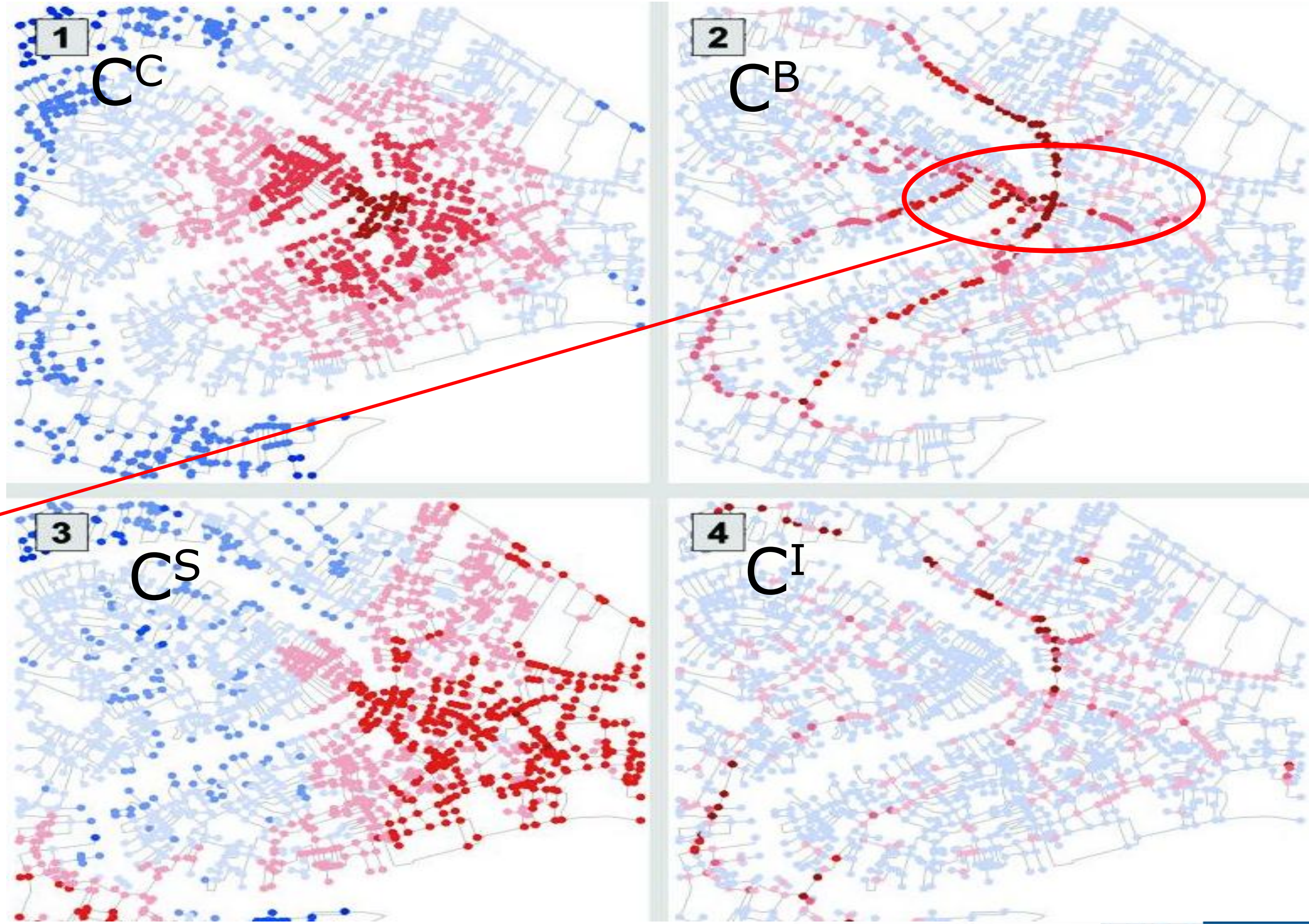


C_B clearly indicates central roads where traffic and commerce are likely take place.

Centrality measures in urban's networks

Venice

(self-grown)

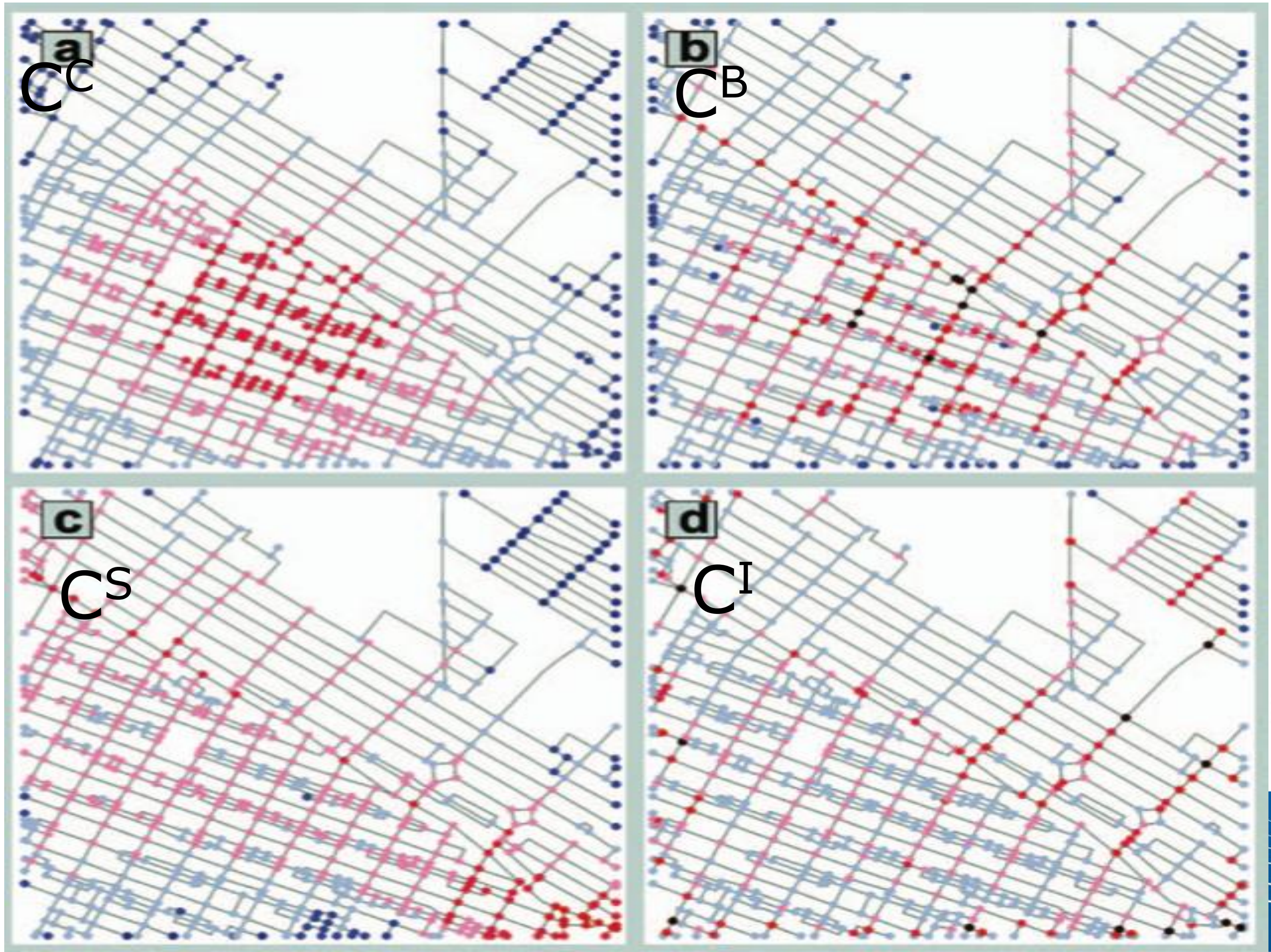


Rialto's bridge

Centrality measures in urban's networks

Richmond

(planned)



Functional models

If we add some further dynamical detail to graphs, we could produce dynamical models of the systems, i.e. we can attempt to reproduce (even if with simple behavioral models) the functioning of that network in allowing the flow of its specific “good” (i.e. electrical current for electrical networks, digital data packet on internet, traffic in a road network etc.).

Combining dynamic and topological analysis we can hope to address the problem of correlating structure and function in a network and see whether or not simple topological analyses are sufficient to predict functional properties of the network or, at least, their properties when functioning.

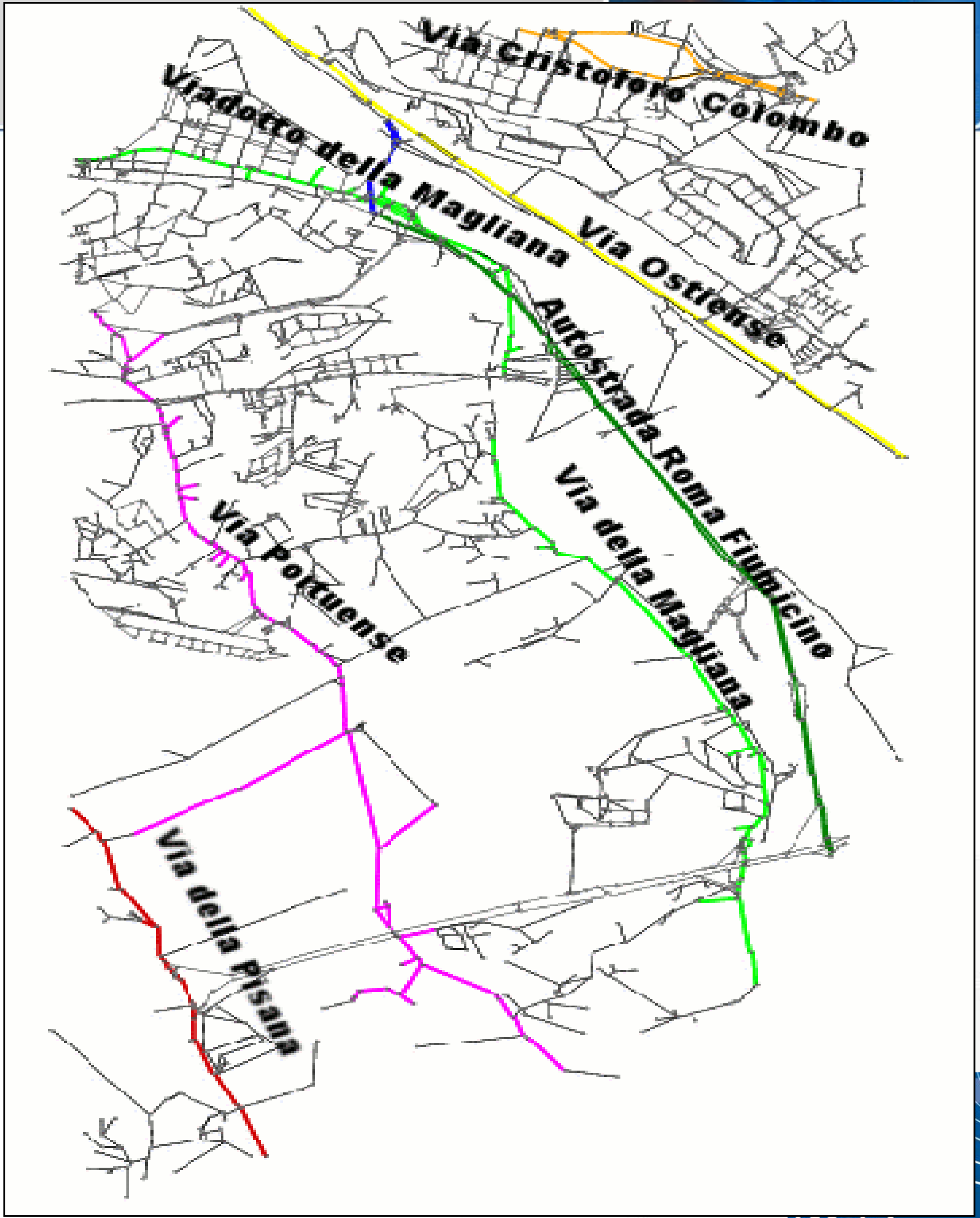
The answer to the last question will be:
YES but not always

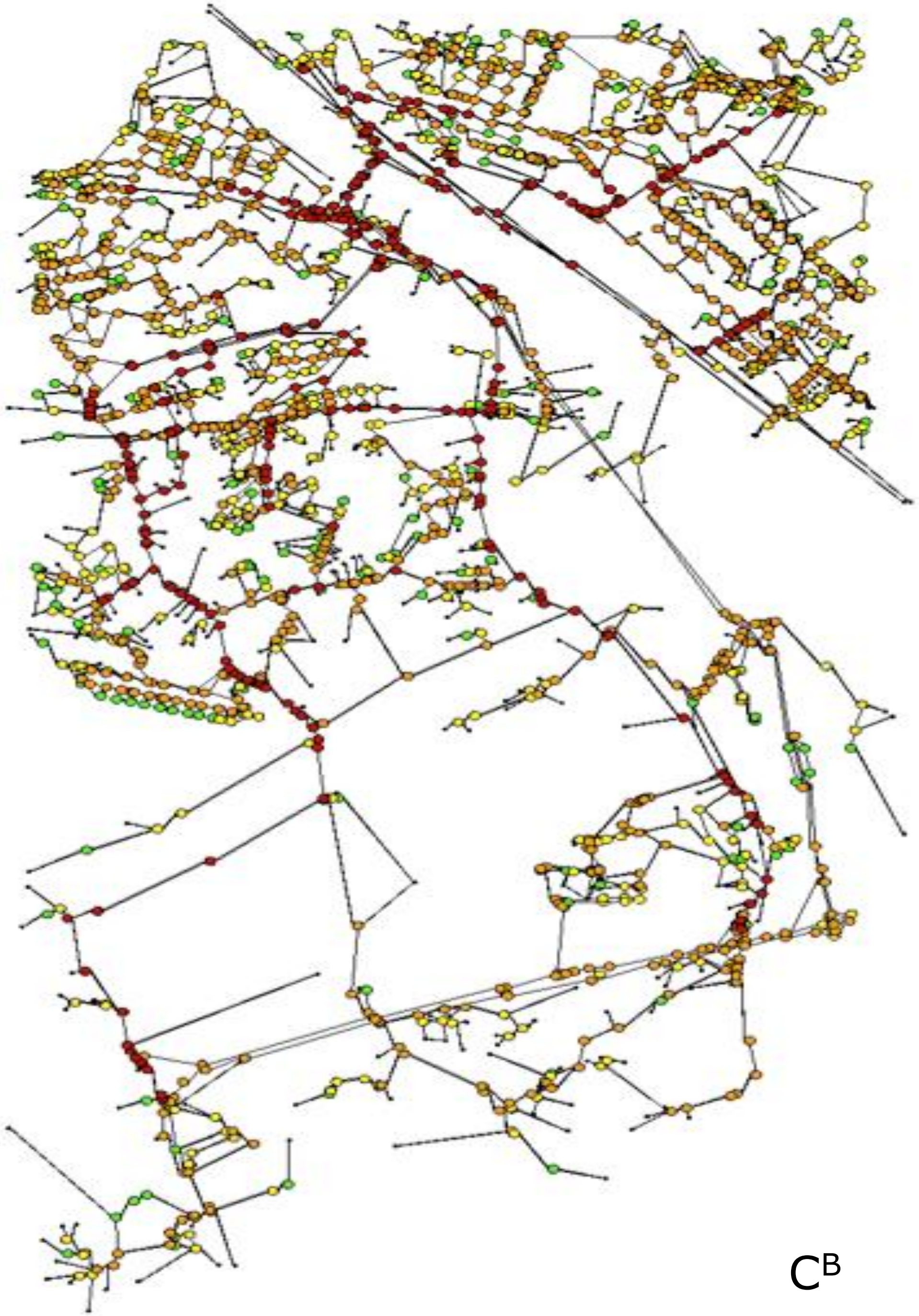
Topology and traffic

- In large cities, urban displacements determine a huge traffic.
- Traffic paths are related to topological properties of urban networks.
- Centrality measures still play a crucial role in this context.
- The case of XV Municipio in Rome.

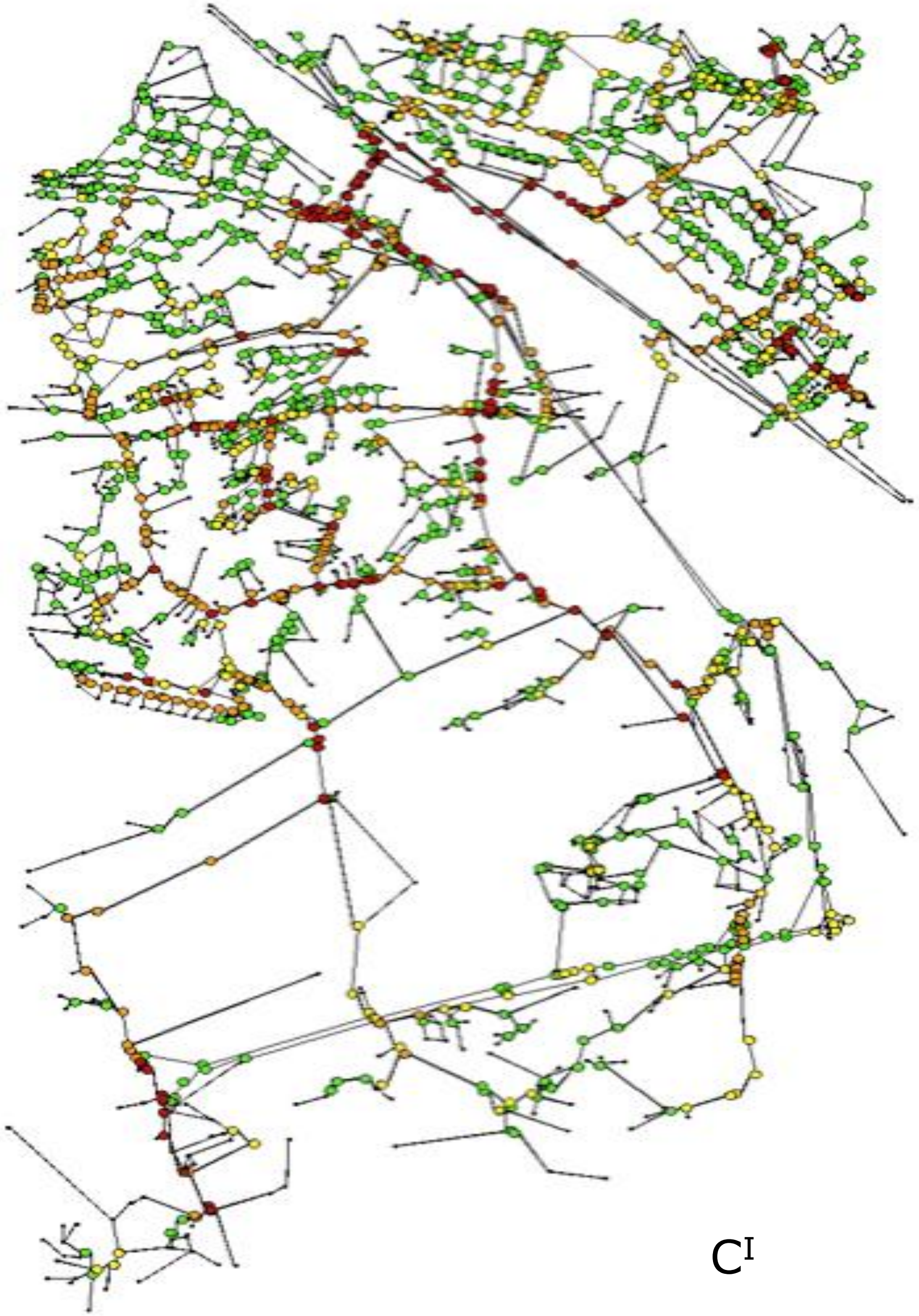
XV municipio

Nodes	2650
Links	5445 (523 km)
Directed links	1195 (101km)
Undirected links	2125 (211km)



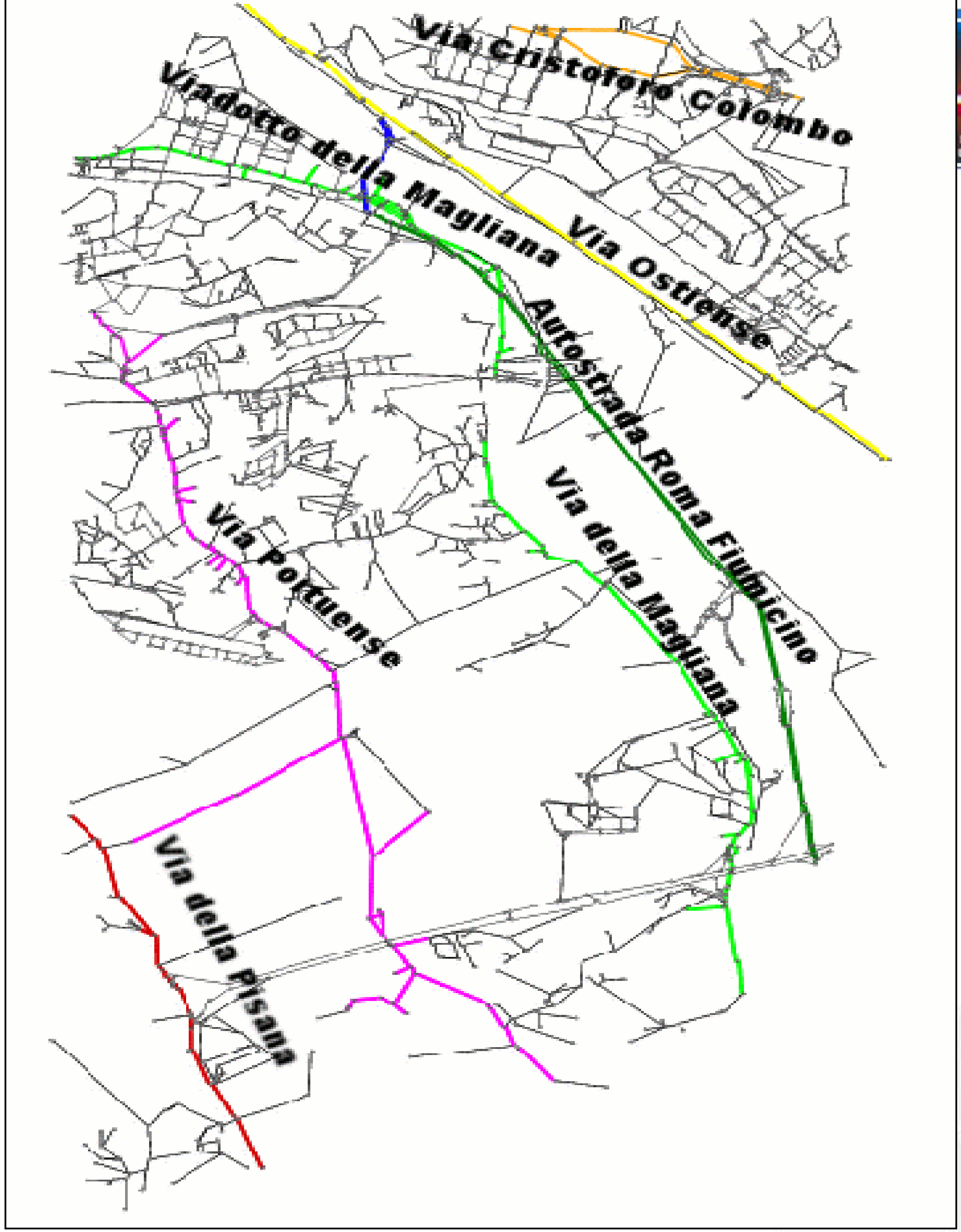


C^B



C^I

Link C^B



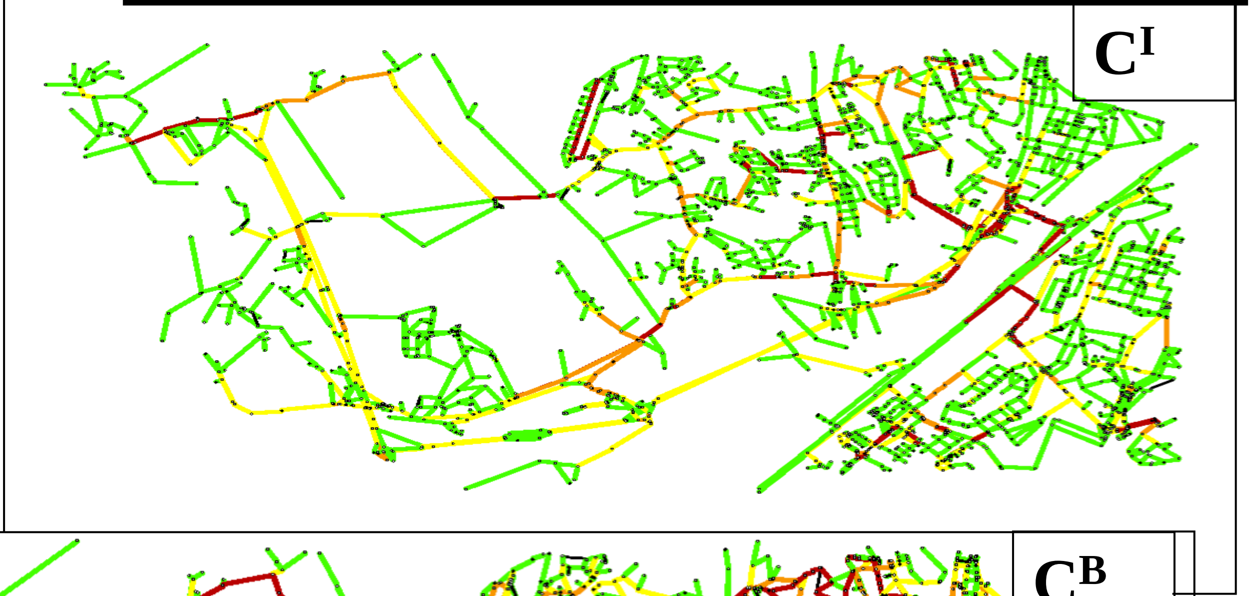
Via Cristoforo Colombo
Viadotto della Magliana
Via Ostiense
Autostrada Roma Fiumicino
Via della Magliana
Via Portuense
Via della Pisana

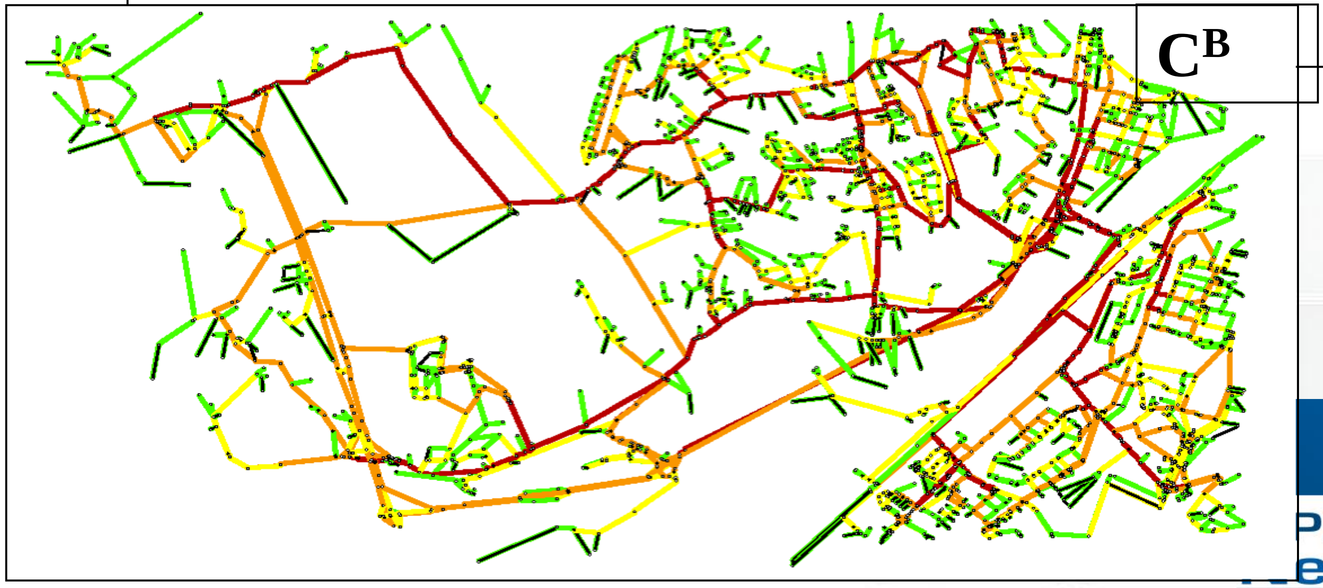
Topology analysis

d^w	L^w	c^w	E_{glob}^{w}
18,54km	4,3km	0.029	0.5378

•Main roads are those with largest C^B

•Some links with large C^B do not exhibit large C^I: their removal has small effect on network's efficiency





Traffic simulation

- Macroscopic-flow models are based on the use of Capacity Restraint Functions and O/D matrices.

- Capacity Restraint Function describes the link’s travelling time variation as a function of the flux that it must sustain.

Capacity Restraint Functions

$$t_l = t_0 + 0.5T(1-\mu)^2 + \frac{0.55}{\mu S}\frac{q_l}{\mu S - q_l} \quad \text{if} \quad q_l \le 0.95\mu S$$

$$t_l = a + b\frac{q_l}{\mu S} \quad \text{if} \quad q_l > 0.95\mu S$$

T = traffic light cycle duration

$$\frac{T_{green}}{T}$$

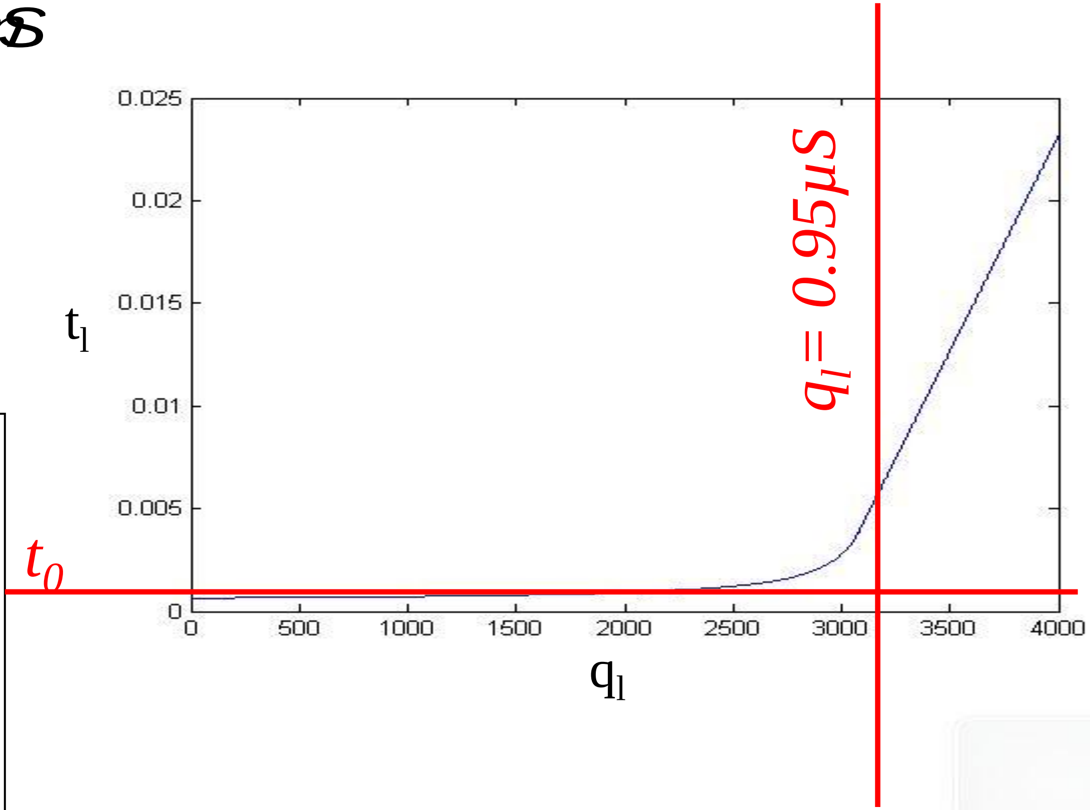
S = Saturation

a,b = coefficients of the tangent

t_l = time to cross link l

t_0=minimum time

q_l=flux on link l



Origin-Destination matrix (O/D)

Square matrix:

The generic element represents the number of displacements from O to D

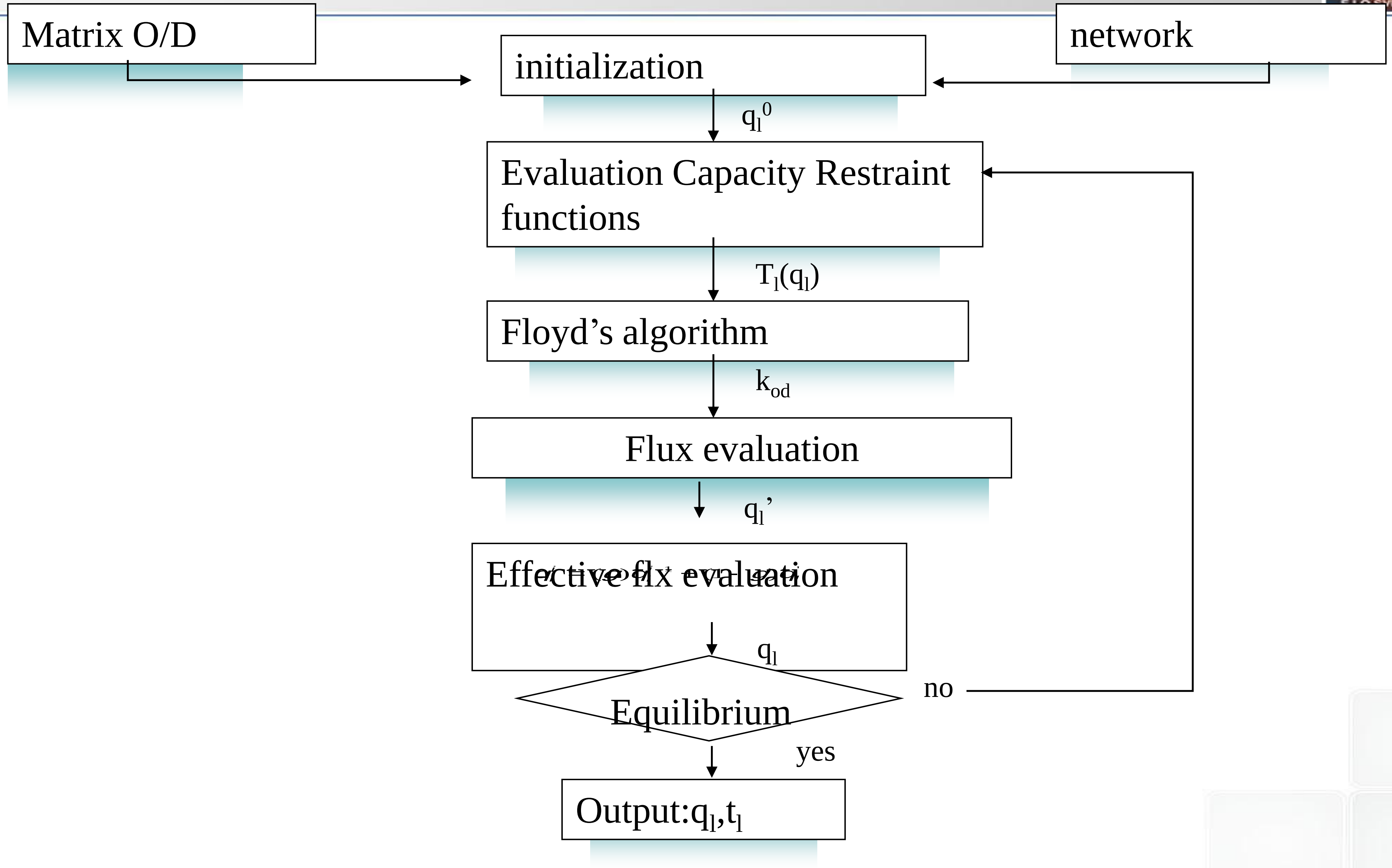
	Destinazioni						
Origini	1	2	3	...	j	n	totali generazioni
1	d_{11}	d_{12}	d_{13}	...	d_{1j}	d_{1n}	g_1
2	d_{21}	d_{22}	d_{23}	...	d_{2j}	d_{2n}	g_2
3	d_{31}	d_{32}	d_{33}	...	d_{3j}	d_{3n}	g_3
:				...			
i	d_{i1}	d_{i2}	d_{i3}	...	d_{ij}	d_{in}	g_i
:				...			
n	d_{n1}	d_{n2}	d_{n3}	...	d_{nj}	d_{nn}	g_n
totali attrazioni	a_1	a_2	a_3	...	a_j	a_n	d

$$g_i = \sum_j d_{ij}$$

$$a_j = \sum_i d_{ij}$$

$$d = \sum_{ij} d_{ij}$$

Nash equilibrium algorithm



Traffic simulation

Equilibrium Flow is determined by searching the **WARDROP-NASH equilibrium.**

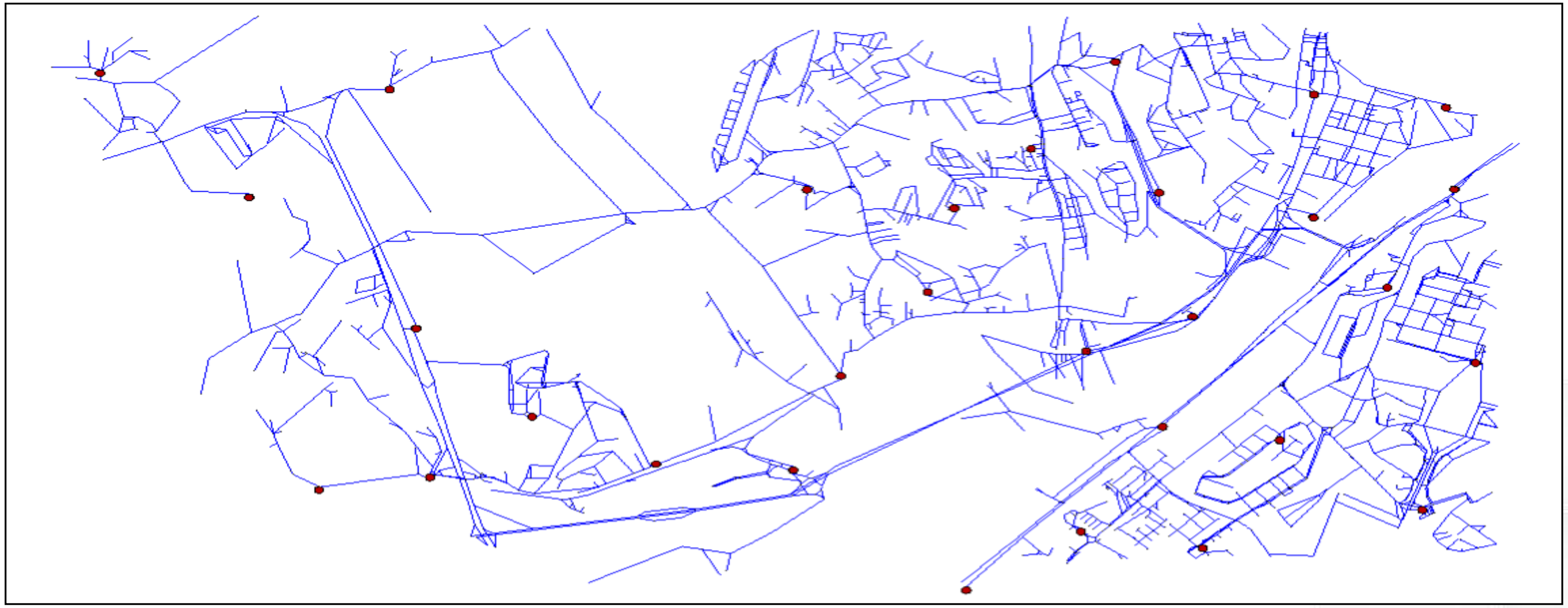
- Cars fulfilling each O/D request are allotted to shortest paths
- Roads are filled up to their capacity
- Total times are evaluated by using Restaint Functions
- Each car tries to select a new path to attempt reducing total time
- Equilibrium stops when no car is able to find any new road solution allowing to reduce its travel time.

This is an EQUILIBRIUM and NOT an OPTIMAL solution

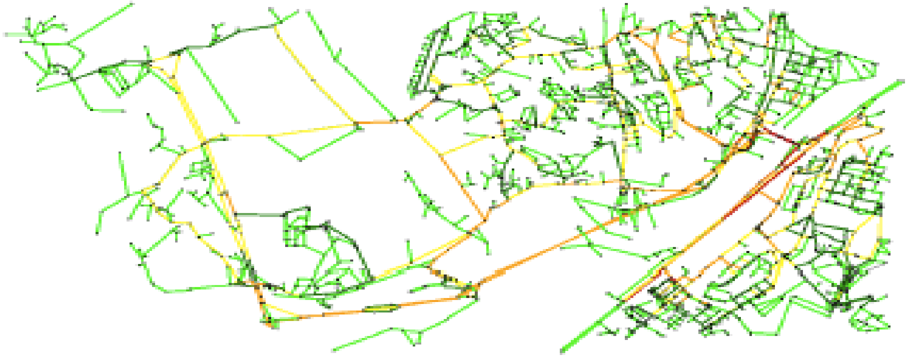
Traffic simulation

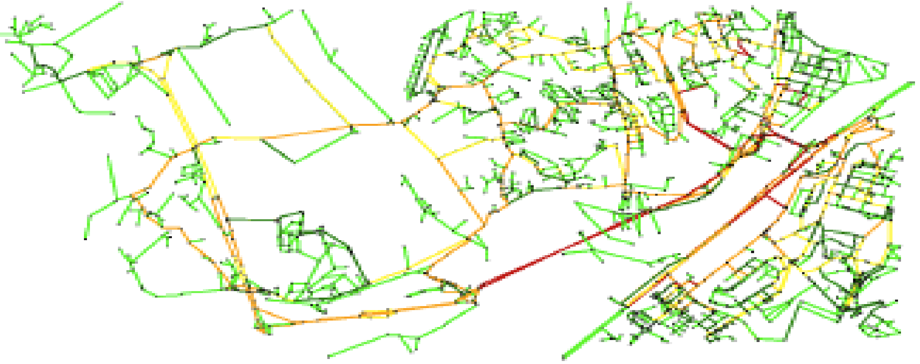
Three scenarios:

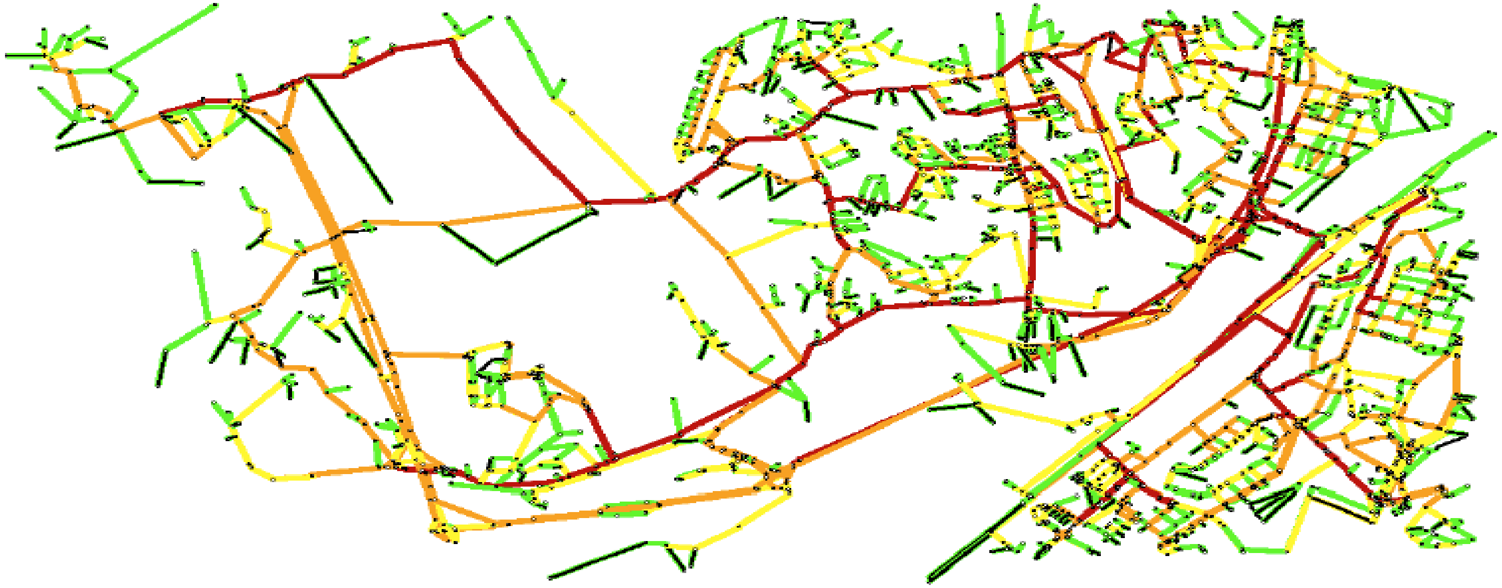
- Traffic leaving and entering in each node
- Traffic leaving from all nodes and goes into a pool of 30 nodes
- Traffic exits from a pool of 30 nodes and goes everywhere else



Traffic leaving and entering in each node

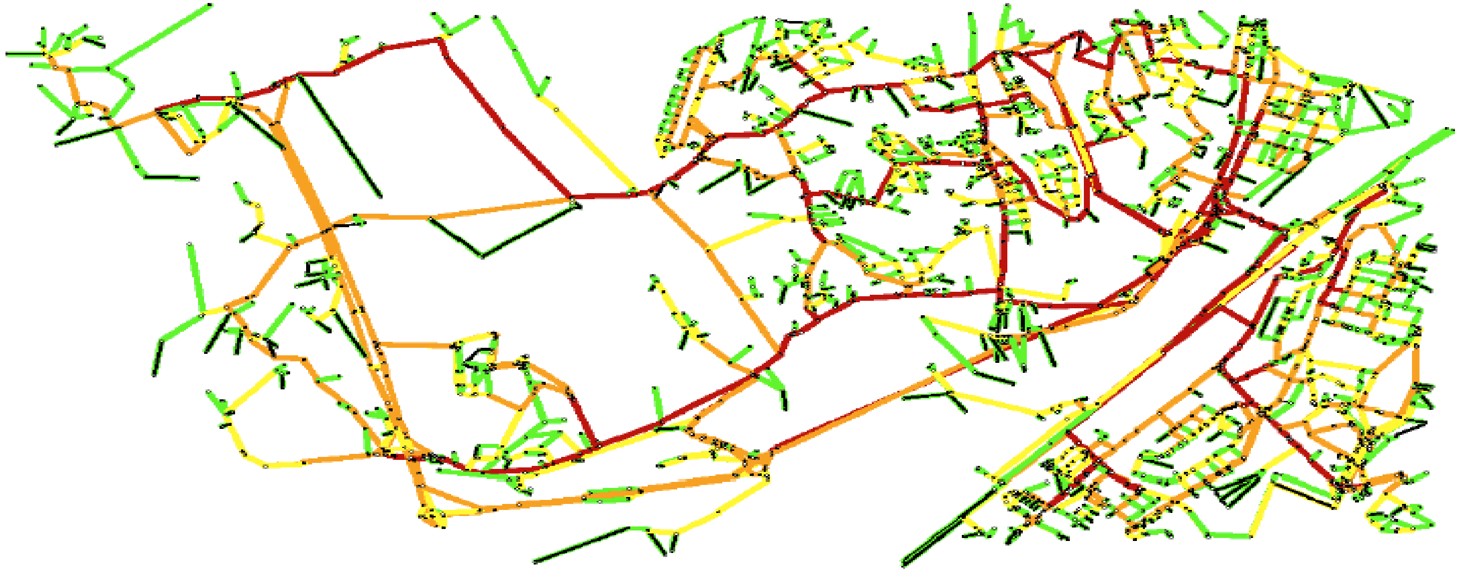






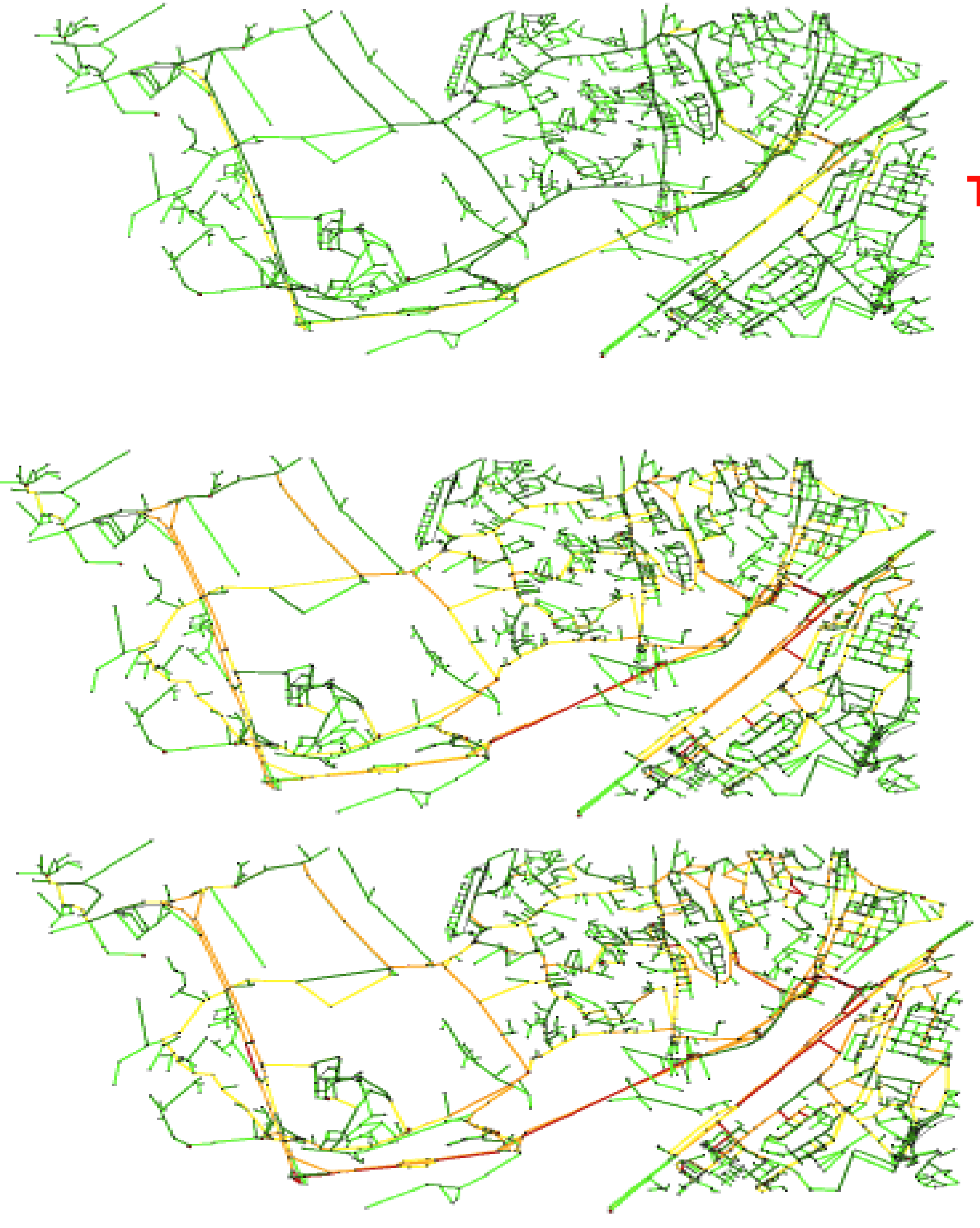
Link C^B

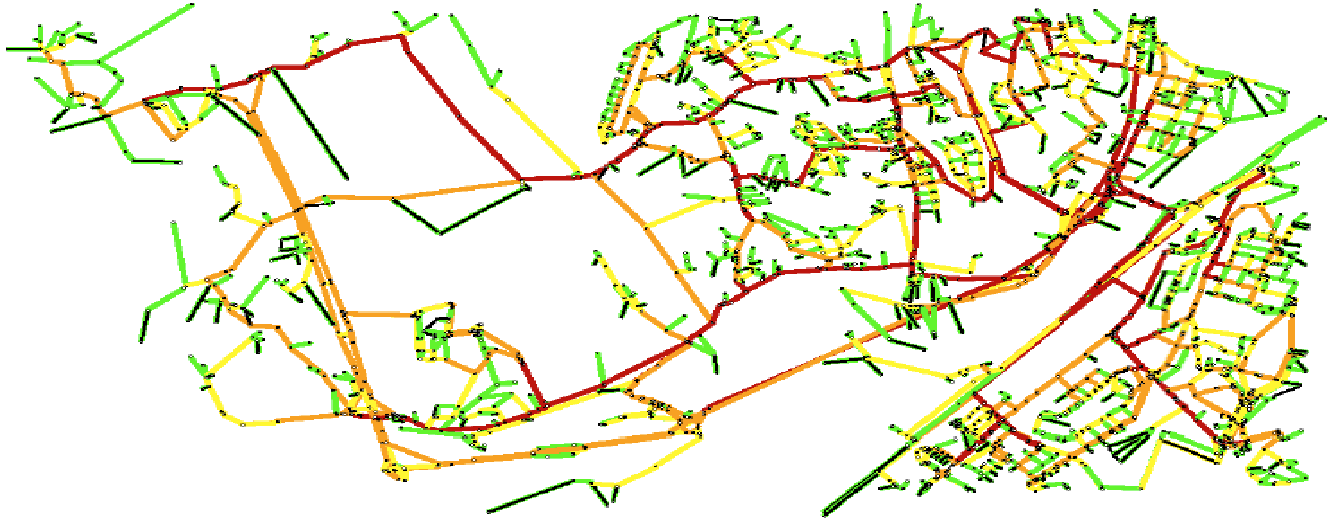
Traffic leaving from a pool of nodes



Link C^B

Traffic entering into a pool of nodes



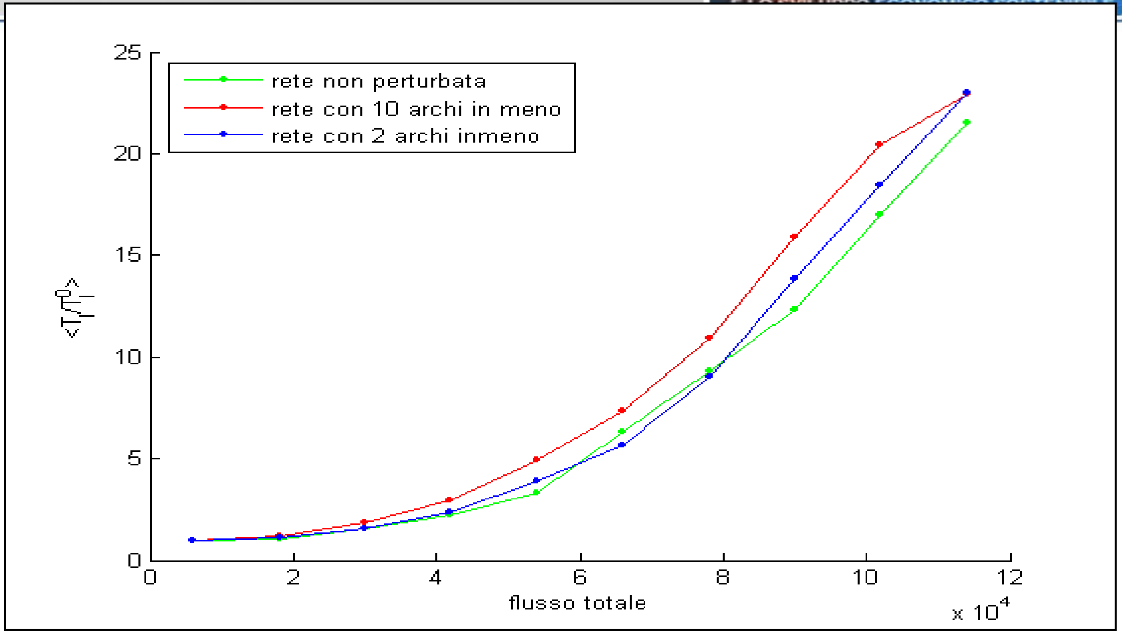


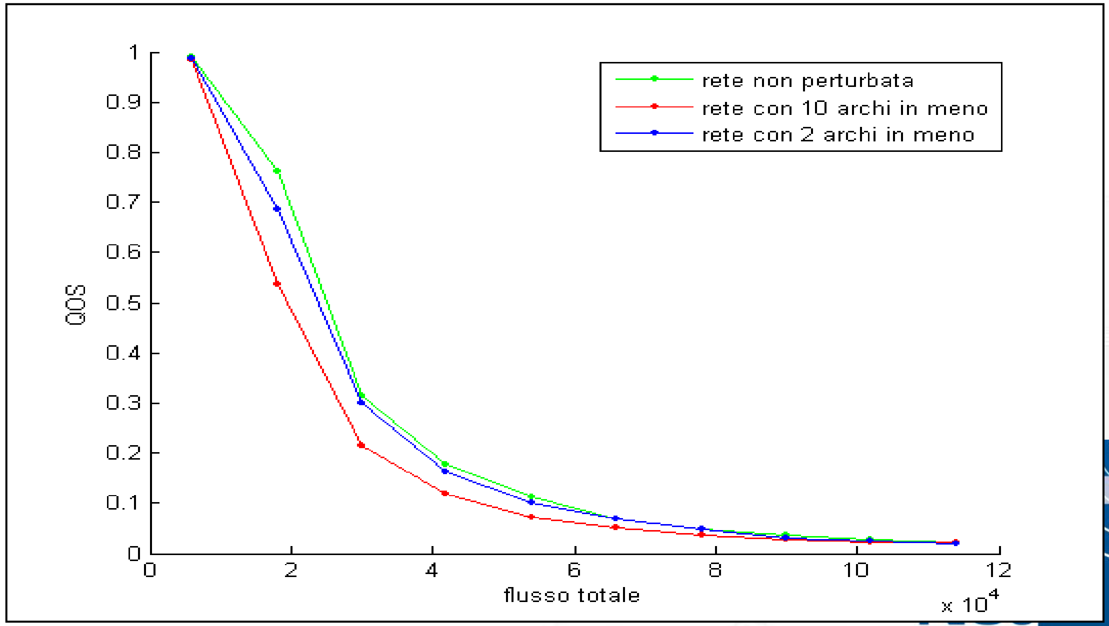
Link C^B

Vulnerability

Estimate the response of the system to perturbations.

- Nodes with largest CI have been removed
- In the case of 10 links elimination, situation worsens
- In the case of 2 elimination, situation improves (Braess paradox)





Topology vs function

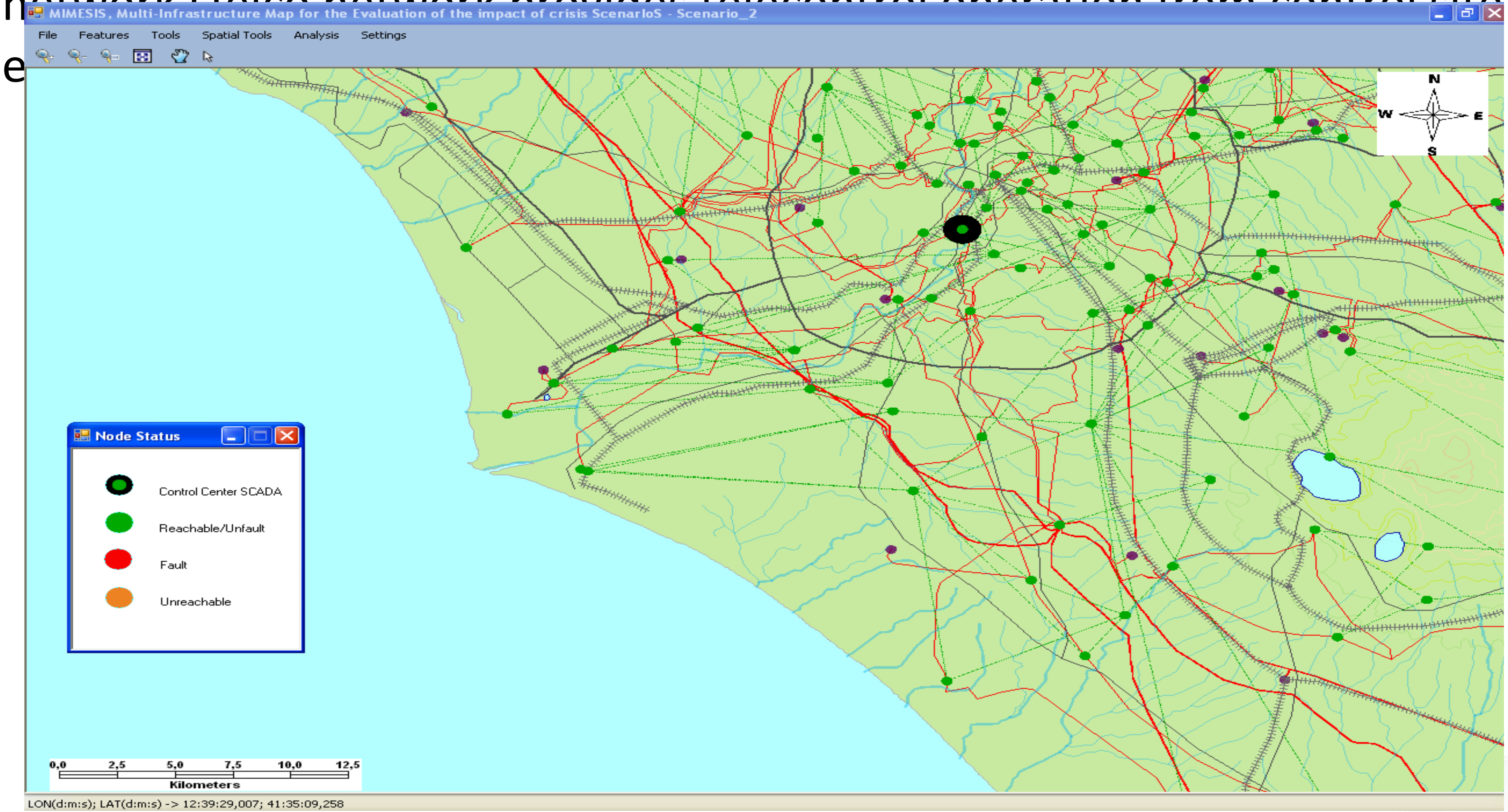
- Centrality measures can differentiate cities structures and help to explain the main direction of social and economical developments.
- C^I distribution for self-assembled cities is *power-law*, while is *exponential* for planned cities.
- Centrality acts as a driving force in the formation and constitution of urban structures. Betweennees Centrality correlates with the commerce density.
- Link Betweennees centrality highly correlates with traffic flow results

P.Crucitti, V.Latora, S.Porta, Chaos, **16** (2006) 015113

E.Strano et al., arXiv:physics/0701111

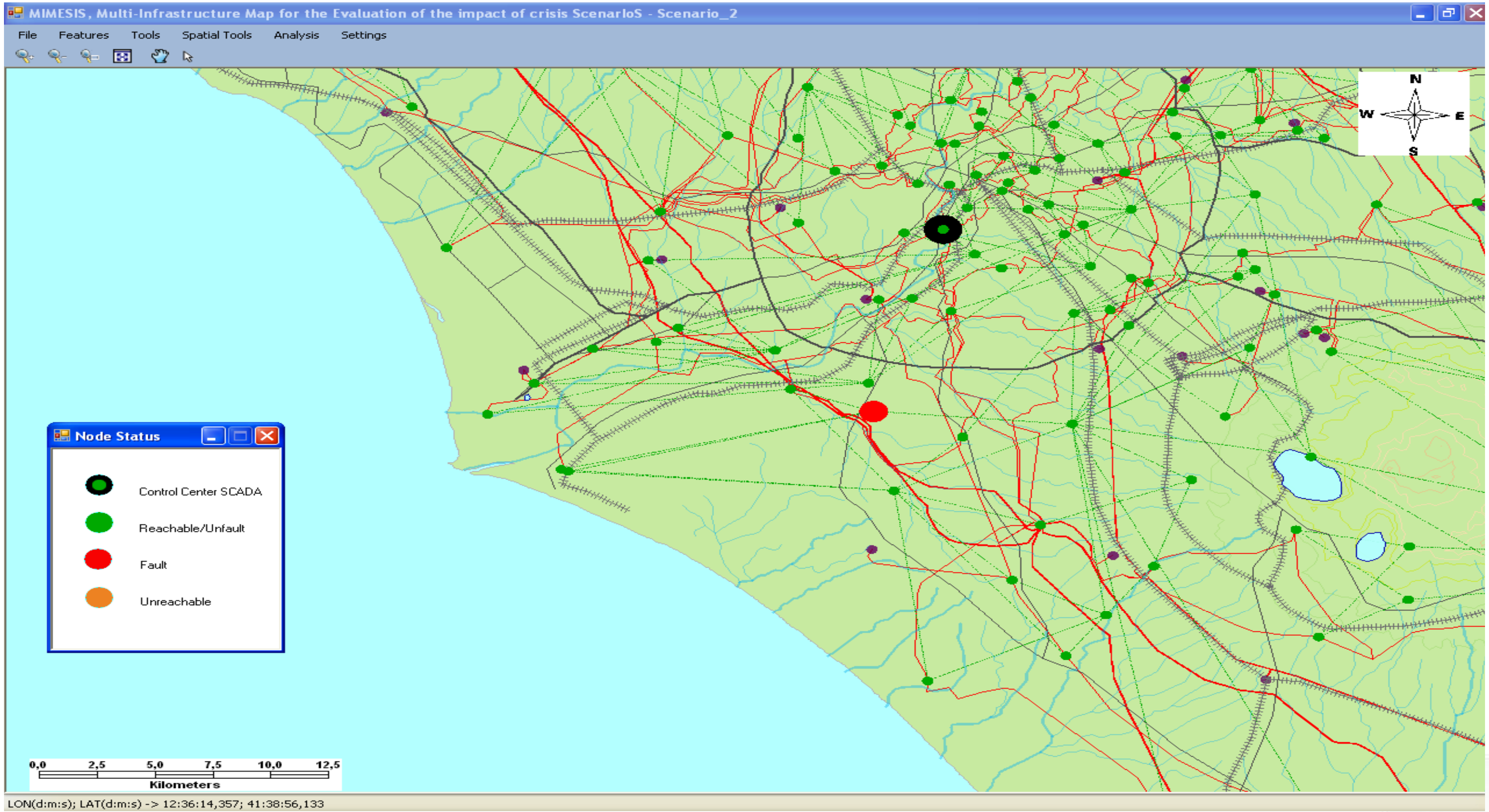
Topological dependence (1)

Let us assume to have a Telco network coupled with an HV electrical transmission network (Telco network provides telecontrol operation from control site of the e



Topological dependence (2)

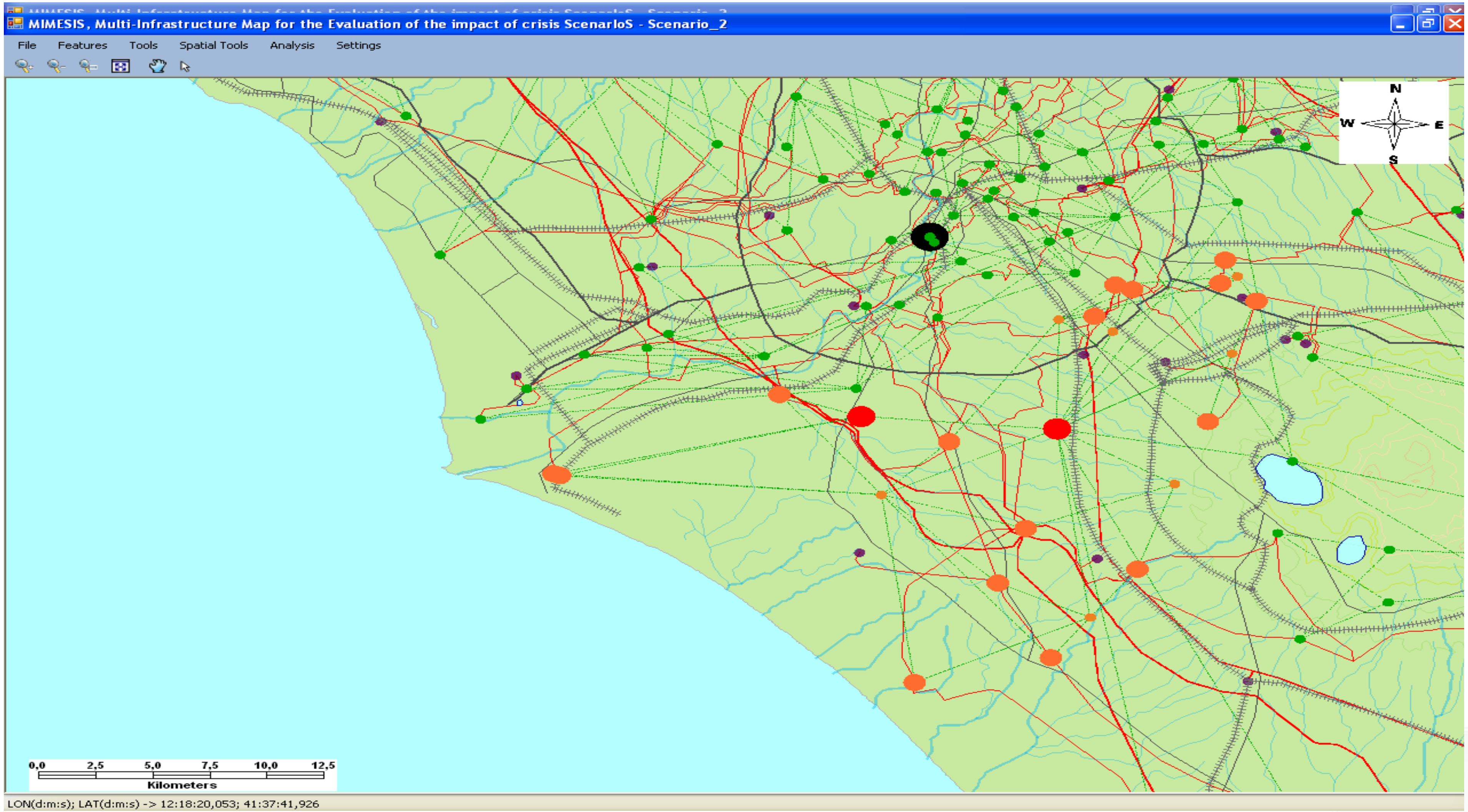
Let us introduce a fault on a Telco node (red one).



Topological dependence (3)

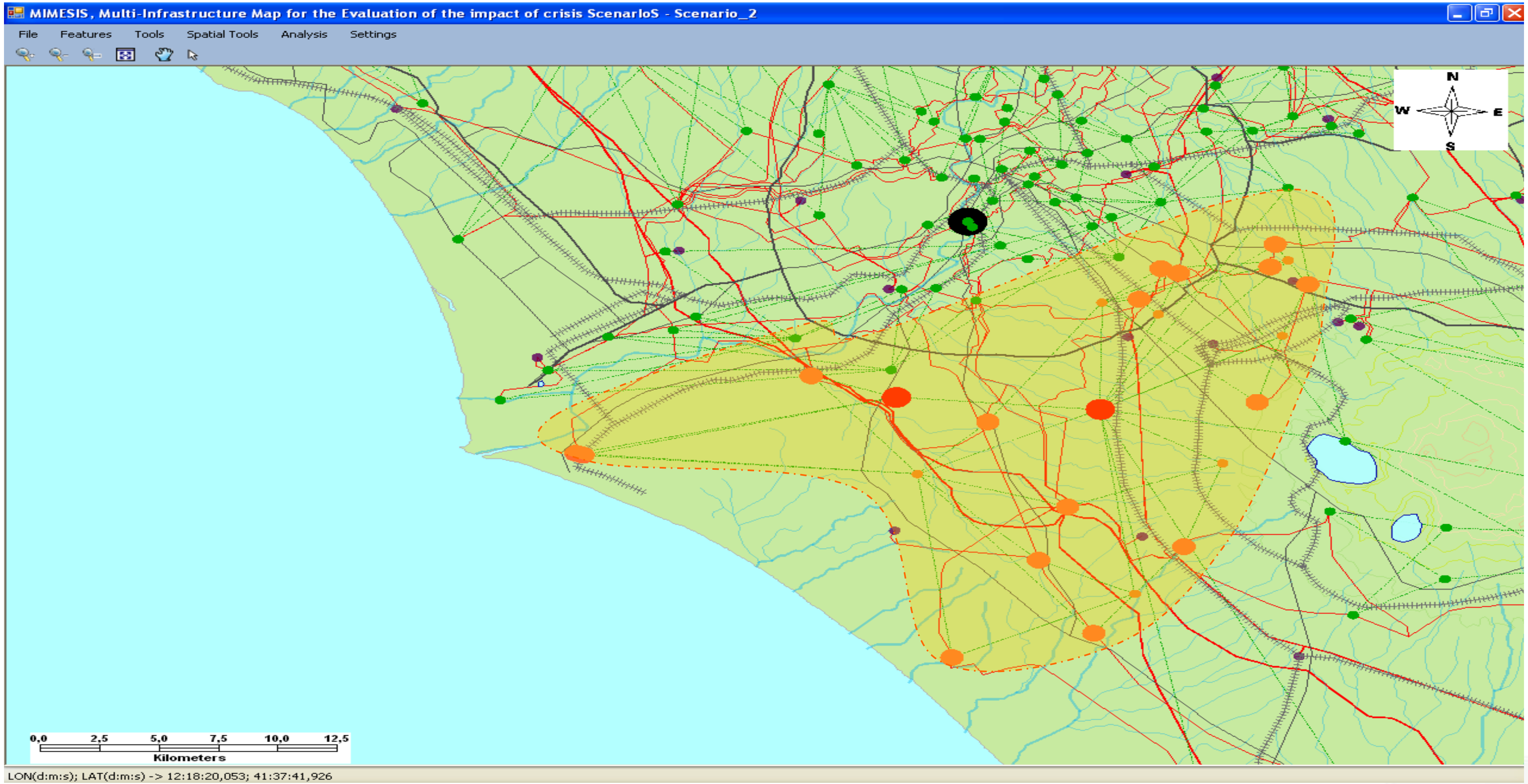
As a consequence of those faults, a number of telecontrolling nodes cannot be reached anymore from the control center

Let us introduce a further fault Telco node.

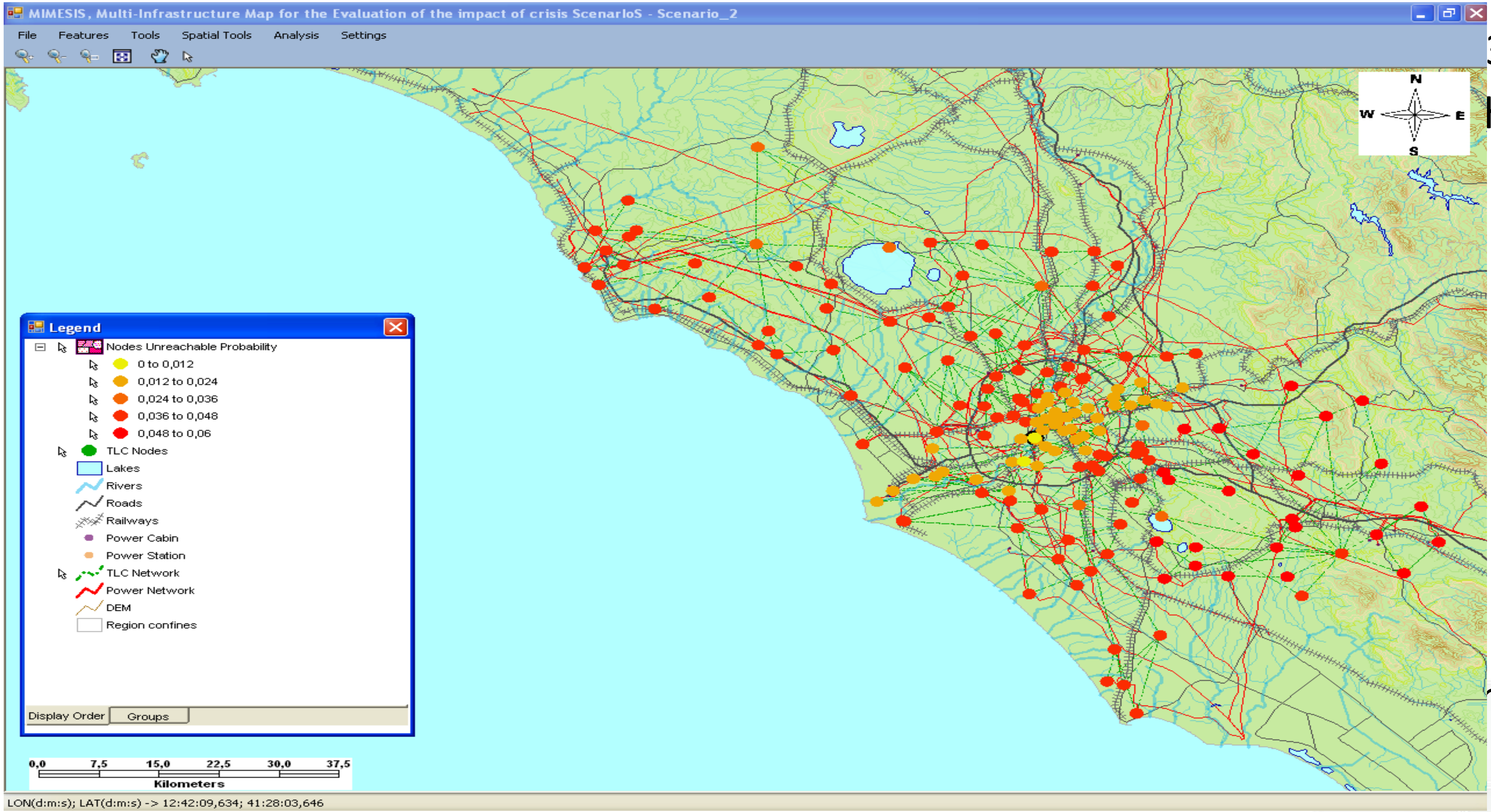


Topological dependence (4)

Shaded area cannot be (electrically) controlled upon that fault



Topological dependence (5)



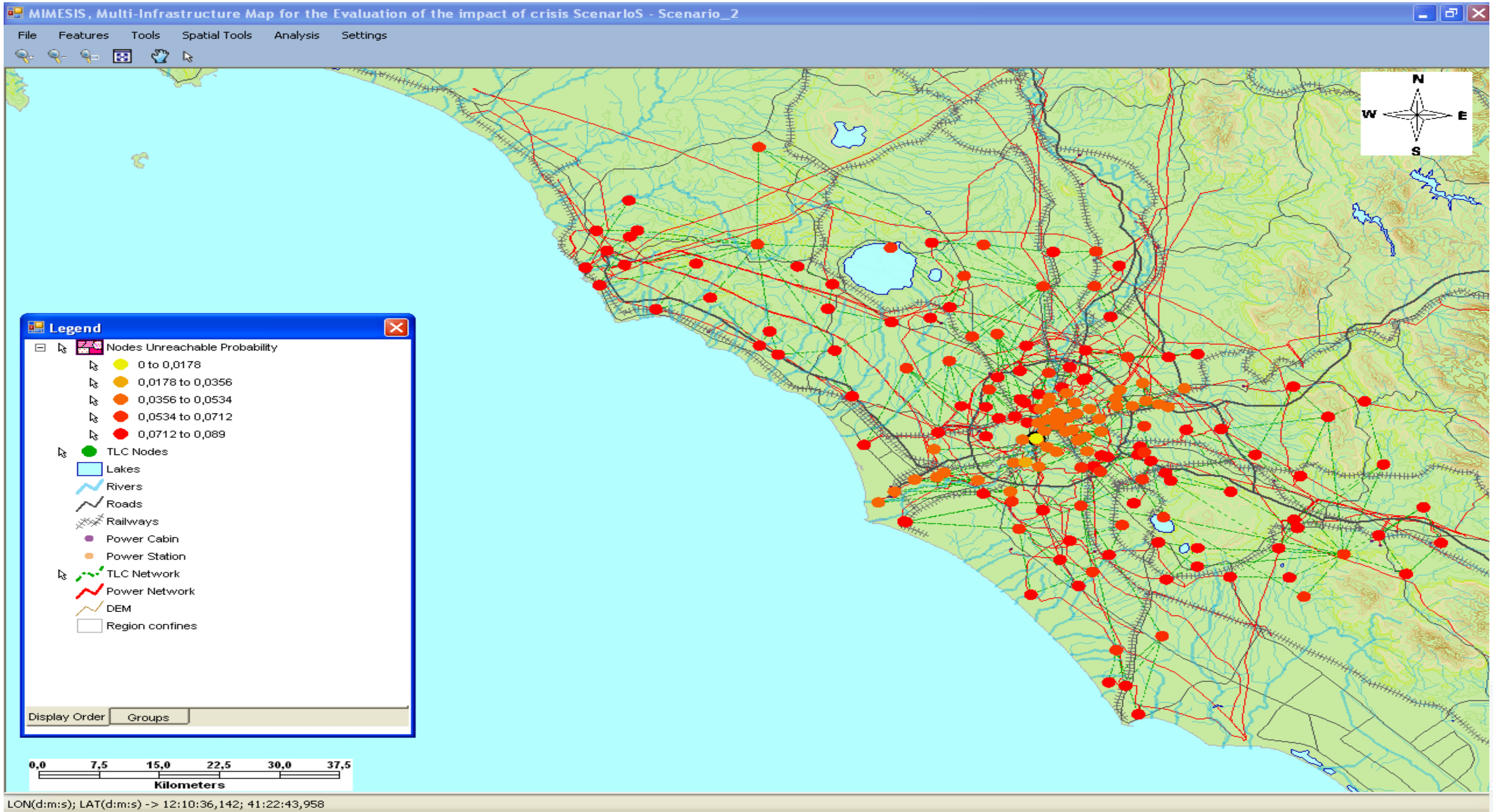
3).. of

he impact

k=2

ndex

Topological dependence (6)



k=3

Topological dependence (7)

One can define, for each node i of the telecontrol network, the probability that it could still be reached upon the fault of k nodes of the telco network

$$NodeDependency(i) = 1 - P_k(i)$$

Averaging on all telecontrol nodes, one can define an averaged dependence estimate based on the topological reachability of nodes.

$$NetDependency = < 1 - P_k > = \frac{\sum_{i=1}^{N} 1 - P_k(i)}{N}$$

Conclusions

- Static models can provide information on topological dependences linking different networks

- Dynamic models can improve this analysis by allowing estimate of impacts in terms of functioning and service variation

- Next step: instead of using “synthetic” faults, implement estimate of risks (by natural hazards) and generate a number of possible “correlated” faults (and their impacts) due to predicted events.

This what we will do in the CIPRNET DSS

Conclusions

Data quality is a key issue. Good-quality CI data are (often) protected (for both security and commercial reasons). This prevents their use for quantitative assessment of vulnerability and for the prediction of crisis scenarios. We thus rely on very raw data. Topological analysis can be an udeful tool for extracting relevant info on the systems.

Graph analysis can be used as a preliminary test to study “intrinsic” robustness of network and to highlight specific structural vulnerability issues.

Thanks

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E0-D1-M5

Geomatics as a basic technique to describe interacting scenarios between natural and technological systems

Maurizio Pollino
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Key Points

1. **Geomatics basics**
   - Introduction to Geographical Information Systems (GIS); Geodesy and Map Projections; Data formats and concepts; DBMS and GIS; GPS.
2. **GIS and Mapping**
   - Basic functions provided by a GIS system: Spatial data analysis (Geoprocessing, Overlay, Buffering, etc.); Thematic mapping
3. **Example of application**
   - Integration of GIS and computational modules in a complex application: Impact and consequence analysis of structures and infrastructures upon an earthquake

1 GEOMATICS


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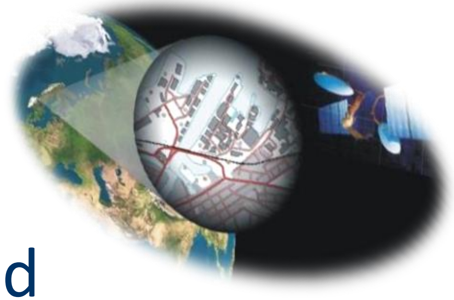
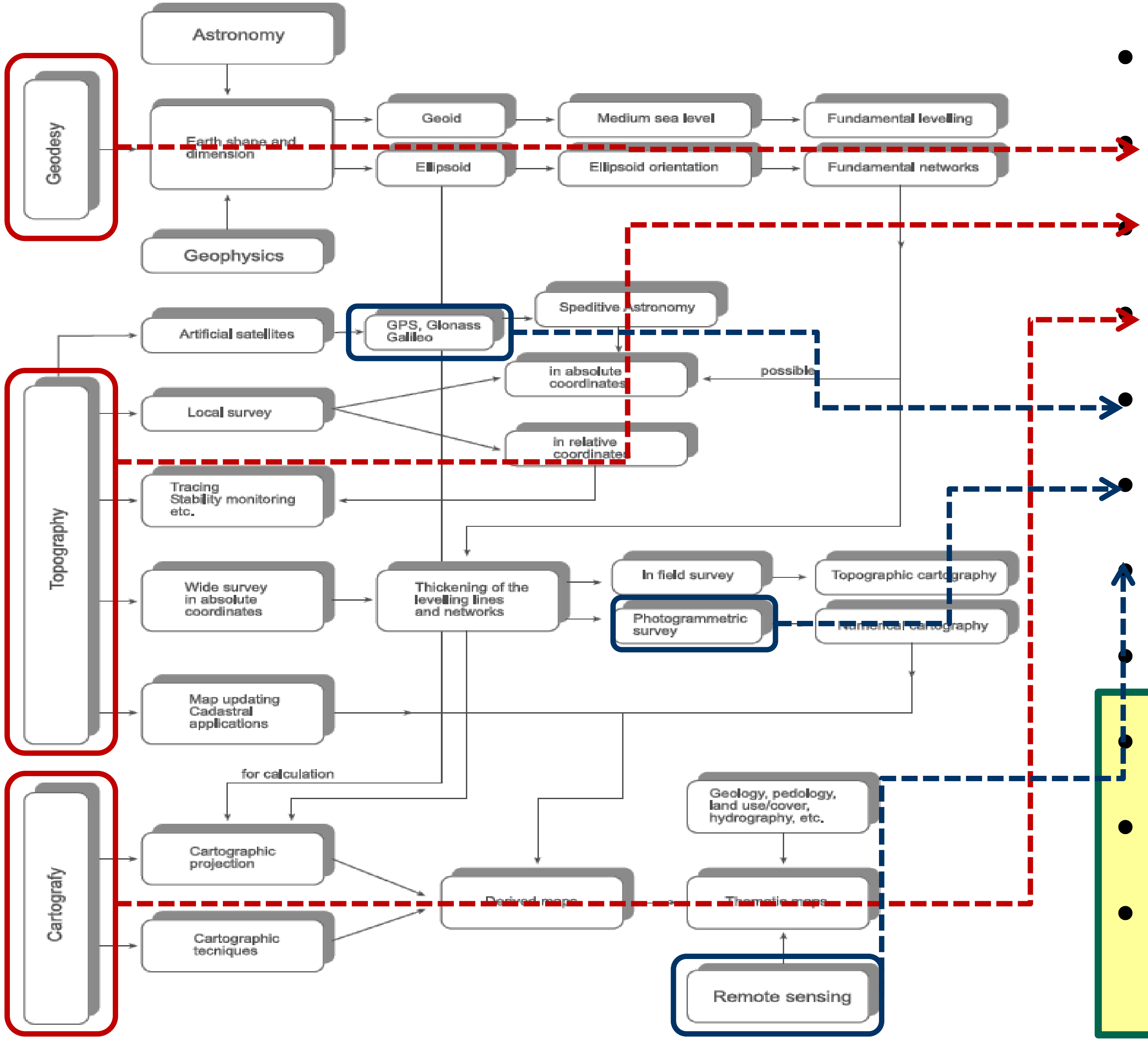


The term *Geomatics*[1] was created at Laval University in Canada in the early 1980s:

- Geomatics is defined as a systemic, multidisciplinary, integrated approach to selecting the instruments and the appropriate techniques for collecting, storing, integrating, modeling, analyzing, retrieving at will, transforming, displaying, and distributing spatially georeferenced data from different sources with well-defined accuracy characteristics and continuity in a digital format.

[1]***Mario A. Gomarasca, (2009), Basics of Geomatics, Springer Netherlands, DOI 10.1007/978-1-4020-9014-1***
http://link.springer.com/book/10.1007%2F978-1-4020-9014-1

Most relevant elements of Geomatics



- **Computer science**
- **Geodesy**
- **Topography**
- **Cartography**
- **Global positioning system (GPS)**
- **Photogrammetry**
- **Remote sensing**
- **Laser scanning system**
- **Geographical information system (GIS)**
- **Decision support system (DSS)**
- **WebGIS**

Geomatics

The disciplines and techniques constituting Geomatics are:

- **Computer science**: to represent and process applicable information through the development of technological instruments (i.e., hardware) and of methods, models and systems (i.e., software);
- **Geodesy**: to determine the shape and size of the Earth; it defines on the one hand the surface of reference in its complete form, the geoid, as well as in its simplified form, the ellipsoid, and on the other hand the external gravitational field as a function of time;
- **Topography**: started with and part of geodesy, this is a combination of procedures for direct land survey. Topography is a combination of methods and instruments to comprehensively measure and represent details of the Earth's surface.

Geomatics

- **Cartography**: to supply a possible description of the shape and dimension of the Earth and its natural and artificial details, by means of graphical or numerical representation of more or less wide areas, following fixed rules;
- **Photogrammetry**: to determine the position and shapes of the objects by measuring them on photographic images;
- **Remote sensing**: to remotely acquire territorial and environmental data and to combine methods and techniques for subsequent processing and interpretation (this definition also fits digital photogrammetry);
- **Laser scanning system**: to locate objects and measure their distance by means of the incident radiation in the optical frequencies (0.3–15 μm) of the electromagnetic spectrum;
- **Global positioning system (GPS)**: to provide the three-dimensional position of fixed or moving objects, in space and time, all over the Earth's surface, under any meteorological conditions and in real time.

Geomatics

- **Geographical information system (GIS)**: to make use of a powerful combination of instruments capable of receiving, recording, recalling, transforming, representing, and processing georeferenced spatial data;
- **Decision support system (DSS)**: to implement complex geographical information systems meant to create possible scenarios by modeling the ground truth and to offer a set of solutions to the decision maker;
- **WebGIS**: to distribute geographic data remotely stored on dedicated machines for databases, according to complex network architectures.

Geographic Information System

We define **GIS (Geographic Information System)** as a structure constituted by a powerful set of instruments and technologies committed to acquire, store, manage, transform, analyze and visualize georeferenced spatial data.

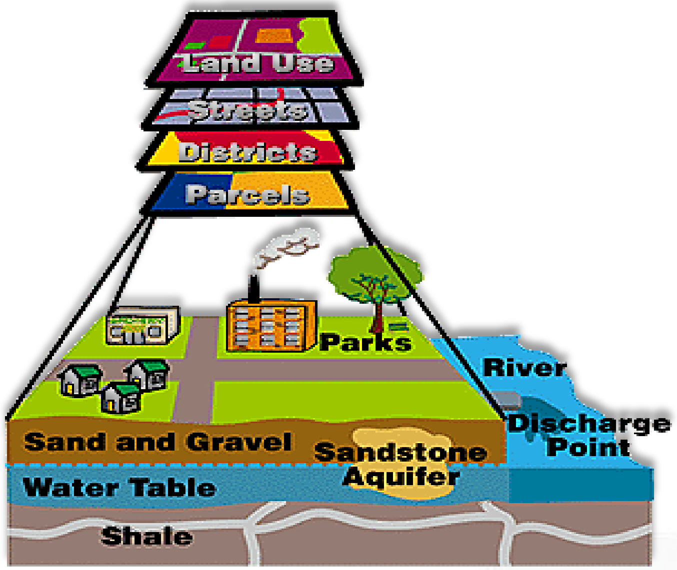
- Georeferenced information: every document or event referred to a particular portion of Earth's surface is an example of georeferenced information
- Geospatial information: every document or event that is also represented from a cartographic point of view or by maps or aerial/satellite images is an example of geospatial information

Often the two terms (georeferenced and geospatial) are used as synonyms.

Geographic Information System

Spatial or geographic data represent REAL WORLD PHENOMENA and they characterized by:

- their POSITION in space with respect to a reference and coordinate system
- NON-SPATIAL ATTRIBUTES (color, temperature, etc…)
- mutual SPATIAL RELATIONS (topological, directional, distance relations)



The definition of a GIS contextually requires the definition of its objectives and methods

- **GIS OBJECTIVES** means the set of results pursued at the moment of the definition and creation of the GIS itself
- **GIS METHODS** means the set of operators, coded in an abstract form, which allows to accomplish such objectives

Definitions

"…a system of hardware, software, and procedures designed to support the capture, management, manipulation, analysis, modeling, and display of spatially referenced data for solving complex planning & management problems" (Rhind, 1989)

"…a computer system capable of assembling, storing, manipulating, and displaying geographically referenced information…" (USGS, 1997)

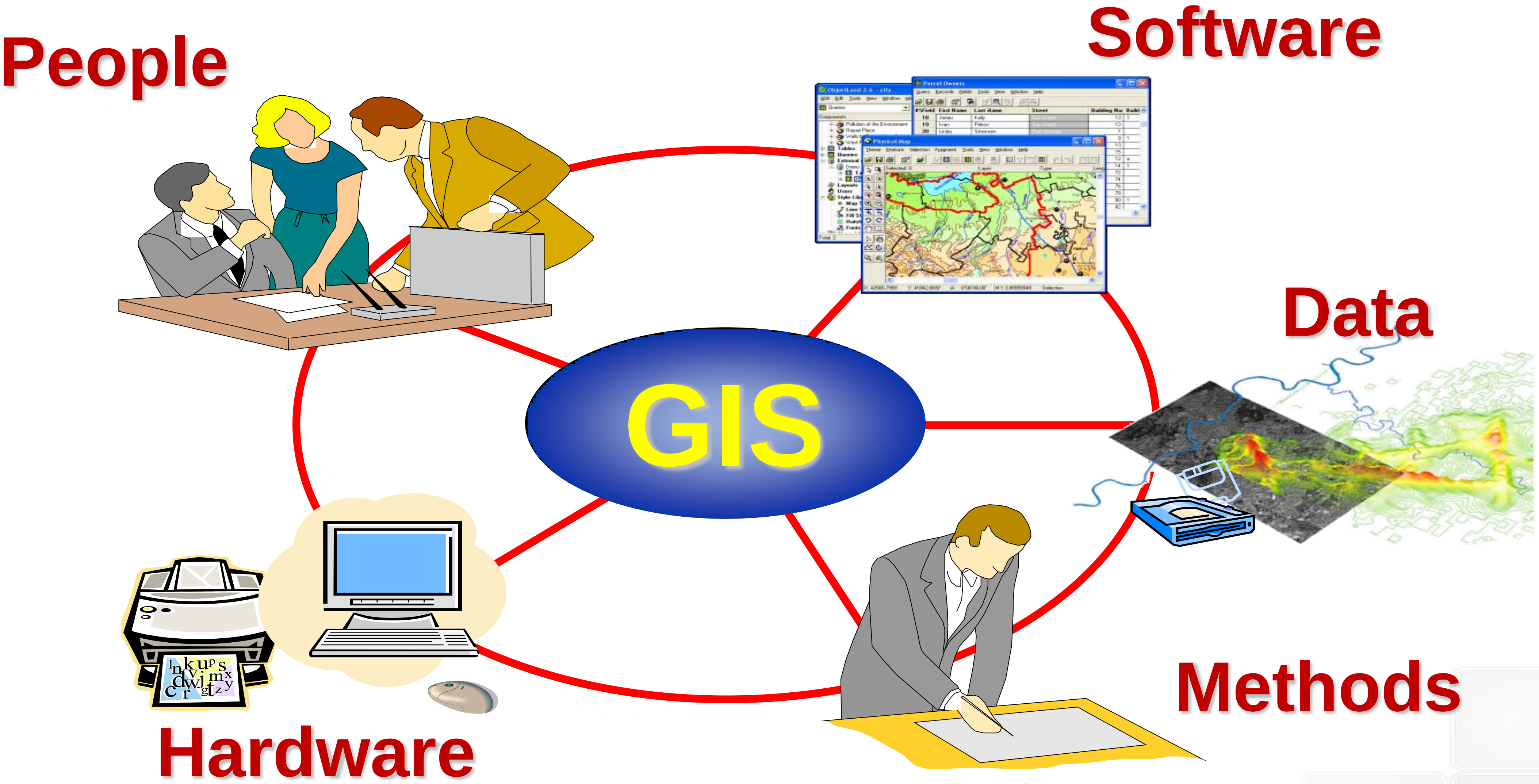
"…a set of computer-based systems for managing geographic data and using those data to solve spatial problems" (Lo & Yeung, 2002)

"A computer system that allows the analysis and display of data with a spatial component" (Phillips, 2002)

And also…

- **data: collection of facts/figures**
- **information: data in useful form**
- **knowledge: what you have**
- **intelligence: what you use**

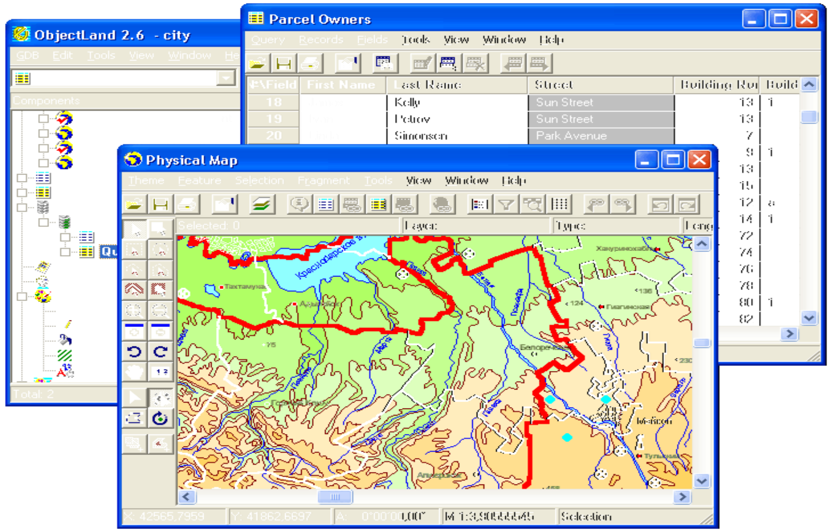
GIS elements



GIS technology

Software

- **Proprietary**
  - ✓ESRI ArcGIS
  - ✓Intergraph
  - ✓MapInfo



- **Free/Open Source (FOSS)**
  - QuantumGIS (QGIS) (http://qgis.org/)
  - GRASS GIS (http://grass.osgeo.org/)

Geographic Data

Spatial data

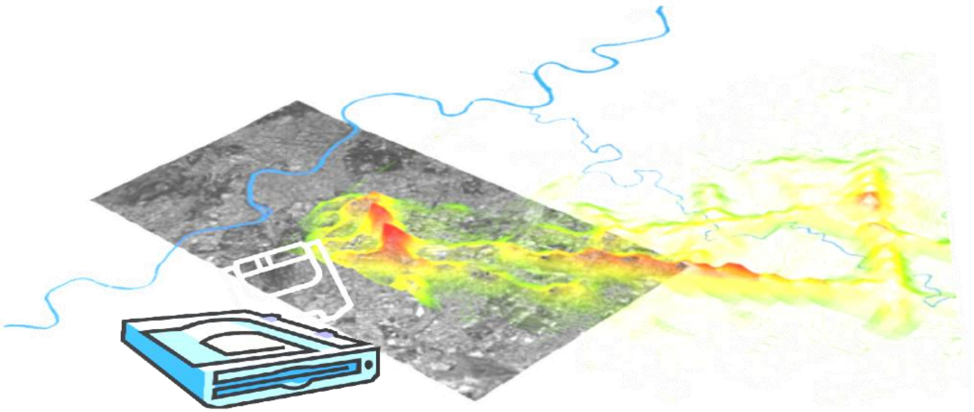
Referenced to "geographic space"

- coordinate system
- projection

Source

- land survey
- GPS
- Aerial/satellite imagery

Represented at a "geographic scale"



Types

geodetic control network: surface location

topographic base: point elevation

graphical overlays: thematic data

Representation

vector: point, lines, polygons

raster: grid cells

surface

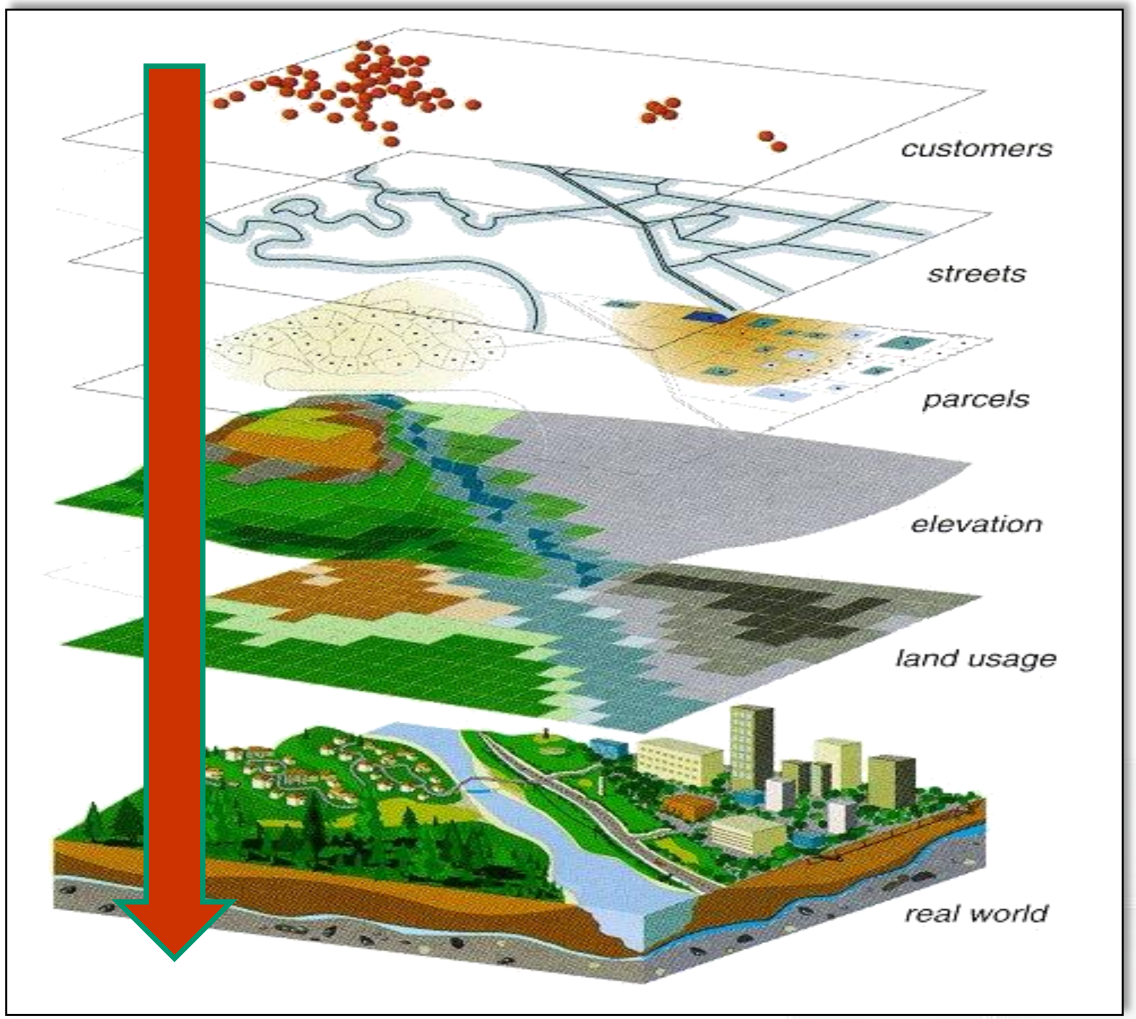
Metadata

information about the data

key when sharing data

How GIS works

- ✓ In a GIS, different types of information are represented as separate map layers, coming from different sources or disciplines (multidisciplinary)
- ✓ Each layer is linked to descriptive information
- ✓ Layers are numerically combined to make a new map containing further information

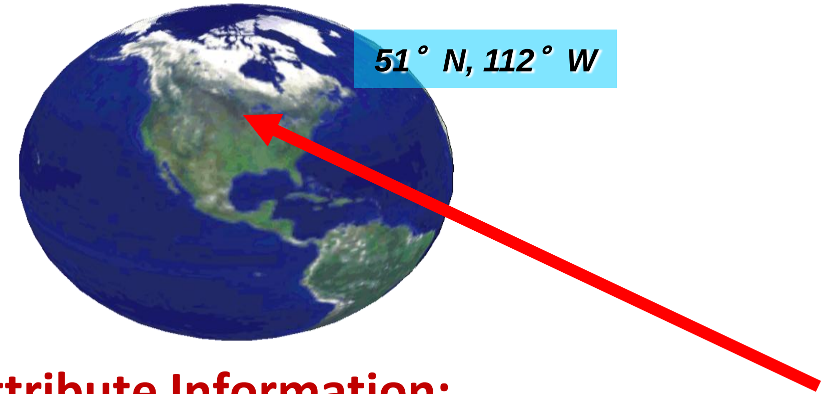


- ✓ Data modeling in environmental GIS:
  - Basic functionalities
  - Specific functionalities

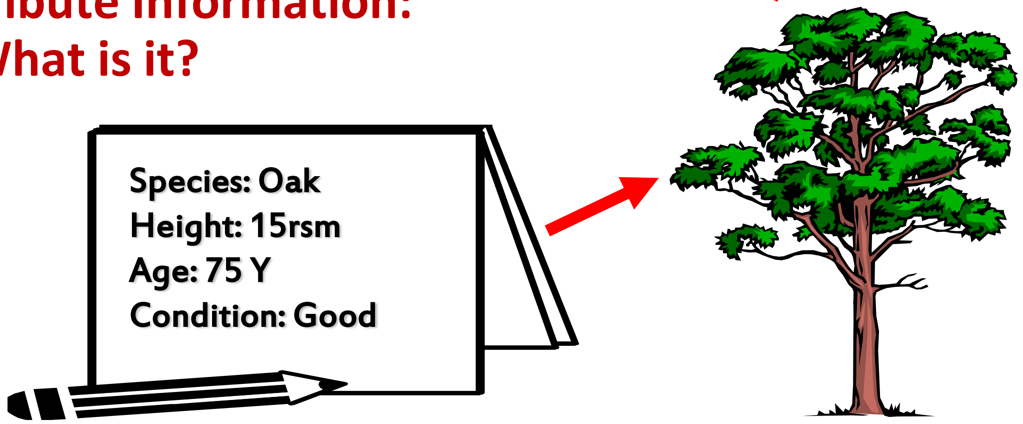
Data formats and concepts

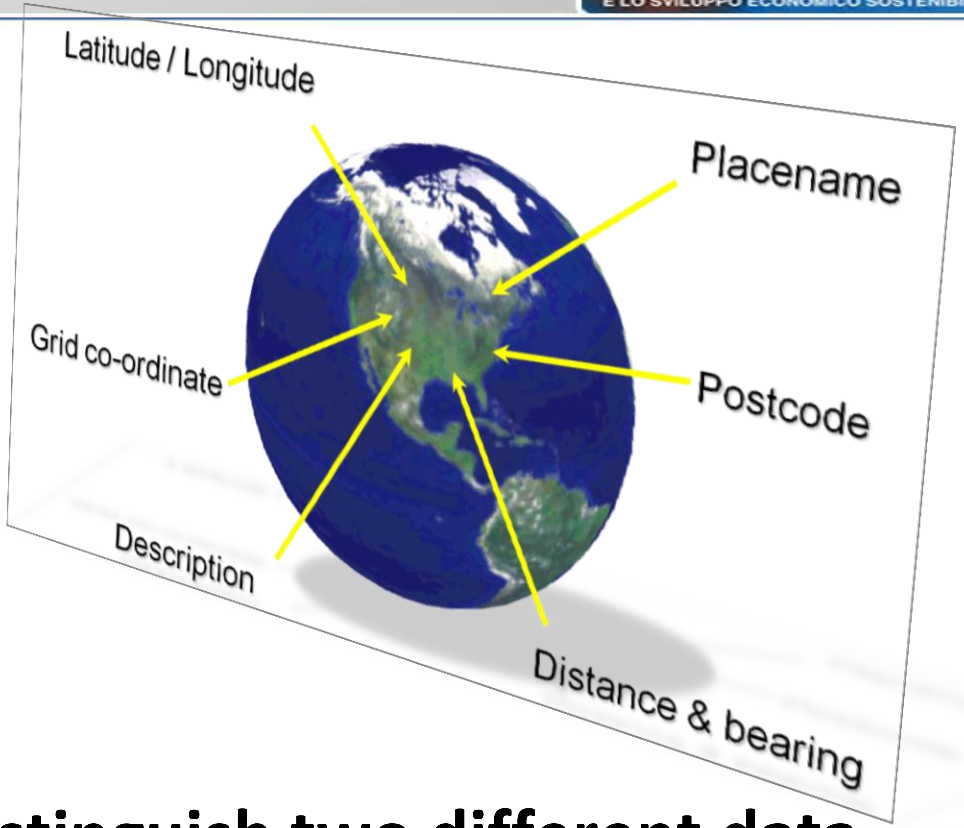
We can describe any element of our world in two ways:

Location Information: Where is it?



Attribute Information: What is it?





We distinguish two different data models:

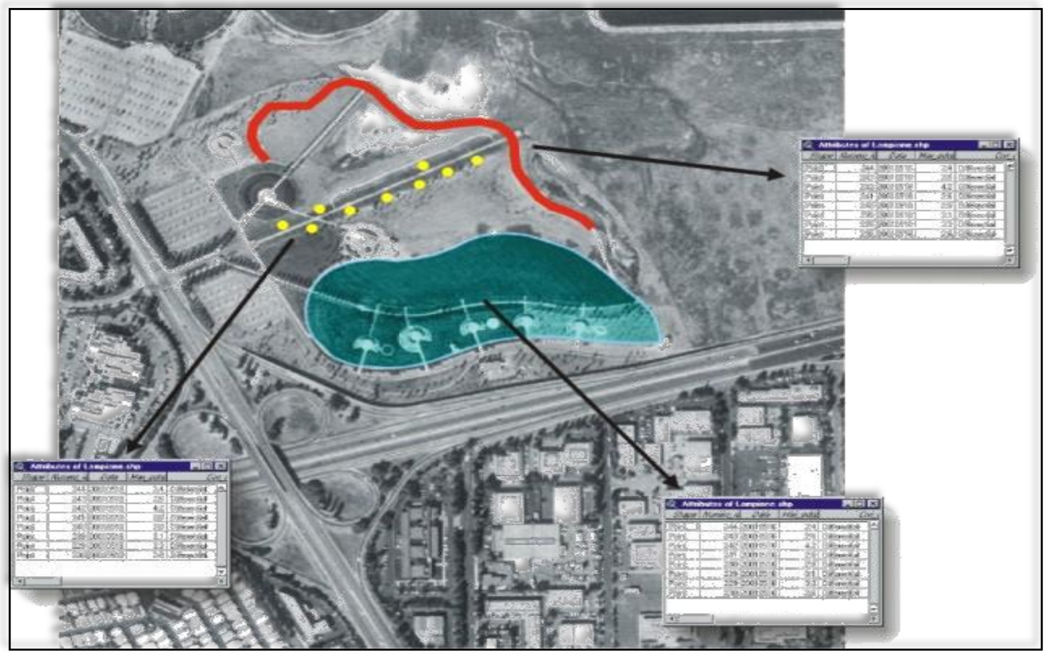
- Vector data
- Raster data

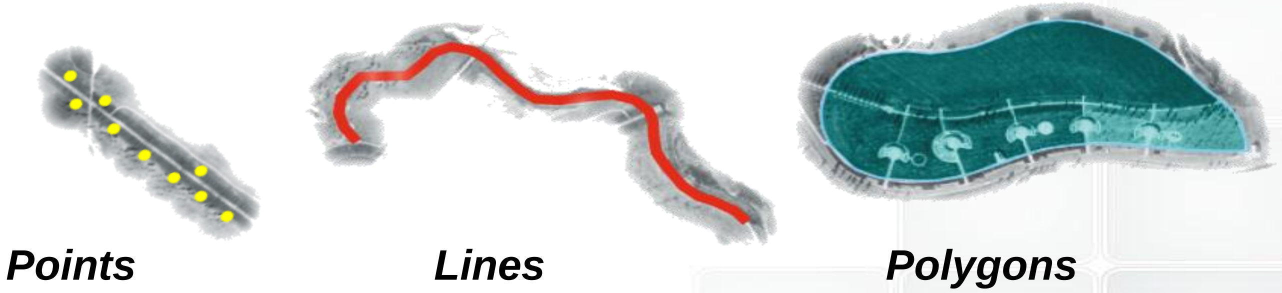
Vector data

Represented by means of coordinates. In that case you can use the following geometric entities as primitives: point, line and polygon (surface).

You can also represent the topological properties of data, allowing the description of spatial relationship between them (disjoint, touch, in, equal, contain, cross, overlap).

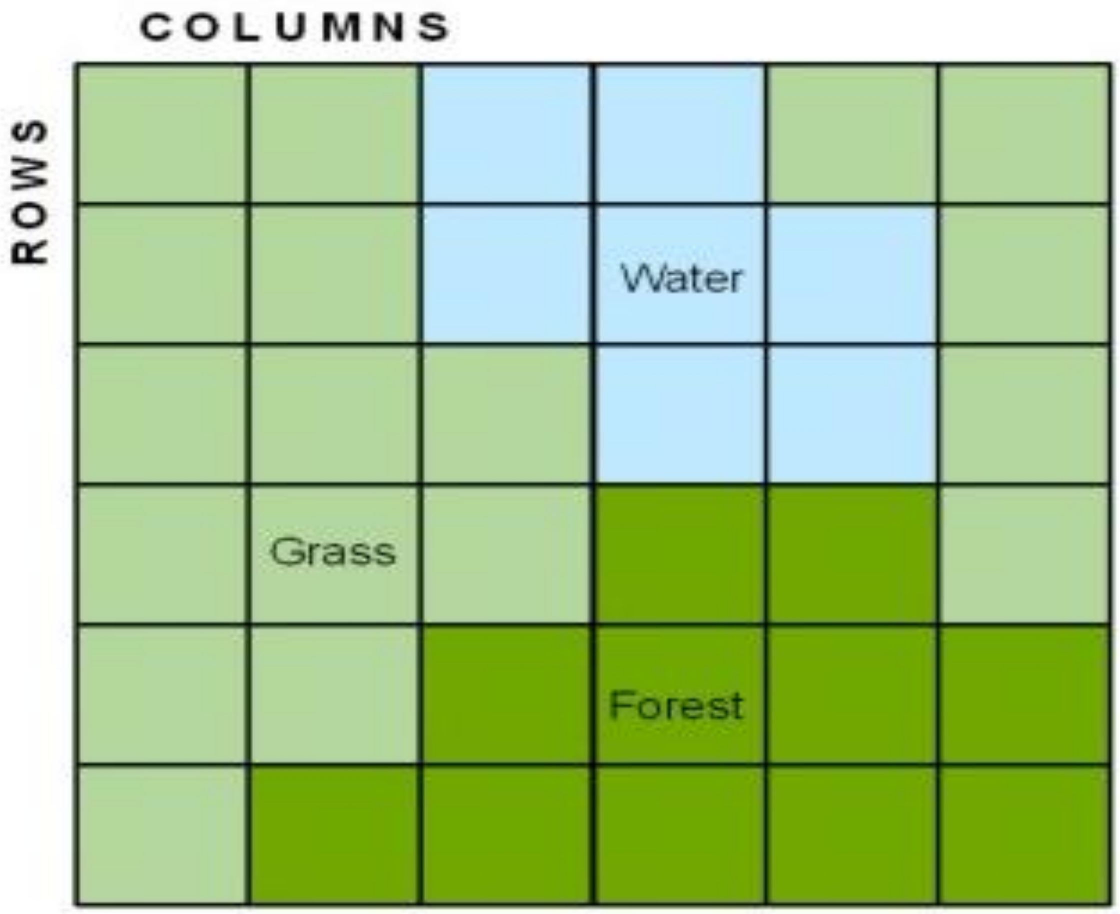
We imagine the world as an empty space filled by objects having different shape. That's the reason why sometimes this model is called the "object model".





Raster data

- ✓ Raster data, on the contrary, allows the representation of the world by means of a regular grid of small units, called pixels.
- ✓ A pixel contains as information if the phenomenon we are analysing doesn’t happen on it (usually in this case the value of the pixel is set to null) or if it does.
- ✓ In the latter case the specific value of the phenomenon on the pixel can be stored.

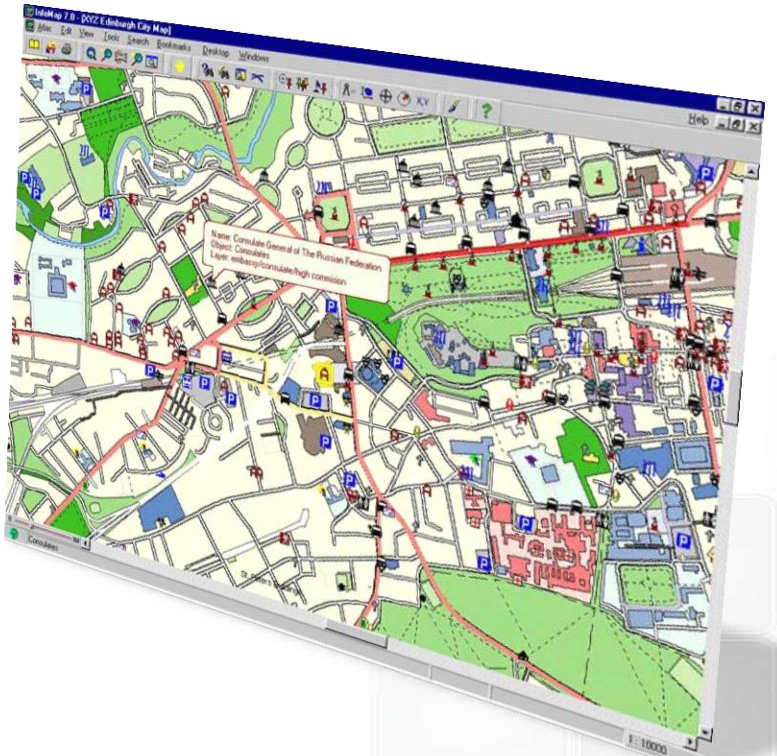


Maps are a graphical representation of the spatial structure of physical and/or cultural environments.

Map are abstractions since they present the real world in a simplified fashion at a reduced scale.

Maps are used for:

- the display of spatial data
- the analysis of spatial data



Advantages of digital maps over paper:

- Easier to produce
- Easier to store
- Easier to distribute
- Dimensional stability

Georeferencing

Is the representation of the location of real world features within the spatial framework of a particular coordinate system.

Relationship between coordinate systems and map projections:

- Map projections define how positions on the Earth's curved surface are transformed onto a flat map surface
- Coordinate systems provide a referencing framework by which positions are measured and computed.

Coordinate Systems: Spatial Referencing

Spherical Coordinate Systems

- Geographical coordinate system (Latitude & Longitude)

Rectangular Coordinate Systems

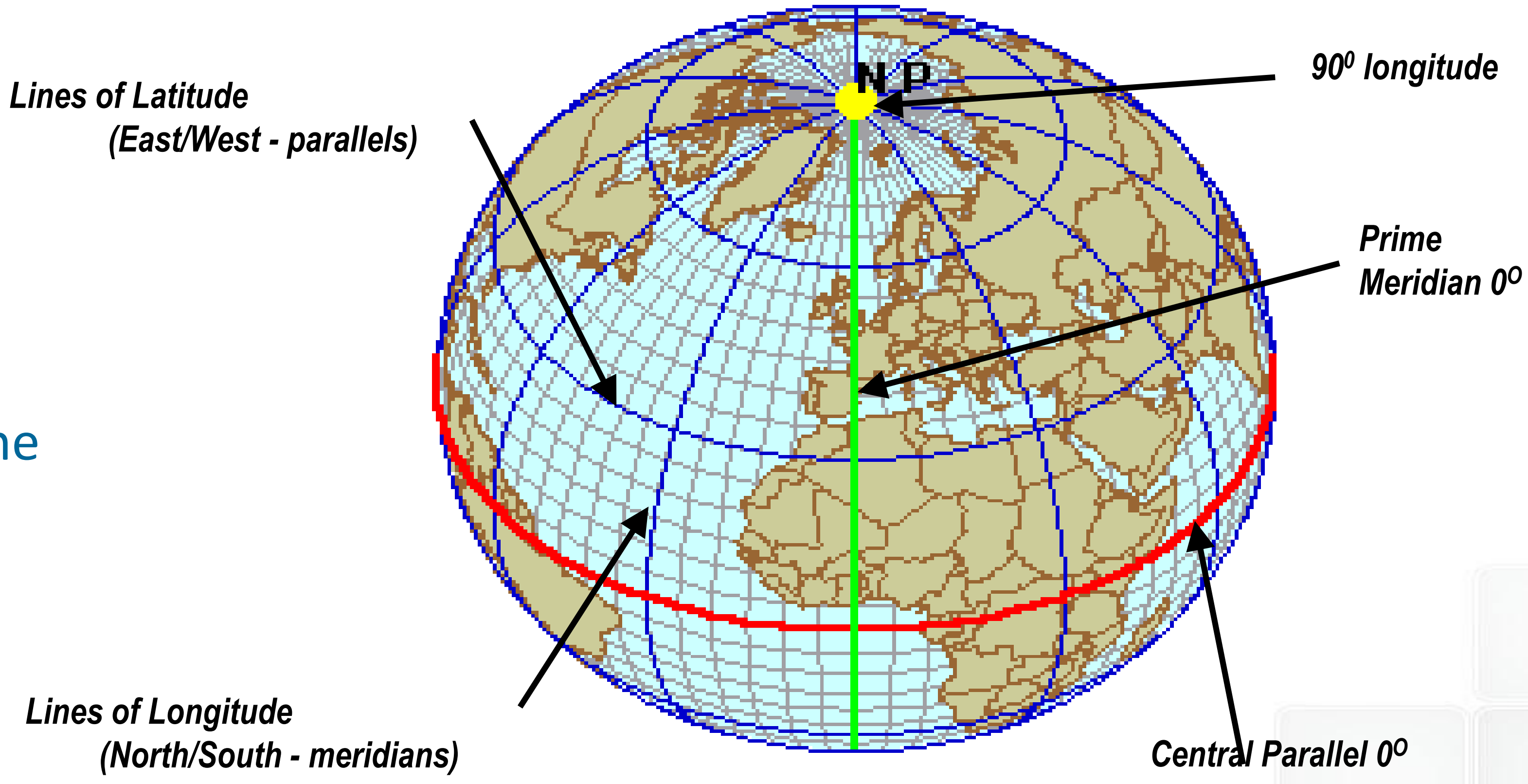
- UTM (Universal Transverse Mercator)
- UPS
- National Grids (e.g., in Italy: Gauss-Boaga)

Geographic Coordinate System(2)

Latitude: angular distance north/south of baseline (equator)

Longitude: angular distance east/west of baseline (prime meridian)

- ✓ Graticule: grid of latitude and longitude lines (**parallels** and **meridians**) on a map or globe
- ✓ Axis: the center of Earth rotation.
- ✓ Equator: The plane through the center of mass perpendicular to the axis.



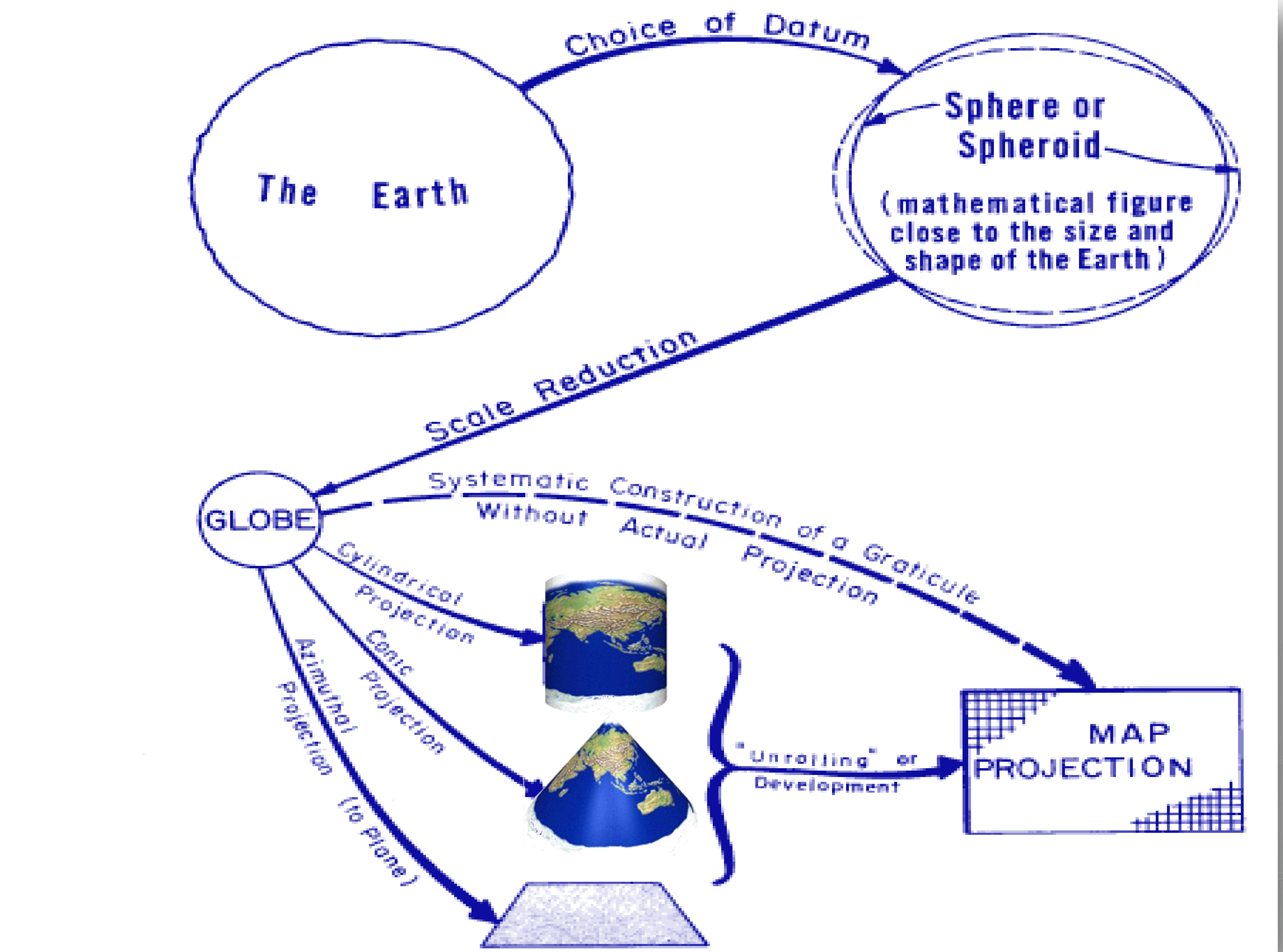
(2)*Peter Dana (University of Colorado): http://www.colorado.edu/geography/gcraft/notes/mapproj/mapproj_f.html*

Map projections

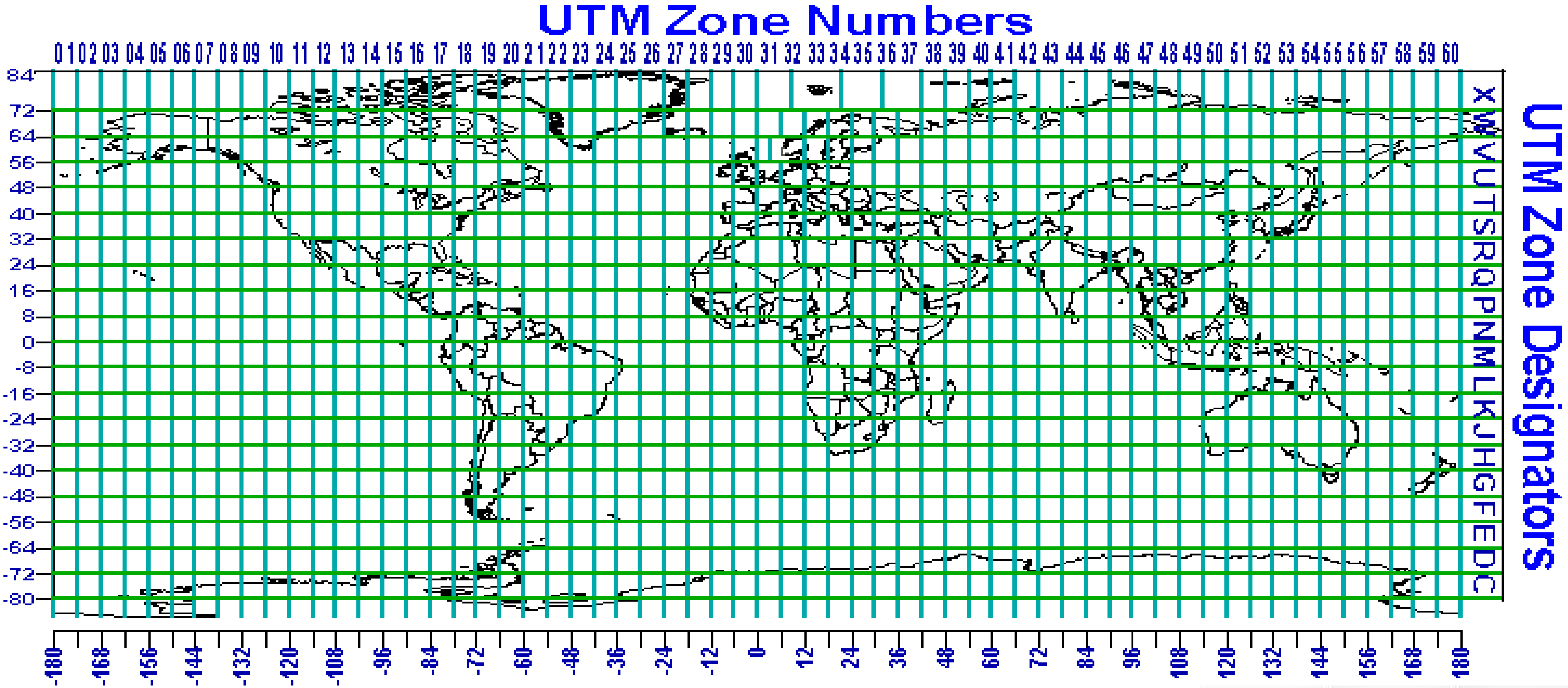
Map projections transform the curved, 3-D surface of the planet into a flat, 2-D plane. Note, that Map Projections distort map scale in various ways.

Transform a position on the Earth's surface identified by latitude and longitude (Φ, λ) into a position in Cartesian coordinates (x, y).

Map projections necessarily distort the Earth and the map scale.

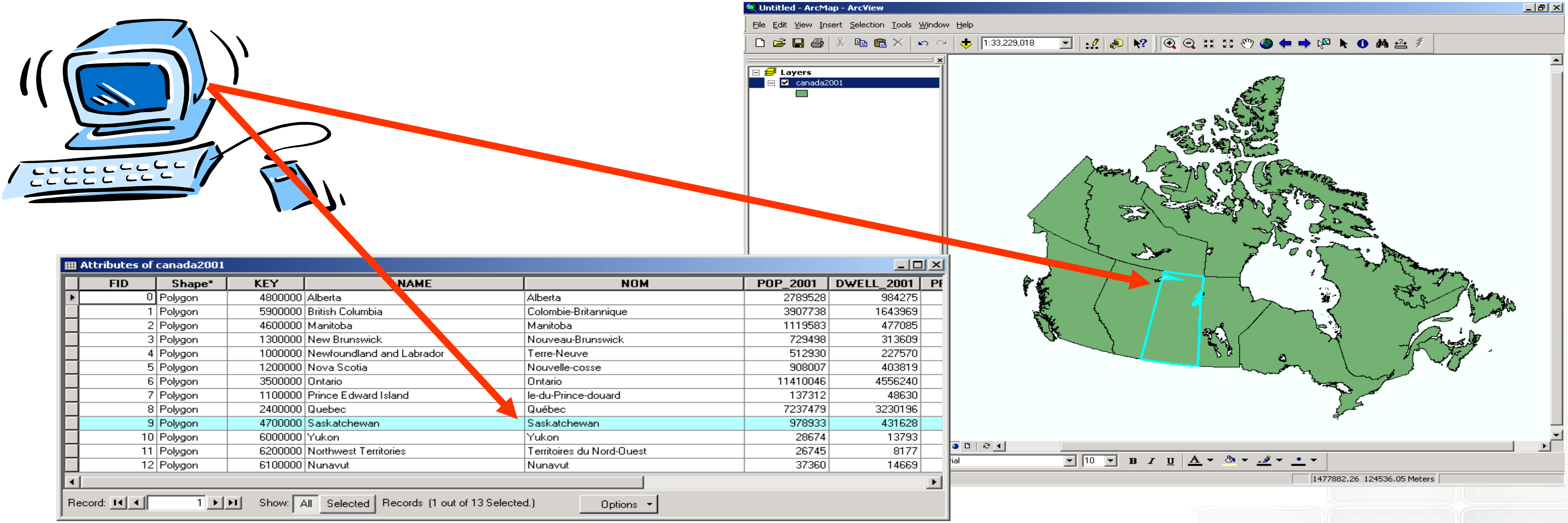


Universal Transverse Mercator (UTM) Projection



GIS and DBMS

The location and attribute information is stored inside your computer and a GIS links the two types of information together. It uses a map to display the location information and a table to display the attribute information.

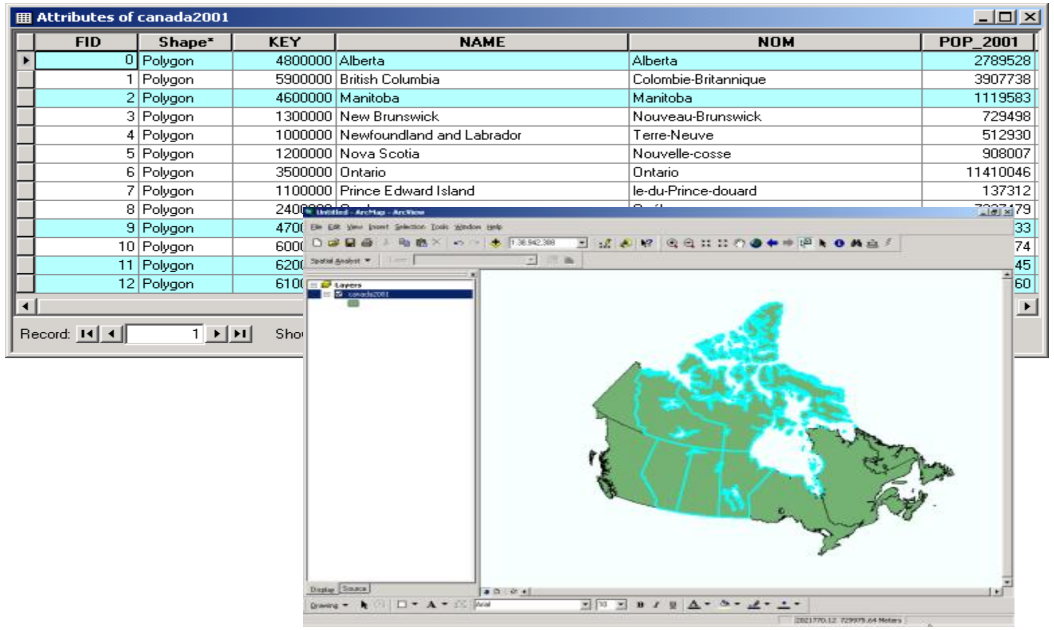


FID	Shape*	KEY	NAME	NOM	POP_2001	DWELL_2001	PF
0	Polygon	4800000	Alberta	Alberta	2789528	984275	
1	Polygon	5900000	British Columbia	Colombie-Britannique	3907738	1643969	
2	Polygon	4600000	Manitoba	Manitoba	1119583	477085	
3	Polygon	1300000	New Brunswick	Nouveau-Brunswick	729498	313609	
4	Polygon	1000000	Newfoundland and Labrador	Terre-Neuve	512930	227570	
5	Polygon	1200000	Nova Scotia	Nouvelle-cosse	908007	403819	
6	Polygon	3500000	Ontario	Ontario	11410046	4556240	
7	Polygon	1100000	Prince Edward Island	le-du-Prince-douard	137312	48630	
8	Polygon	2400000	Quebec	Québec	7237479	3230196	
9	Polygon	4700000	Saskatchewan	Saskatchewan	978933	431628	
10	Polygon	6000000	Yukon	Yukon	28674	13793	
11	Polygon	6200000	Northwest Territories	Territoires du Nord-Ouest	26745	8177	
12	Polygon	6100000	Nunavut	Nunavut	37360	14669	

GIS software can answer questions about our world:

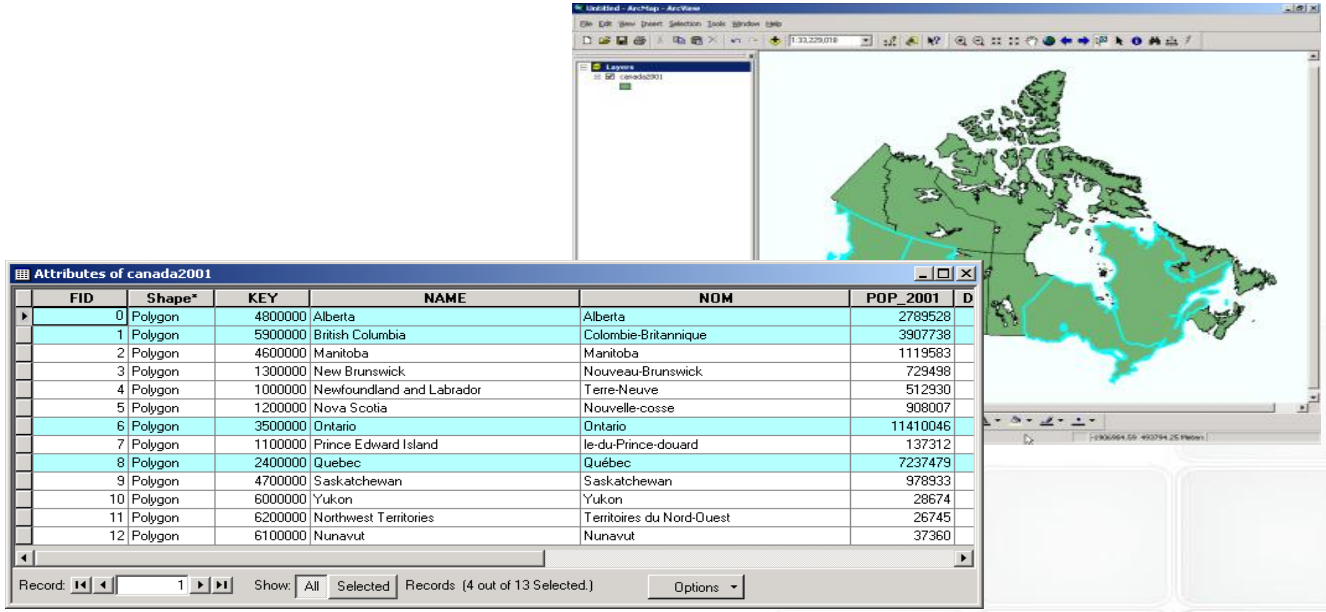
Spatial Questions:

What provinces border Saskatchewan?



Attribute Questions:

What provinces have more than 1.5 million people?



FID	Shape*	KEY	NAME	NOM	POP_2001
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1	Polygon	5900000	British Columbia	Colombie-Britannique	3907738
2	Polygon	4600000	Manitoba	Manitoba	1119583
3	Polygon	1300000	New Brunswick	Nouveau-Brunswick	729498
4	Polygon	1000000	Newfoundland and Labrador	Terre-Neuve	512930
5	Polygon	1200000	Nova Scotia	Nouvelle-cosse	908007
6	Polygon	3500000	Ontario	Ontario	11410046
7	Polygon	1100000	Prince Edward Island	le-du-Prince-douard	137312
8	Polygon	2400000	Quebec	Québec	7237479
9	Polygon	4700000	Saskatchewan	Saskatchewan	978933
10	Polygon	6000000	Yukon	Yukon	28674
11	Polygon	6200000	Northwest Territories	Territoires du Nord-Ouest	26745
12	Polygon	6100000	Nunavut	Nunavut	37360

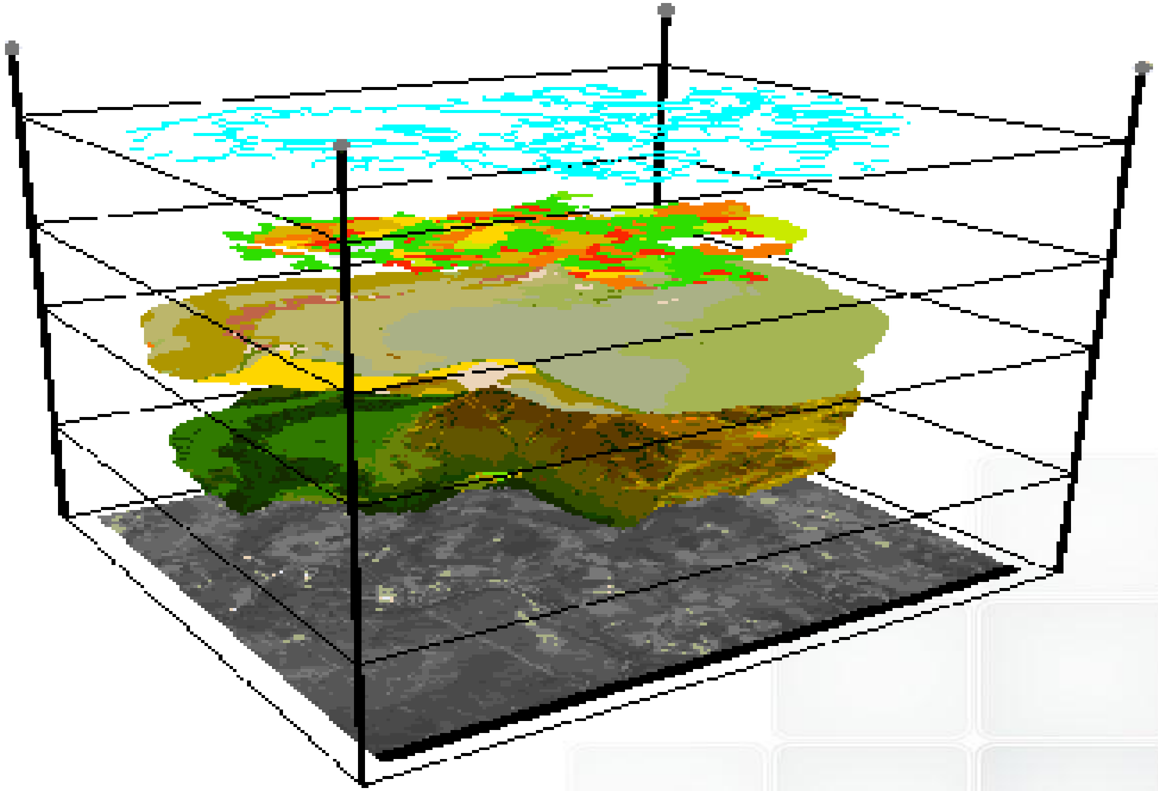
Record: 1 Show: All Selected Records (4 out of 13 Selected.) Options

2 GIS AND MAPPING

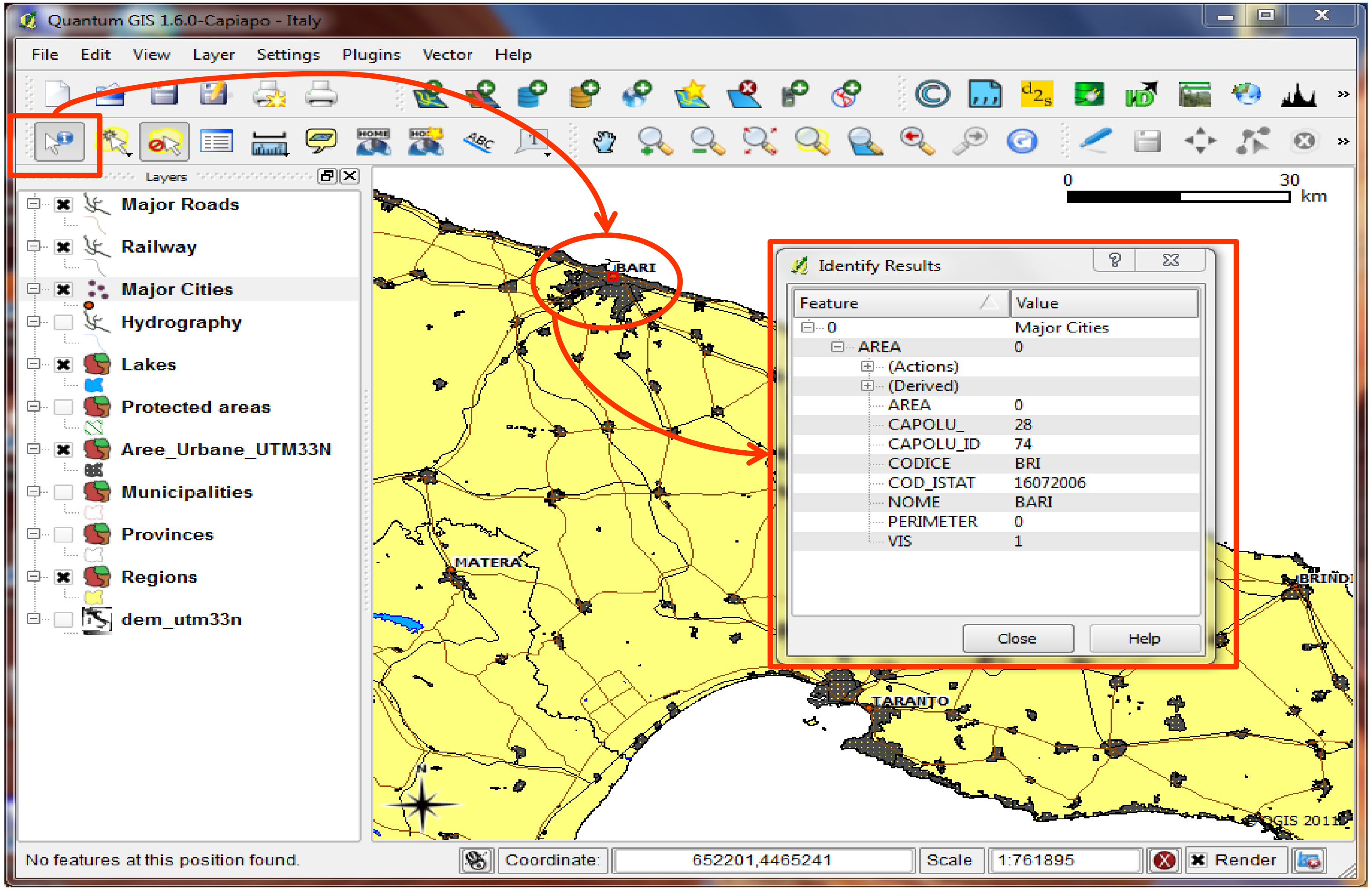
GIS Analysis Functions

Main categories:

- Retrieval, Classification and Measurement
- Overlay
- Extraction
- Proximity
- Map algebra (Raster)



Identify



Quantum GIS 1.6.0-Capiapo - Italy
File Edit View Layer Settings Plugins Vector Help
Layers
Major Roads
Railway
Major Cities
Hydrography
Lakes
Protected areas
Aree_Urbane_UTM33N
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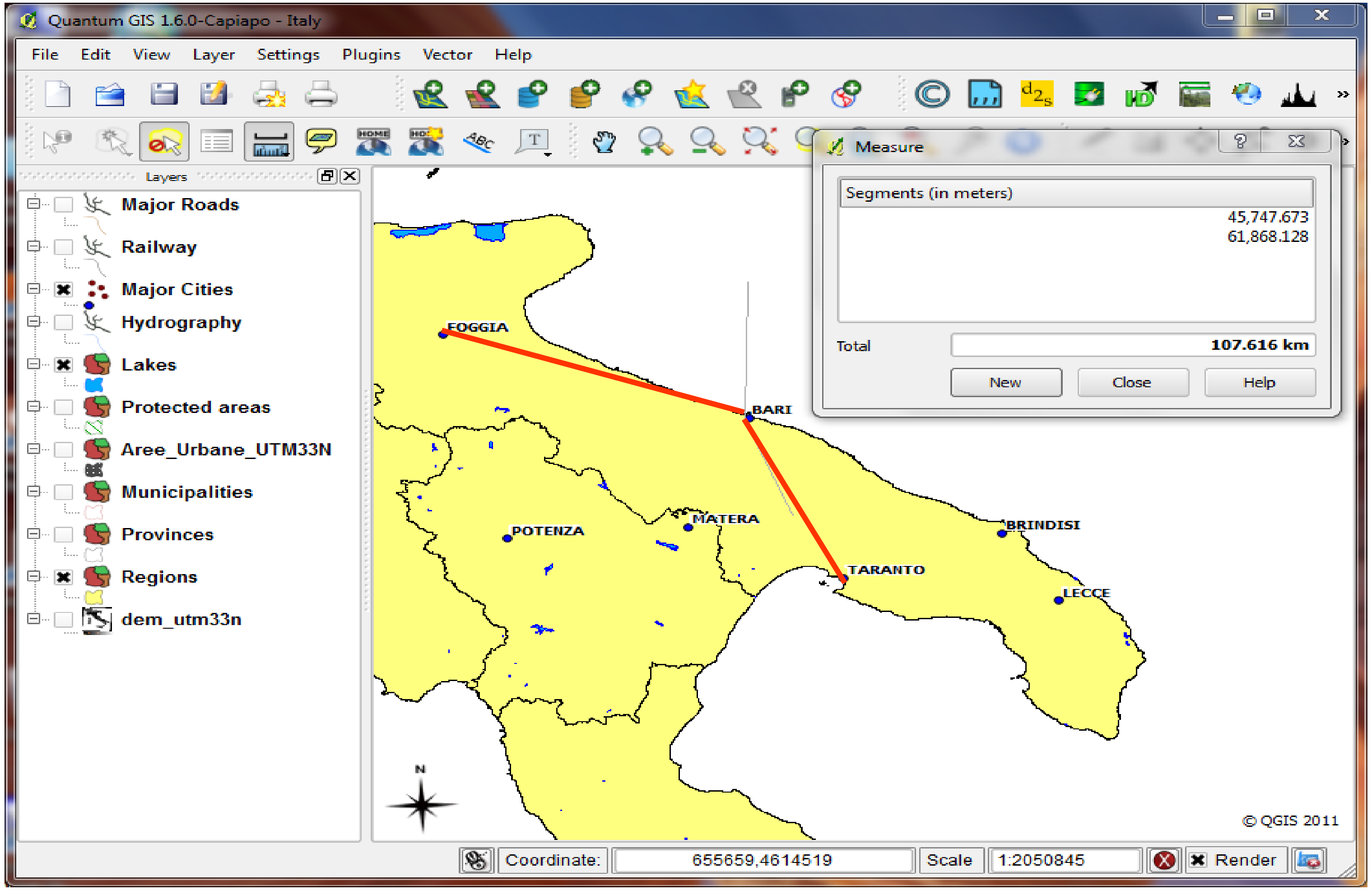
Measure



Quantum GIS 1.6.0-Capiapo - Italy
File
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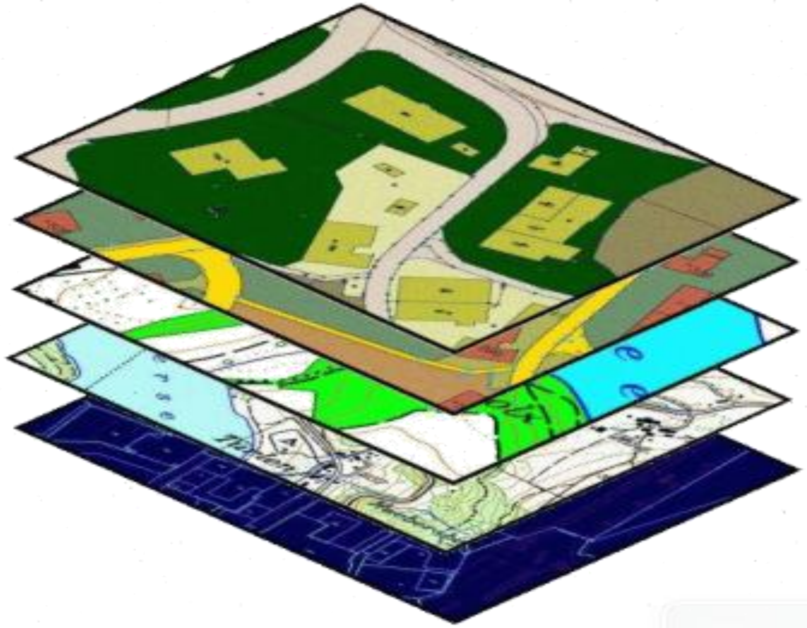
Layers
Major Roads
Railway
Major Cities
Hydrography
Lakes
Protected areas
Aree_Urbane_UTM33N
Municipalities
Provinces
Regions
dem_utm33n
Measure
Segments (in meters)
45,747.673
61,868.128
Total
107.616 km
New
Close
Help
FOGGIA
BARI
MATERA
POTENZA
BRINDISI
TARANTO
LECCE
N
© QGIS 2011
Coordinate:
655659,4614519
Scale
1:2050845
Render

Overlay Functions

Overlay function creates new “layers” to solve spatial problems

- Arithmetic
  - addition, subtraction, division, multiplication
- Logical
  - find where specified conditions occur (and, or, >, <, etc.)



Basic idea:

- spatially combine/compare two data layers to:
  - (a) generate new output data layer, or
  - (b) assign attributes of one data layer to another
- most cases: one of the data layers will contain polygon entities

Overlay Functions

Overlay analyses

- Operate on spatial entities from two or more maps to determine spatial overlap, combination, containment, intersection…etc.
- One of the most “fundamental” of GIS operations
- Formalized in 1960s by landscape architects who used acetate map overlays
- Now a basic part of the GIS toolbox

Vector overlays:

- combine point, line, and polygon features
- computationally complex

Raster overlays:

- cell-by-cell comparison, combination, or operation
- computationally less demanding

Raster & Vector methods differences:

- Vector good for sparse data sets
- Raster grid calculations easier

Overlay: Union, Intersect, and Identity

UNION:

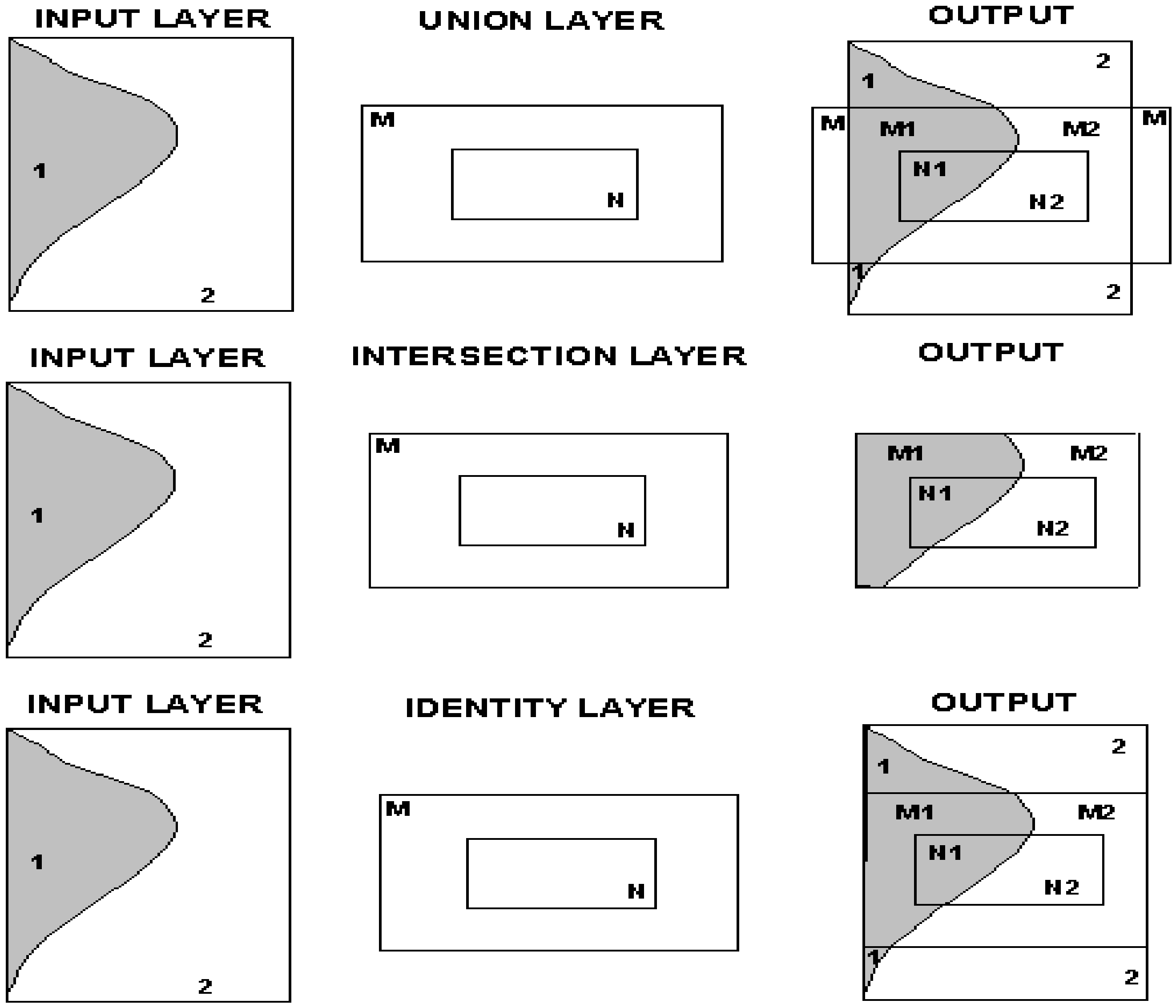
overlay polygons and keep areas from both layers.

INTERSECTION:

overlay polygons and keep only areas in the input layer that fall within the intersection layer.

IDENTITY:

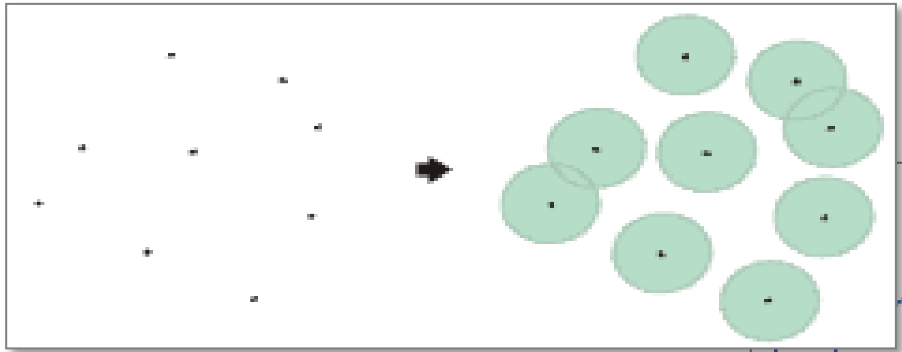
overlay polygons and keep areas from input layer.



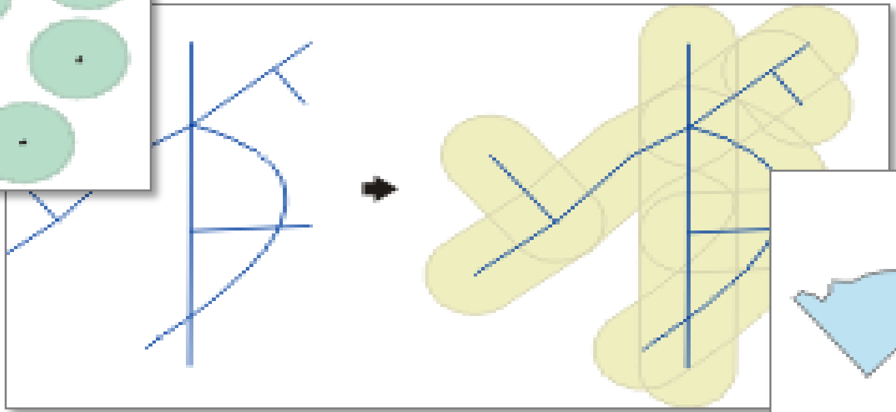
Proximity

Buffer (Vector):

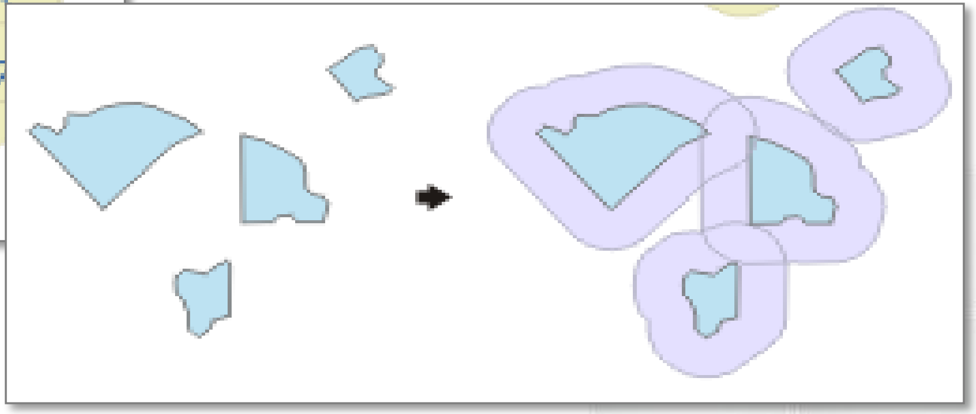
- Creates buffer polygons around input features to a specified distance.



Point Buffer



Line Buffer



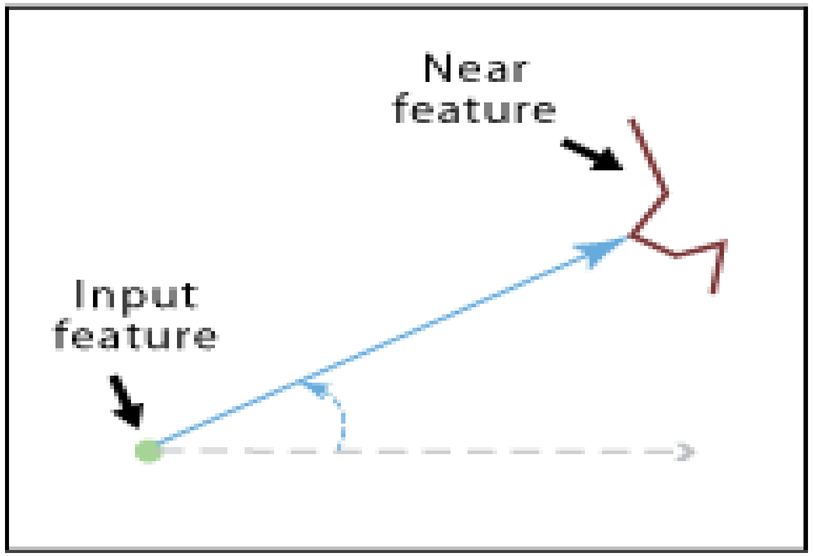
Polygon Buffer

Proximity

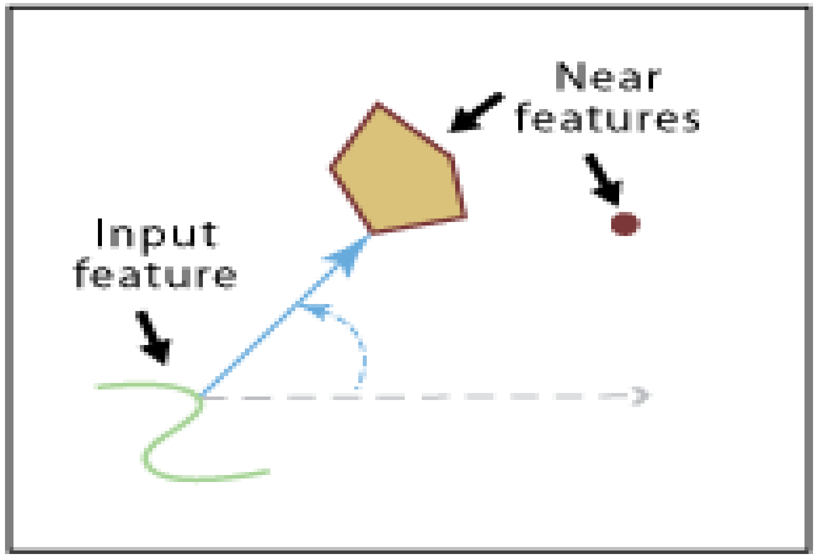
Near

- Determines the distance from each feature in the input features to the nearest feature in the near features, within the search radius.

POINT TO LINE



MIXED FEATURE TYPES



Methods of Spatial Data Analysis

- The GIS can perform a spatial analysis.
- Spatial relationships among the features and their attributes and the persistent link with their geometry (shape and position) make the GIS a tool able to simulate the real world and hence to help decision makers in solving actual problems.
- Operations can be carried out on a single data layer or by combining two or more data layers.
- They can be grouped in three categories:
  - Spatial data analysis;
  - Attributes analysis;
  - Integrated analysis.

Making Map with GIS

Output is the final goal of GIS projects. Two main types of output:

- Maps
- Visualizations

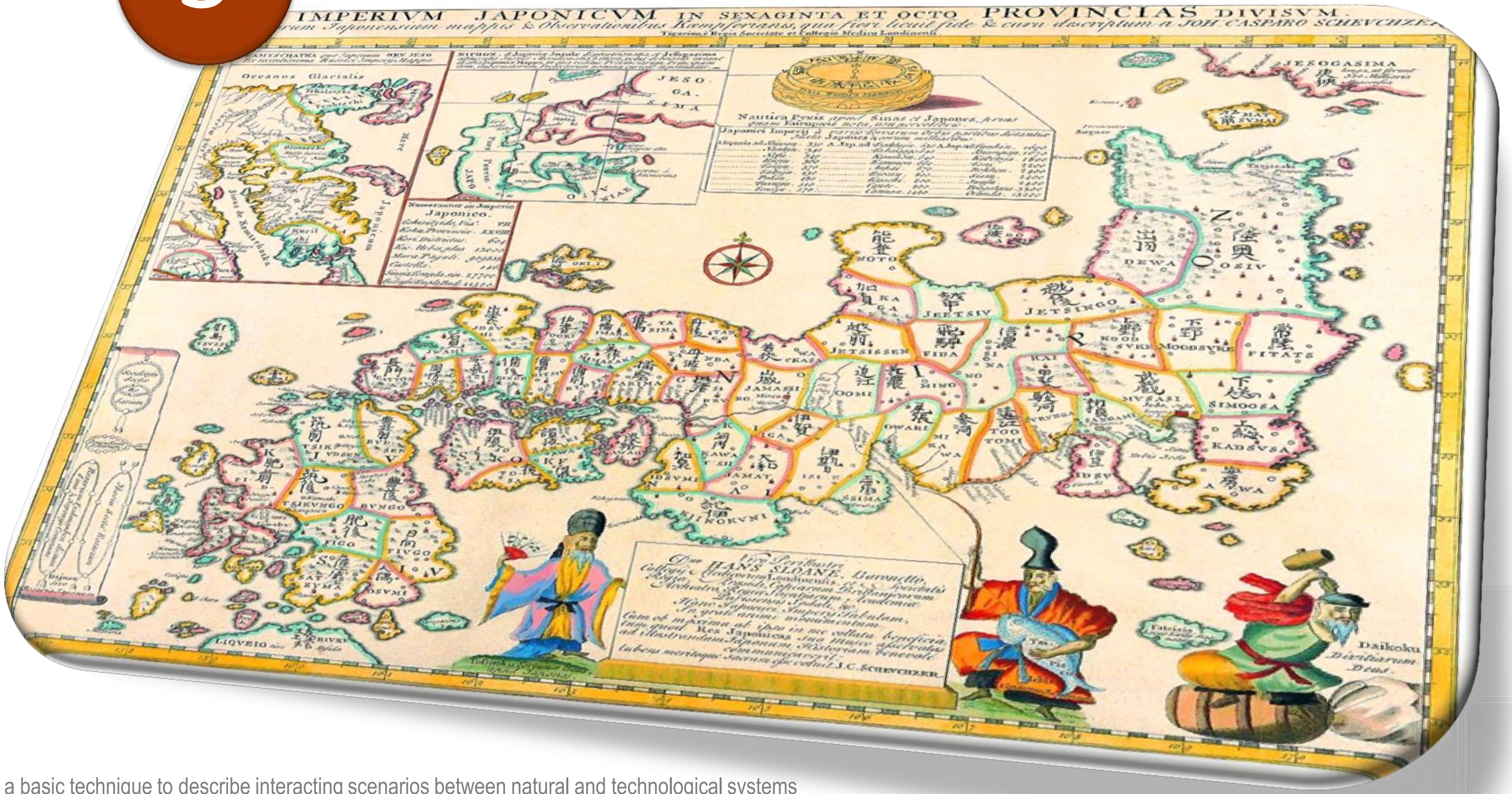
Maps are good at summarizing and communicating.

Primary goals in map design: to share information, highlight patterns and processes, illustrate results.

Maps and Cartography:

- Map is the digital or analog output from a GIS showing information using well established cartographic conventions
- Cartography is the art, science and techniques of making maps

3 EXAMPLE OF APPLICATION



Conceptual framework

- Design and development of Decision Support Systems (DSS) able to integrate, in an unique framework, systems to provide an efficient and accurate risk assessment based on events prediction and their impact.

- With respect to the emergency response issues related to critical events (e.g. natural disasters or industrial accidents), the recent advances in geo-informatics, communication and sensor technologies have been opening new opportunities.

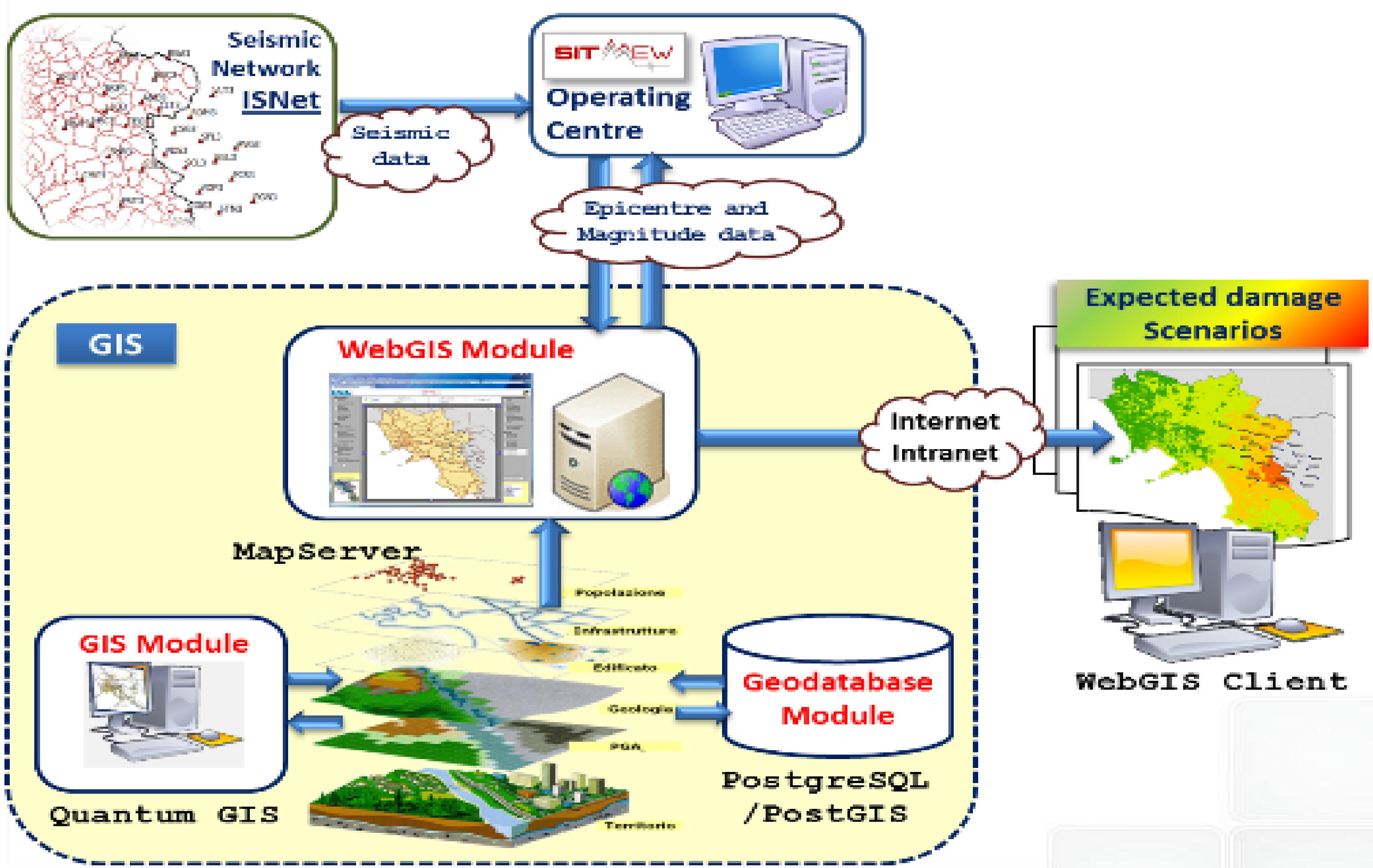
- An interactive DSS based on GIS approach could support the public government to address (in the post-event phases) activities to emergency management, damage evaluations for buildings and lifelines, consequences for population.

Conceptual framework

- The WebGIS interface allows to visualize and analyse the geo-spatial data and thematic maps stored in the system by means of basic functionalities such as: description and characterization of the area of interest, production of thematic maps (e.g., vulnerability), scenarios (e.g. impacts on population, on buildings/facilities, etc.) and their time evolution.
- The results become tools for an interactive DSS, which is able to support the public stakeholders to quickly evaluate consequences and to address activities related to emergency management.

GIS-DSS Supporting the Response Planning to Disastrous Earthquake Events

Web-oriented GIS-DSS application for predicting and mapping seismic vulnerability, assessing potential impacts of disastrous events.



GIS-DSS architecture:

1) Geospatial database system;
2) Local GIS application for analysing and modelling the seismic event and its impacts and supporting post-event emergency management;
3) WebGIS module for sharing the geo-information among the decision makers involved in disaster impact assessment and response management.

The main aims of the GIS-DSS is to make geographic data, thematic maps and probable damage Scenarios available to specific end-users.

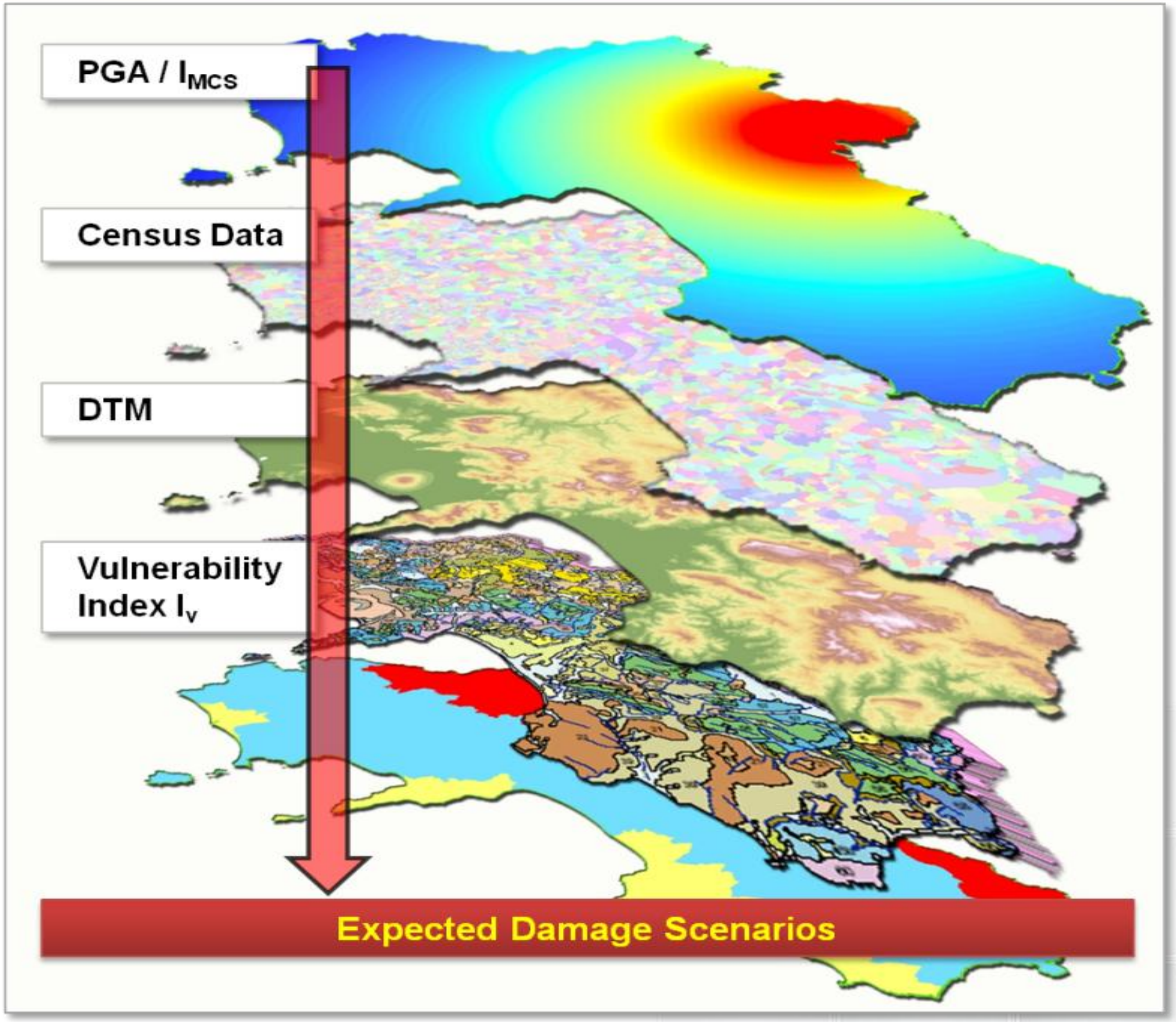
GIS-DSS Supporting the Response Planning to Disastrous Earthquake Events

Spatial analysis procedures and geo-processing operations:

- Description and characterization of the study area (Geodatabase);
- Census Data management;
- Shake maps processing (PGA/I_{MCS});
- Production of buildings Vulnerability index I_v maps (Census parcel based)
- Elaboration of Expected Damage Scenarios.

Results:

- Thematic maps (I_v and Expected damage scenarios) to support the management of near/post-event phases;
- Consultation via intranet/internet to data and maps.



GIS-DSS Supporting the Response Planning to Disastrous Earthquake Events

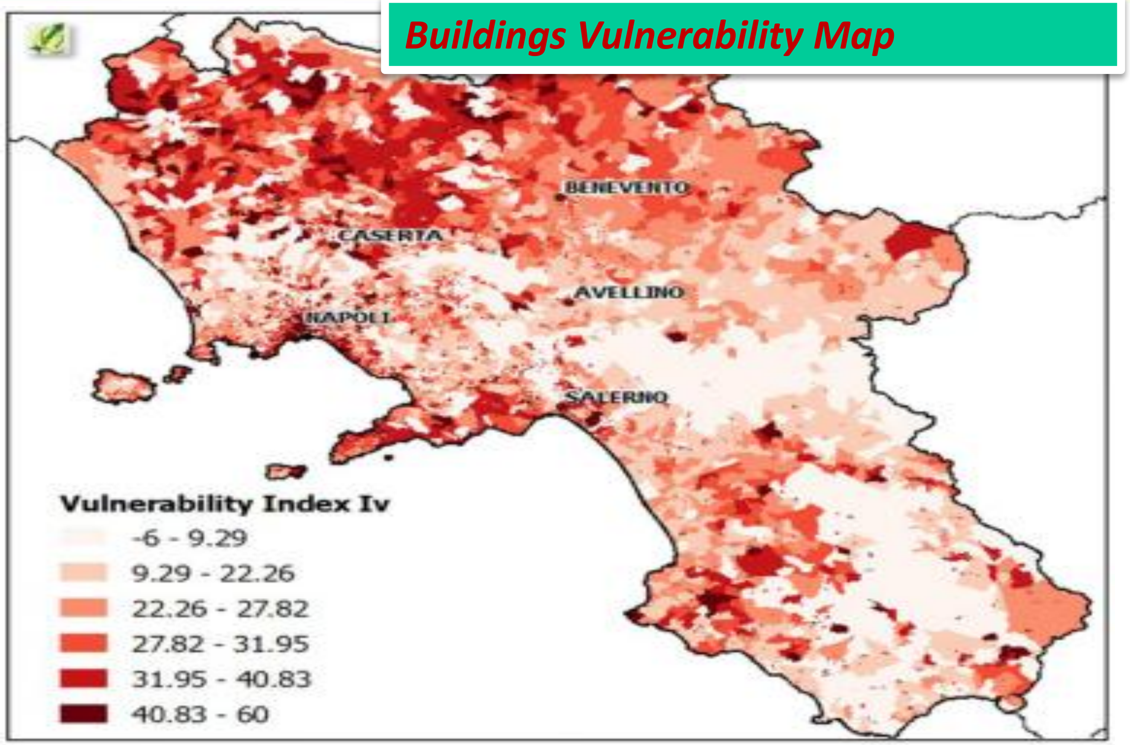
Seismic vulnerability of structures: detailed buildings inventory (source: Census data).

Aggregated data related to buildings :

- built-up density;
- structural typology (Masonry or Reinforced Concrete);
- age of construction;
- number of storeys.

The vulnerability index (I_V) for each census section has been calculated by using the Lagomarsino and Giovinazzi approach[3].

Buildings Vulnerability Map



Age / No. of storeys	<1919	1919–1945	1946–1961	1962–1971	1972–1981	1982–1991	>1991
1	0	0	0	0	0	–6	–6
2	+5	+5	+5	+5	+5	0	0
3	+5	+5	+5	+5	+5	0	0
>4	+10	+10	+10	+10	+10	+6	+6

Construction age	I_V	
	Masonry	RC
Before 1919	50	-
1919–1945	40	-
1946–1961	30	20
1962–1971	30	20
1972–1981	20	20
1982–1991	20	0
After 1991	20	0

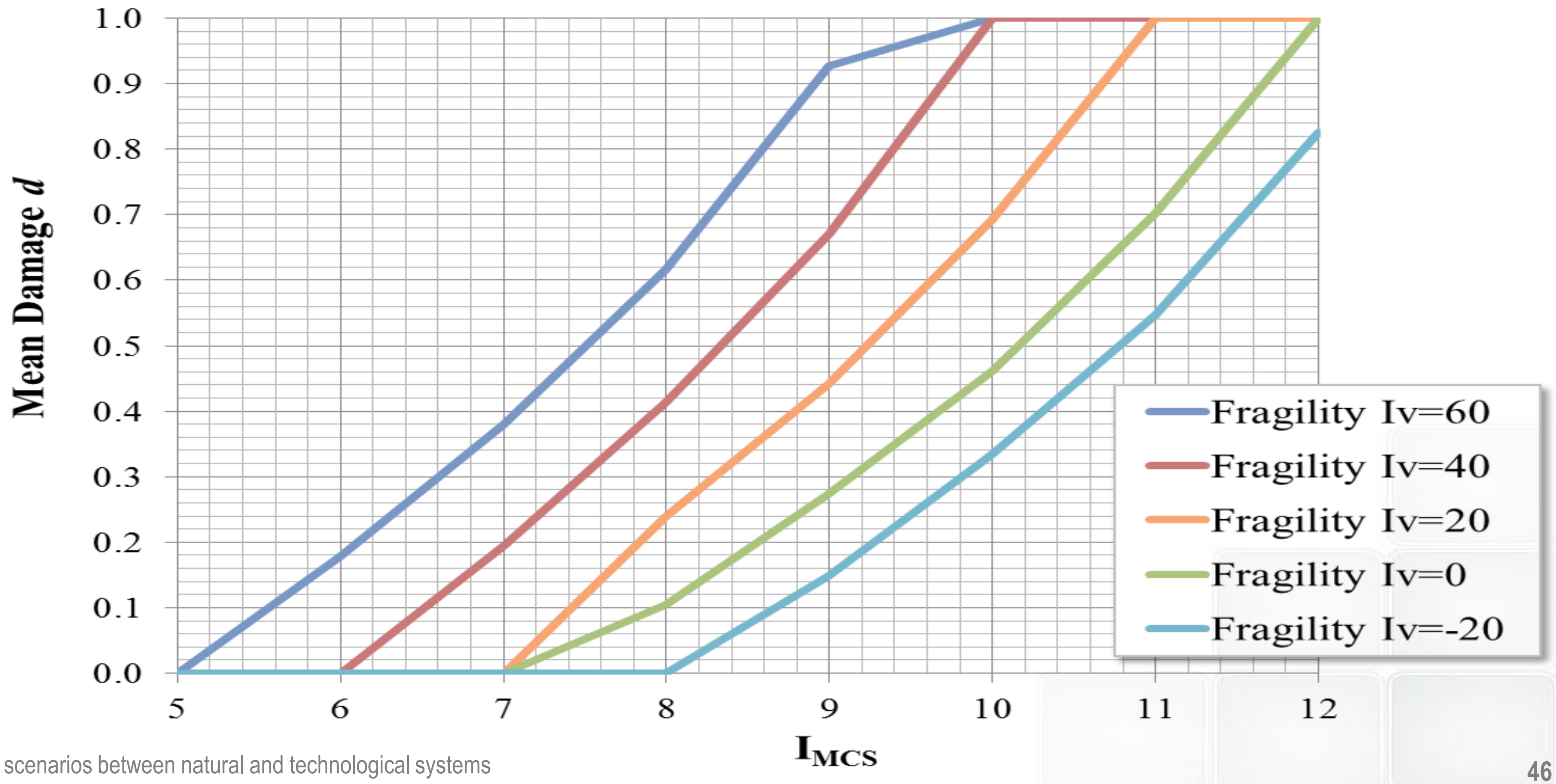
[3]Lagomarsino, S.; Giovinazzi, S.: Macroseismic and mechanical models for the vulnerability and damage assessment of current buildings. Bull. Earthq. Eng. 2006, 4, 415–443

GIS-DSS Supporting the Response Planning to Disastrous Earthquake Events

Despite the obvious approximations, seismic vulnerability assessment by using the proposed approach can be considered a simple and prompt application. Thematic PGA, I_{MCS} and I_V maps can be overlaid to Census data and the damage *d* can be calculated as:

$$d = 0.5 + 0.45\{\arctan[0.55(I_{MCS} - 10.2 + 0.05 \cdot I_V)]\}$$

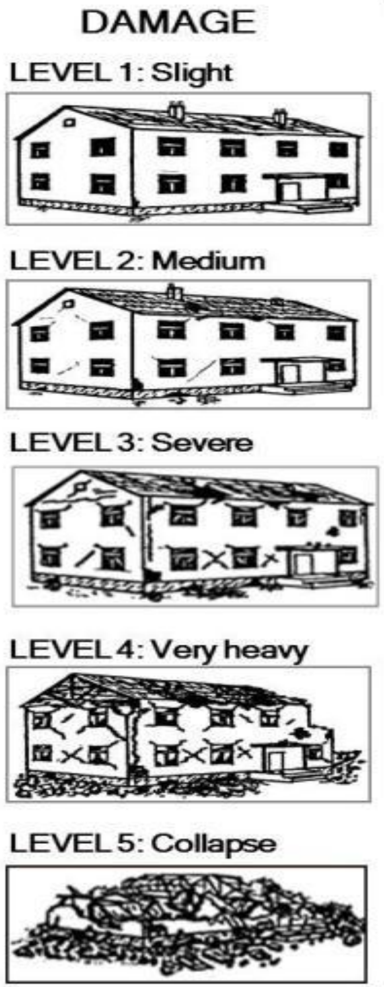
The formula expresses the relationships between I_{MCS} and damage *d*, according to the trend of fragility curves depicted in Figure.
From a qualitative point of view, it is possible to establish a relation between I_{MCS} and *d* values by classifying the mean damage into five different levels (see next slide).

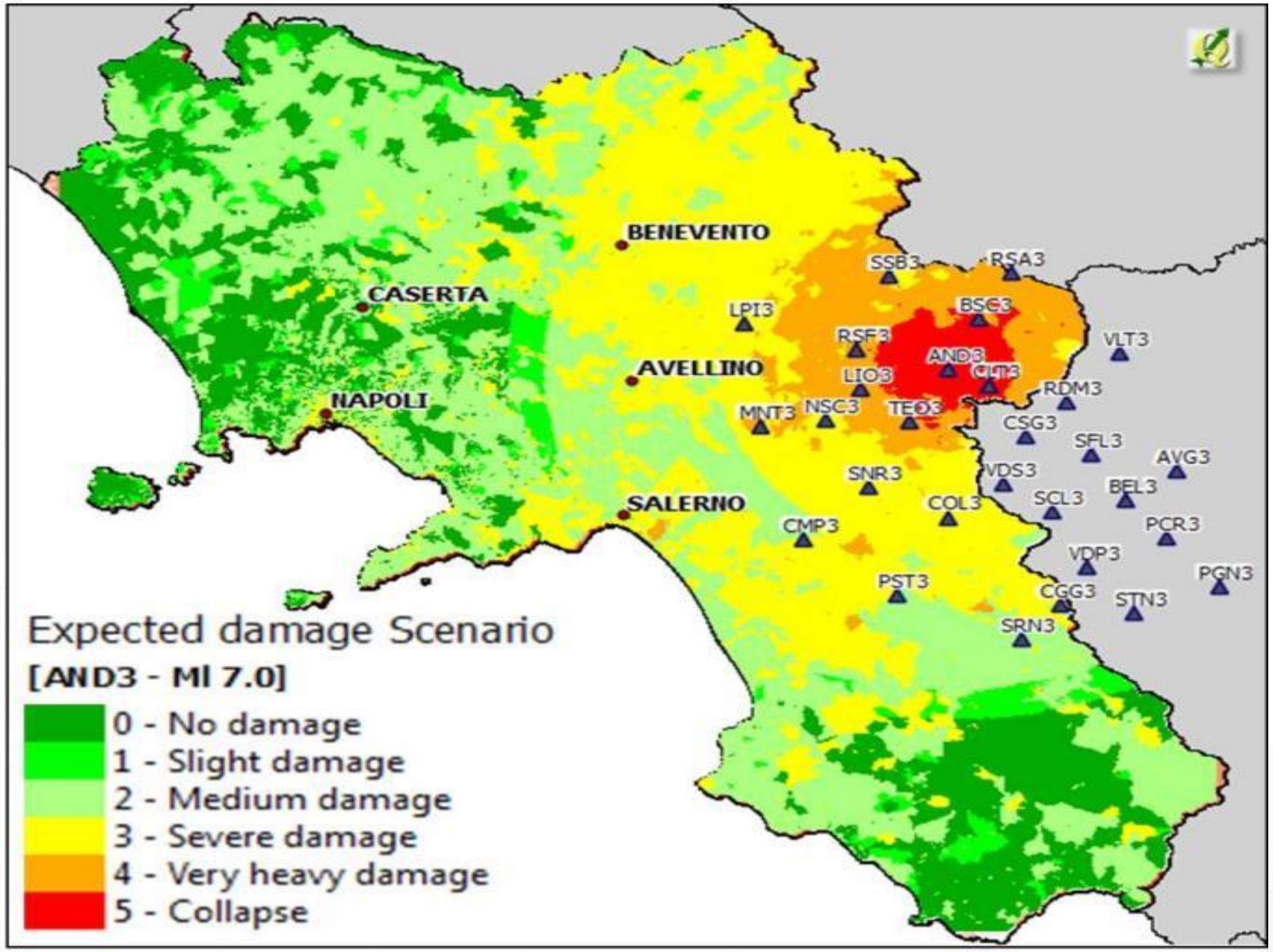


GIS-DSS Supporting the Response Planning to Disastrous Earthquake Events

The GIS-DSS application[4] provides a preliminary assessment of the expected damages on structures a few minutes after the main shock.

*Example of **result**. The map is categorized considering six different levels of damage as described below (level representation on the left)*





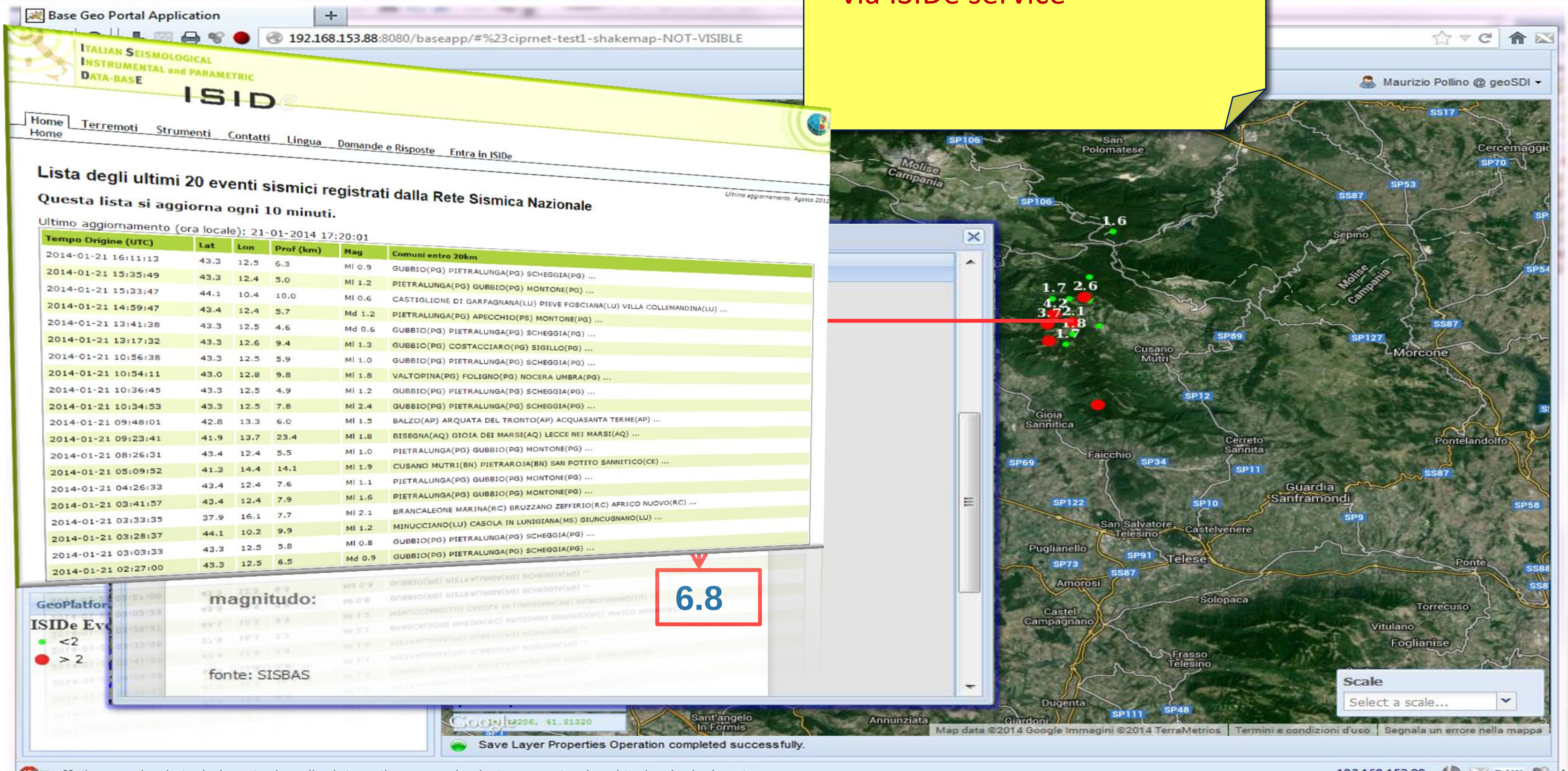
Levels of Damage	0	1	2	3	4	5
Factor of Damage (f_d)	0	0.01	0.1	0.35	0.75	1

[4]M. Pollino et al. (2012), Collaborative Open Source Geospatial Tools and Maps Supporting the Response Planning to Disastrous Earthquake Events. Future Internet 4(2), 451-468, doi:10.3390/fi4020451

Earthquake Event – Step 1

(T_0 ÷ few minutes)

- Get event data (Epicentre and Magnitude) from INGV, via ISIDe service

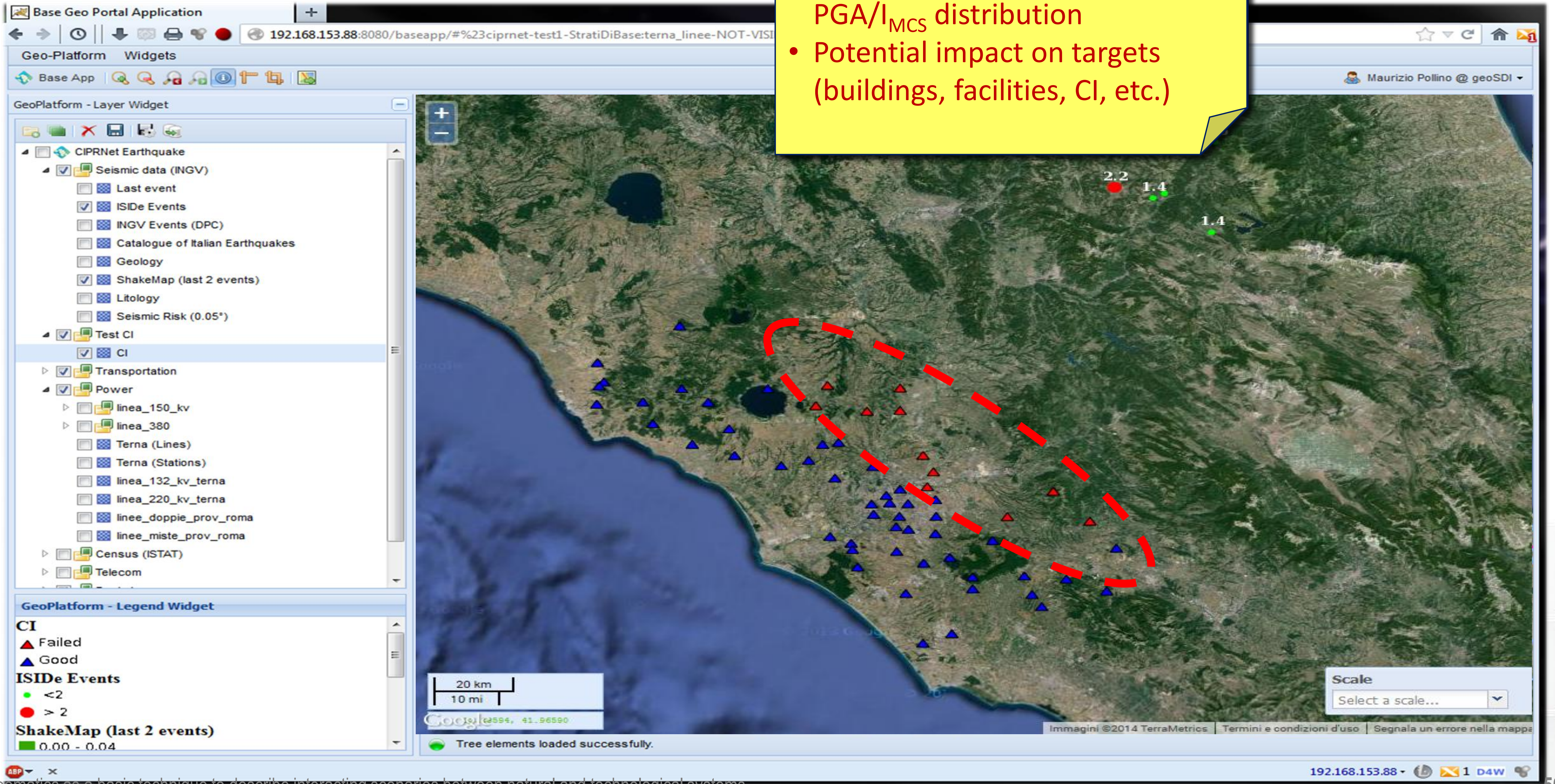


Tempo Origine (UTC)	Lat	Lon	Prof (km)	Mag	Comuni entro 20km
2014-01-21 16:11:13	43.3	12.5	6.3	Ml 0.9	GUBBIO(PG) PIETRALUNGA(PG) SCHEGGIA(PG) ...
2014-01-21 15:35:49	43.3	12.4	5.0	Ml 1.2	PIETRALUNGA(PG) GUBBIO(PG) MONTONE(PG) ...
2014-01-21 15:33:47	44.1	10.4	10.0	Ml 0.6	CASTIGLIONE DI GARFAGNANA(LU) PIEVE FOSCIANA(LU) VILLA COLLEMANDINA(LU) ...
2014-01-21 14:59:47	43.4	12.4	5.7	Md 1.2	PIETRALUNGA(PG) APECCHIO(PS) MONTONE(PG) ...
2014-01-21 13:41:38	43.3	12.5	4.6	Md 0.6	GUBBIO(PG) PIETRALUNGA(PG) SCHEGGIA(PG) ...
2014-01-21 13:17:32	43.3	12.6	9.4	Ml 1.3	GUBBIO(PG) COSTACCIARO(PG) SIGILLO(PG) ...
2014-01-21 10:56:38	43.3	12.5	5.9	Ml 1.0	GUBBIO(PG) PIETRALUNGA(PG) SCHEGGIA(PG) ...
2014-01-21 10:54:11	43.0	12.8	9.8	Ml 1.8	VALTOPINA(PG) FOLIGNO(PG) NOCERA UMBRA(PG) ...
2014-01-21 10:36:45	43.3	12.5	4.9	Ml 1.2	GUBBIO(PG) PIETRALUNGA(PG) SCHEGGIA(PG) ...
2014-01-21 10:34:53	43.3	12.5	7.8	Ml 2.4	GUBBIO(PG) PIETRALUNGA(PG) SCHEGGIA(PG) ...
2014-01-21 09:48:01	42.8	13.3	6.0	Ml 1.5	BALZO(AP) ARQUATA DEL TRONTO(AP) ACQUASANTA TERME(AP) ...
2014-01-21 09:23:41	41.9	13.7	23.4	Ml 1.8	BISEGNA(AQ) GIOIA DEI MARSI(AQ) LECCE NEI MARSI(AQ) ...
2014-01-21 08:26:31	43.4	12.4	5.5	Ml 1.0	PIETRALUNGA(PG) GUBBIO(PG) MONTONE(PG) ...
2014-01-21 05:09:52	41.3	14.4	14.1	Ml 1.9	CUSANO MUTRI(BN) PIETRAROJA(BN) SAN POTITO SANNITICO(CE) ...
2014-01-21 04:26:33	43.4	12.4	7.6	Ml 1.1	PIETRALUNGA(PG) GUBBIO(PG) MONTONE(PG) ...
2014-01-21 03:41:57	43.4	12.4	7.9	Ml 1.6	PIETRALUNGA(PG) GUBBIO(PG) MONTONE(PG) ...
2014-01-21 03:33:35	37.9	16.1	7.7	Ml 2.1	BRANCALEONE MARINA(RC) BRUZZANO ZEFFIRIO(RC) AFRICO NUOVO(RC) ...
2014-01-21 03:28:37	44.1	10.2	9.9	Ml 1.2	MINUCCIANO(LU) CASOLA IN LUNIGIANA(MS) GIUNCUGNANO(LU) ...
2014-01-21 03:03:33	43.3	12.5	5.8	Ml 0.8	GUBBIO(PG) PIETRALUNGA(PG) SCHEGGIA(PG) ...
2014-01-21 02:27:00	43.3	12.5	6.5	Md 0.9	GUBBIO(PG) PIETRALUNGA(PG) SCHEGGIA(PG) ...

Earthquake Event – Step 1

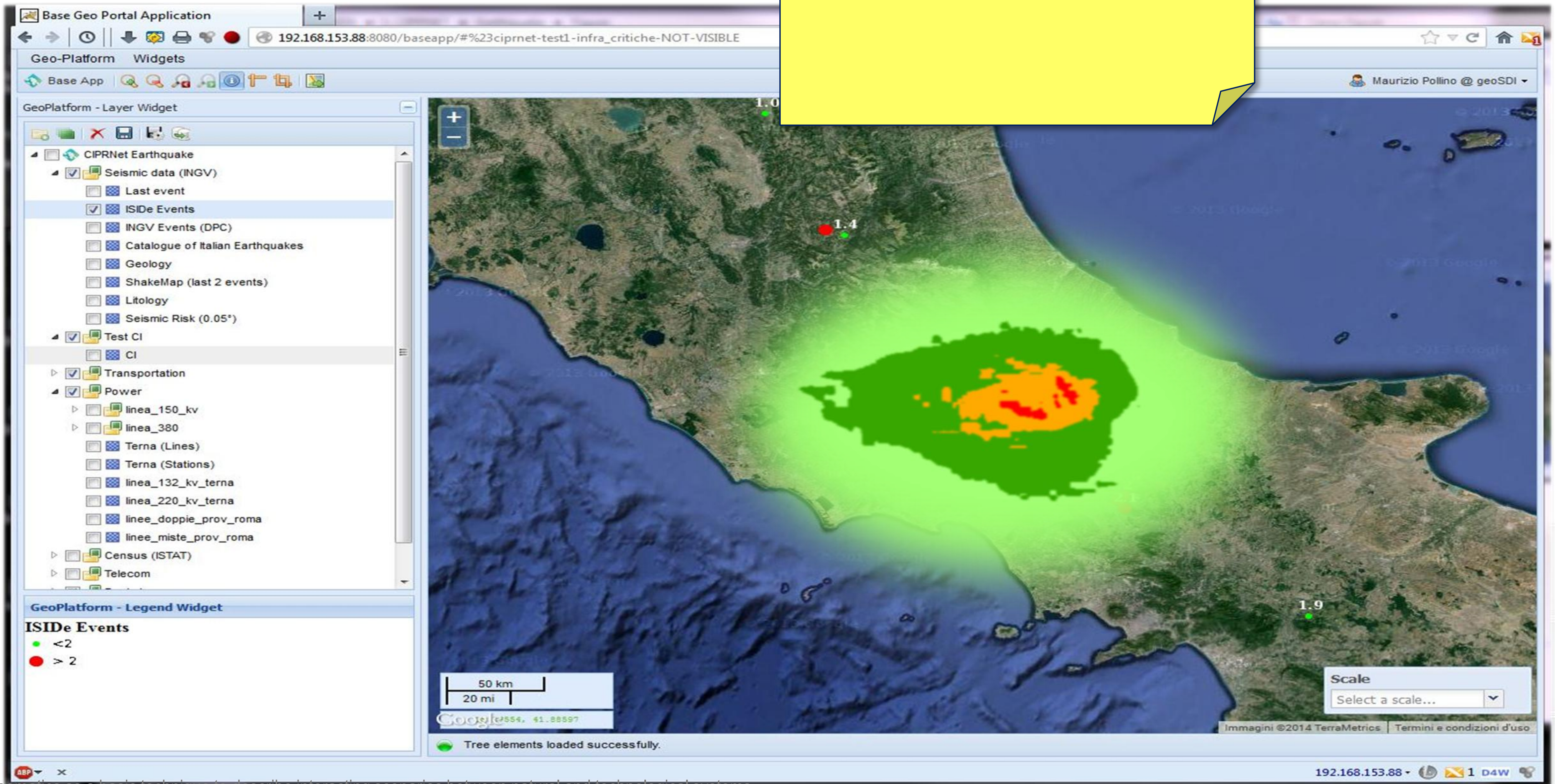
(T_0 ÷ few minutes)

- Theoretical Shake-Maps production
- Preliminary assessment of PGA/I_{MCS} distribution
- Potential impact on targets (buildings, facilities, CI, etc.)



Earthquake Event – Step 2
(T_0 ÷ 1-2 hours)

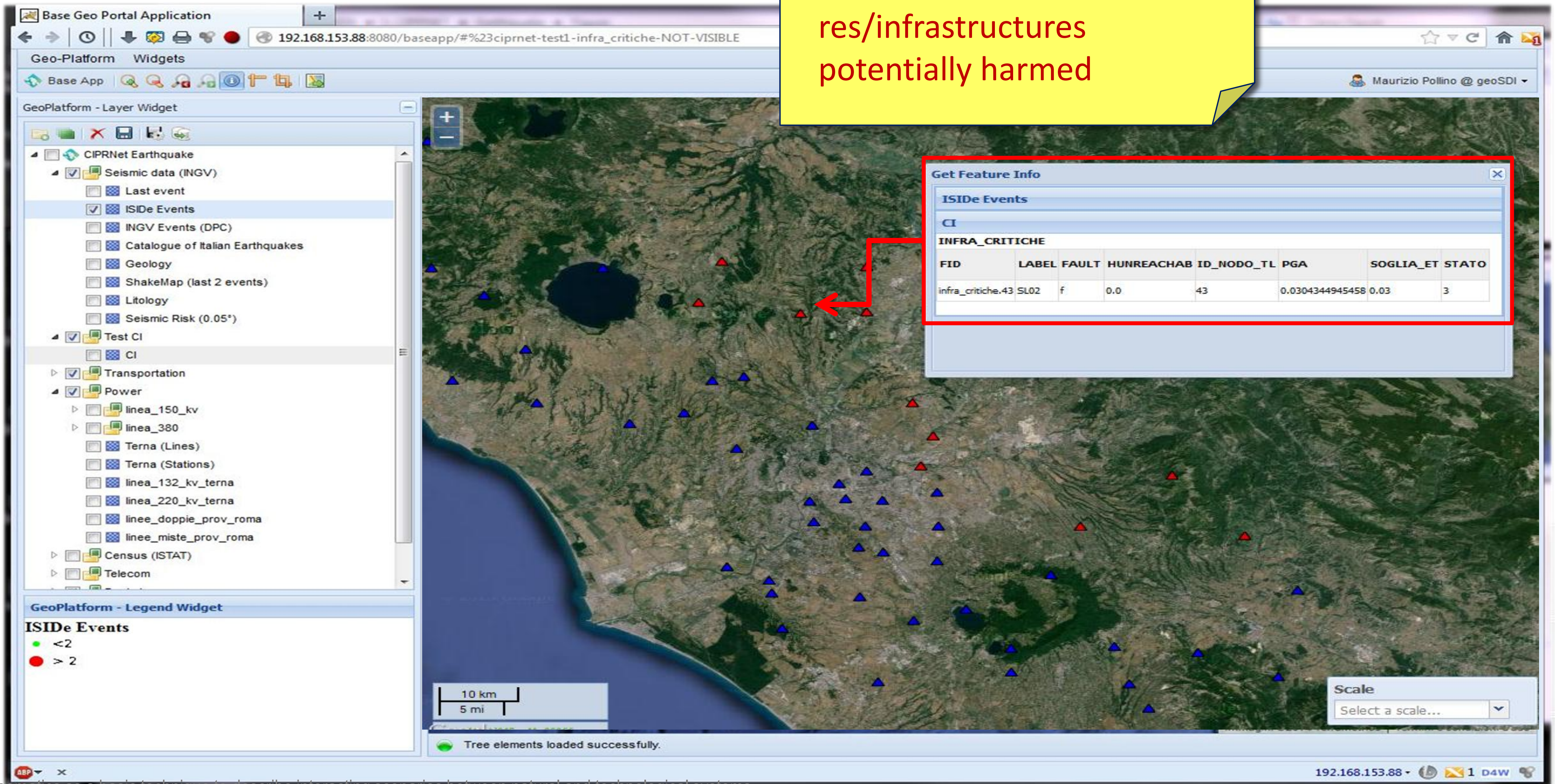
- Get Measured Shake-Maps from INGV: mapping actual distribution of PGA



Earthquake Event – Step 2

($T_0 \div$ 1-2 hours)

- Impact on CI after the main shock
- Assessment of structures/infrastructures potentially harmed



Thank you!

Maurizio Pollino

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"Earth Observations and Analyses" Lab (UTMEA-TER)

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http://utmea.enea.it/people/pollino/

CIPRNet

Critical Infrastructure Preparedness and Resilience Research Network
www.ciprnet.eu

SEVENTH FRAMEWORK PROGRAMME

Federated Simulations

Wim Huiskamp - TNO
<wim.huiskamp@tno.nl>

Modelling, Simulation and Analysis of Critical Infrastructure Training School (Edition 0)

Deltares Headquarters – Delft (The Netherlands)
3-4 February 2014

Contents

- Distributed M&S
- Federated Simulations
- Interoperability Standards
- HLA
- DSEEP process
- Summary

Trained and Ready

Bosnia, Iraq, Afghanistan, Anti-Piracy, Libya, Syria, Mali

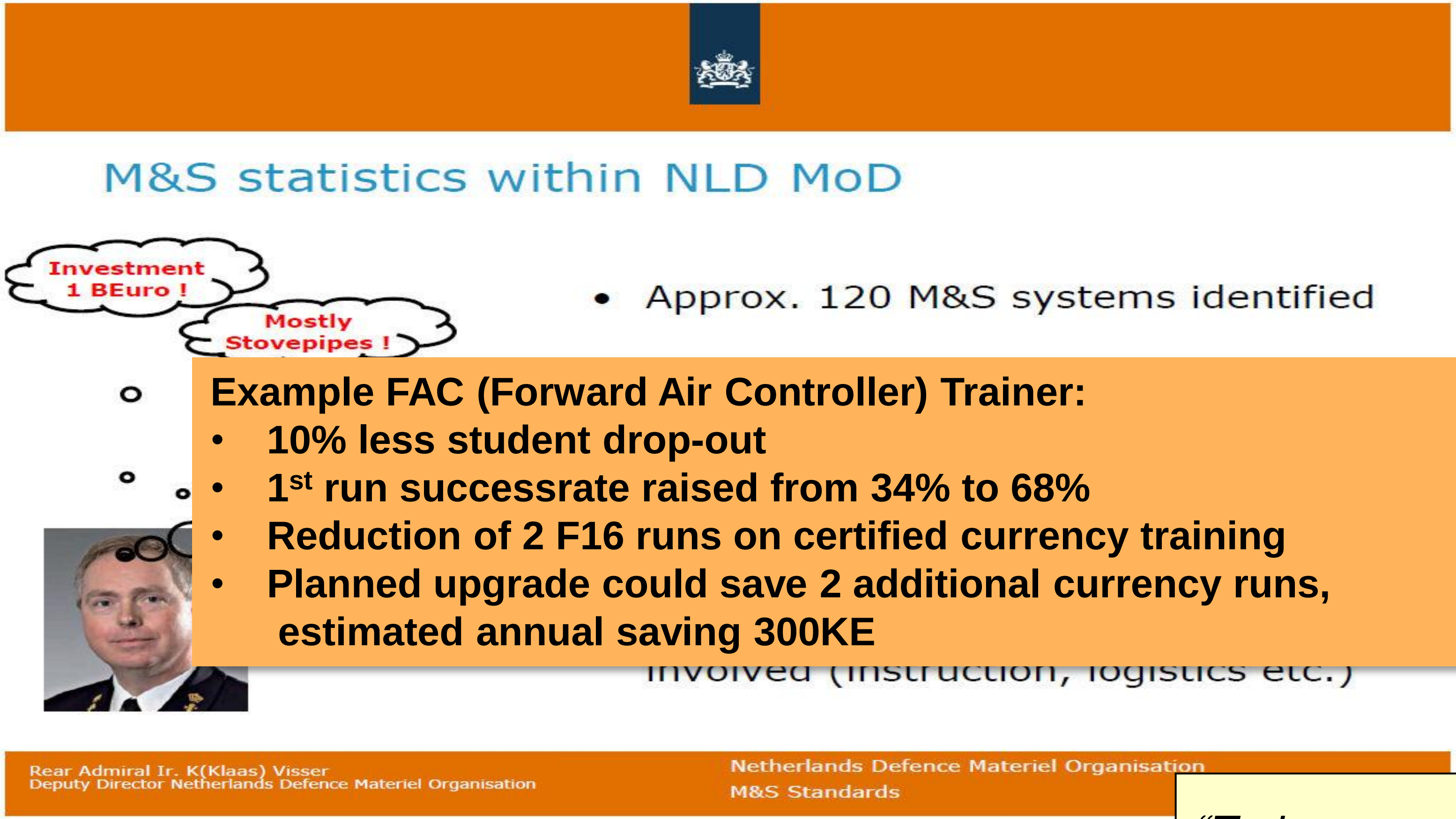
NATO Coalition Operations: UN mandate





"Train as you fight"

Increasing Importance of Simulation

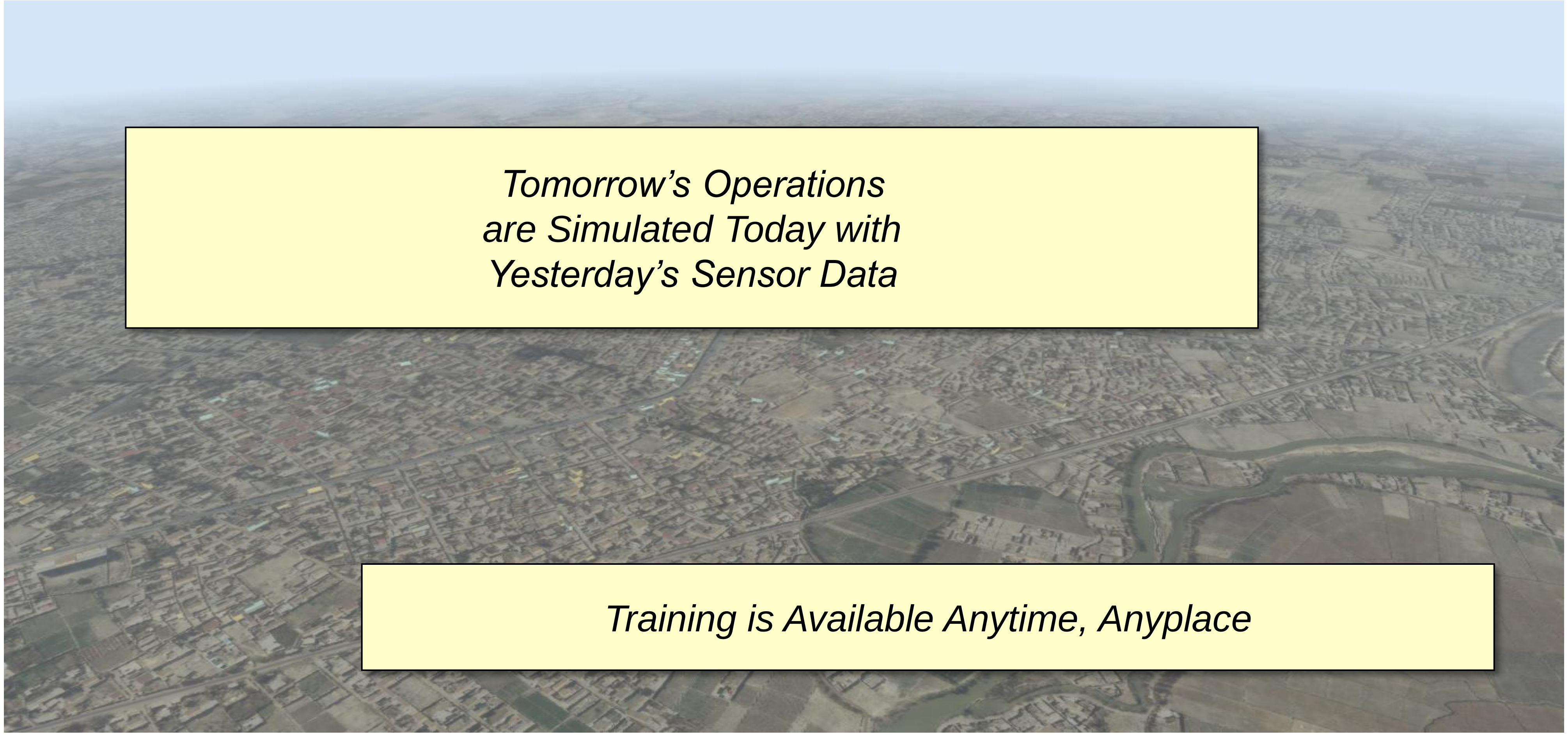


Example FAC (Forward Air Controller) Trainer:

- **10% less student drop-out**
- **1st run successrate raised from 34% to 68%**
- **Reduction of 2 F16 runs on certified currency training**
- **Planned upgrade could save 2 additional currency runs, estimated annual saving 300KE**

"Train as you fight"

Vision on Simulation

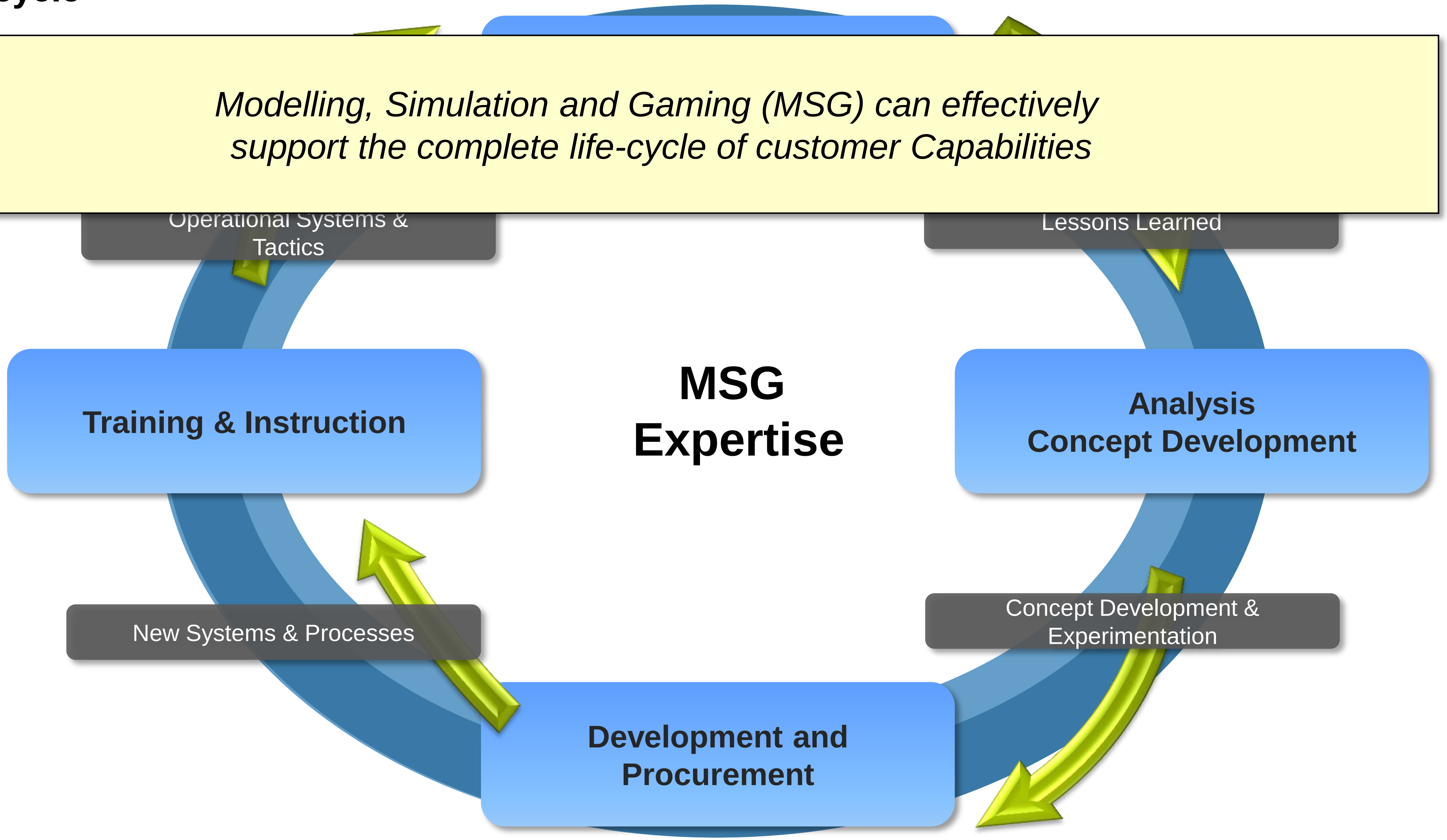


Tomorrow's Operations are Simulated Today with Yesterday's Sensor Data

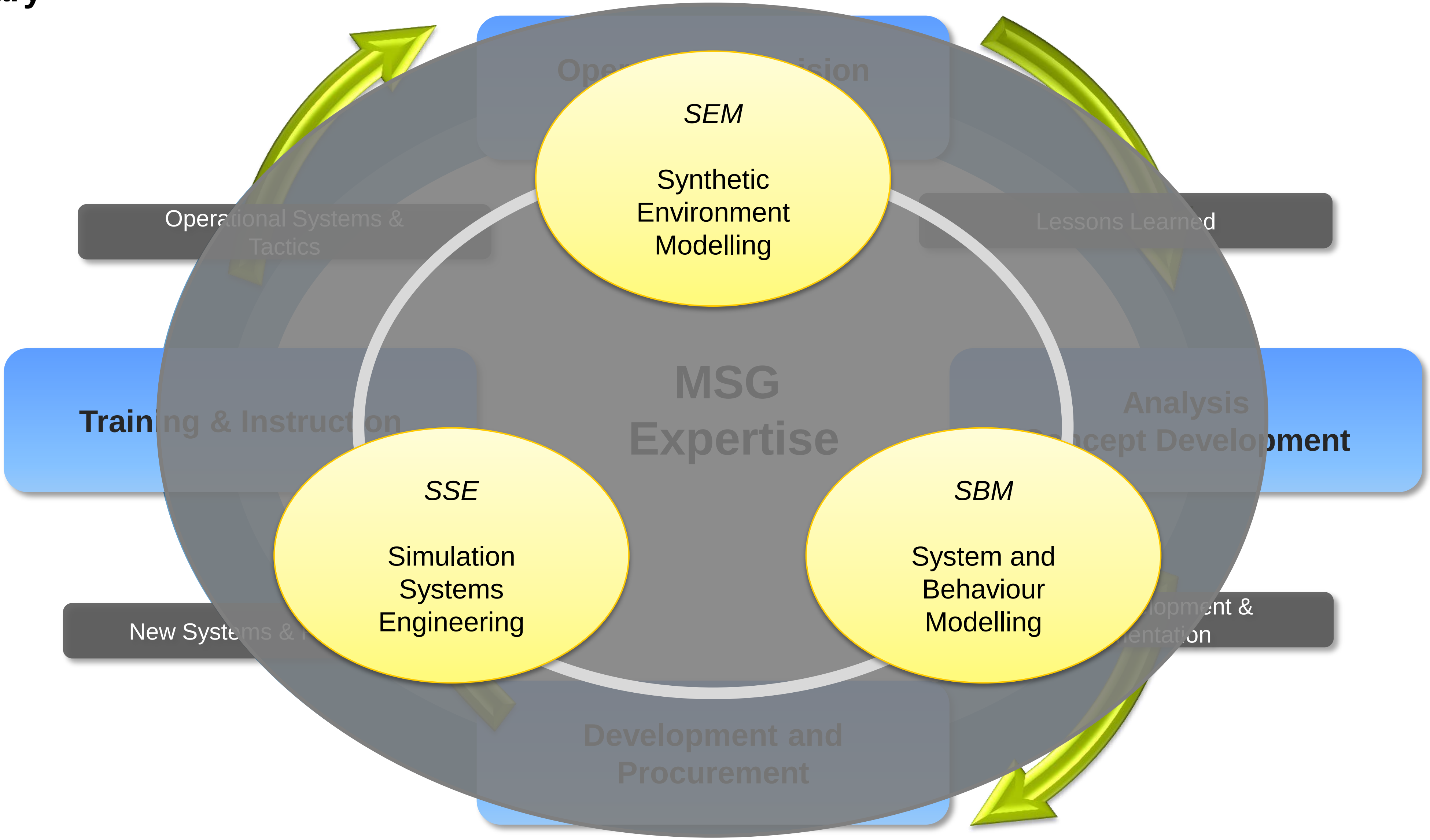
Training is Available Anytime, Anyplace

Capability Lifecycle

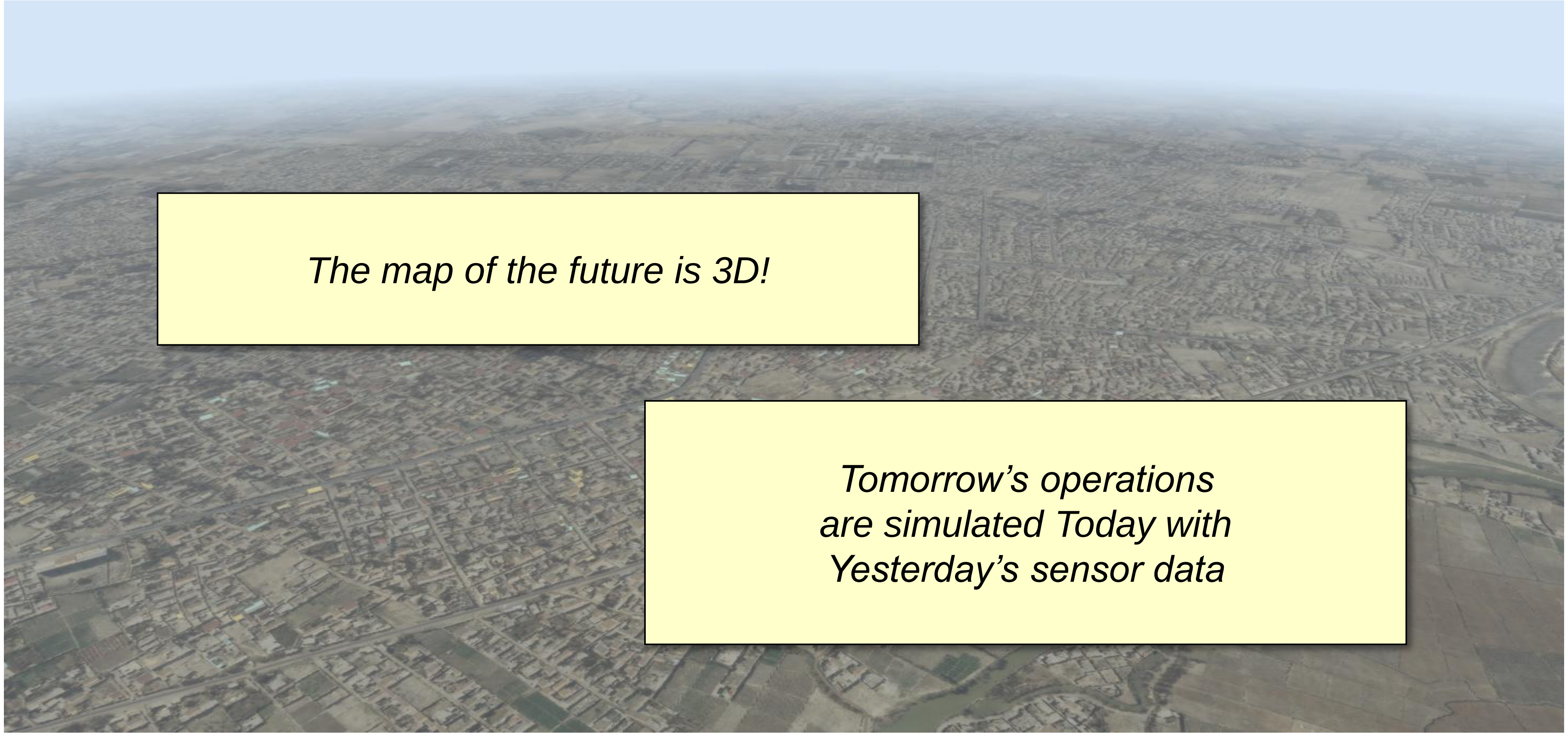
Modelling, Simulation and Gaming (MSG) can effectively support the complete life-cycle of customer Capabilities



Multi-Disciplinary



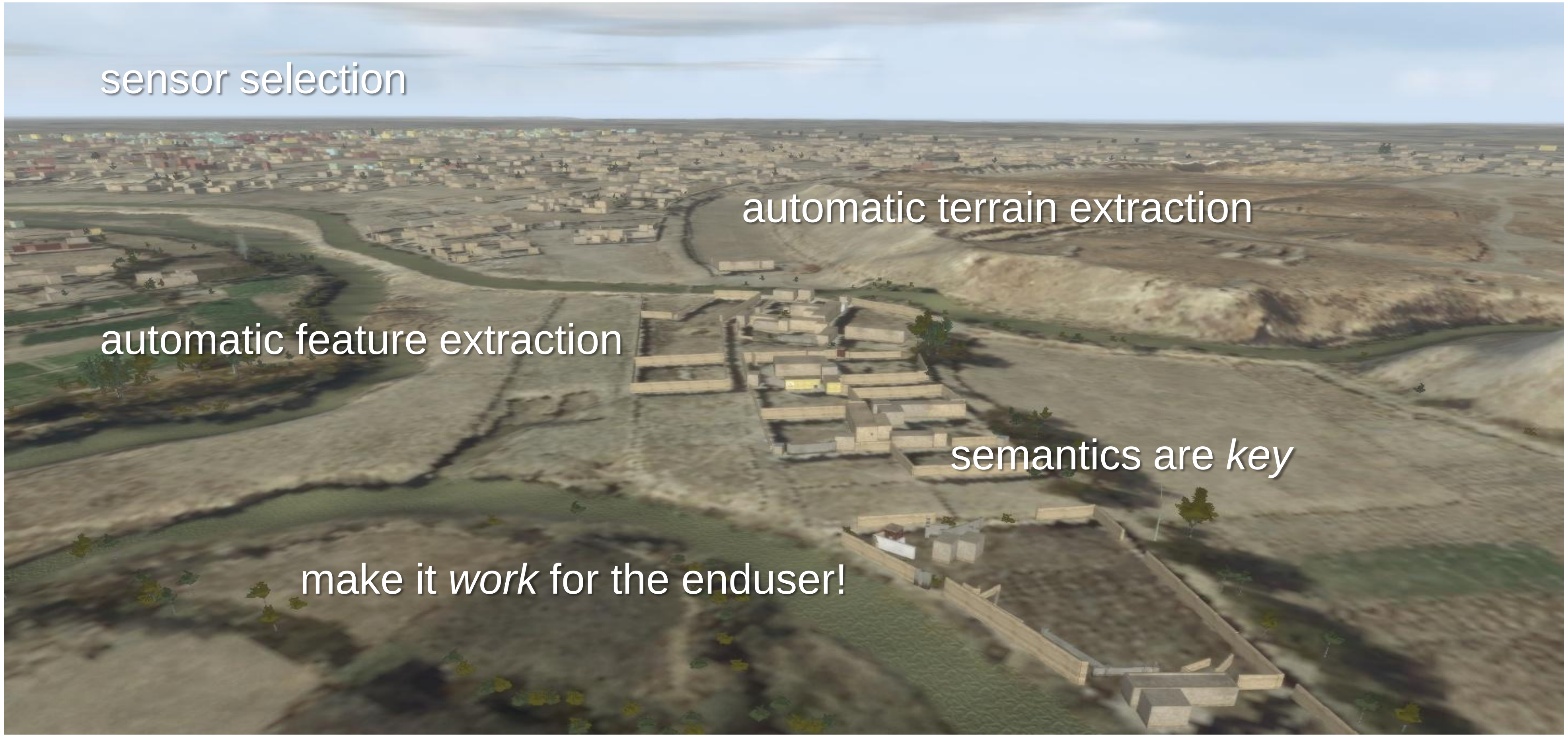
Synthetic Environment Modelling (SEM) Vision



The map of the future is 3D!

Tomorrow's operations are simulated Today with Yesterday's sensor data

.. innovating the modelling pipeline ...



System and Behaviour Modelling (SBM) Vision

Create Realistic and Rich Scenarios with minimal expert Resources.

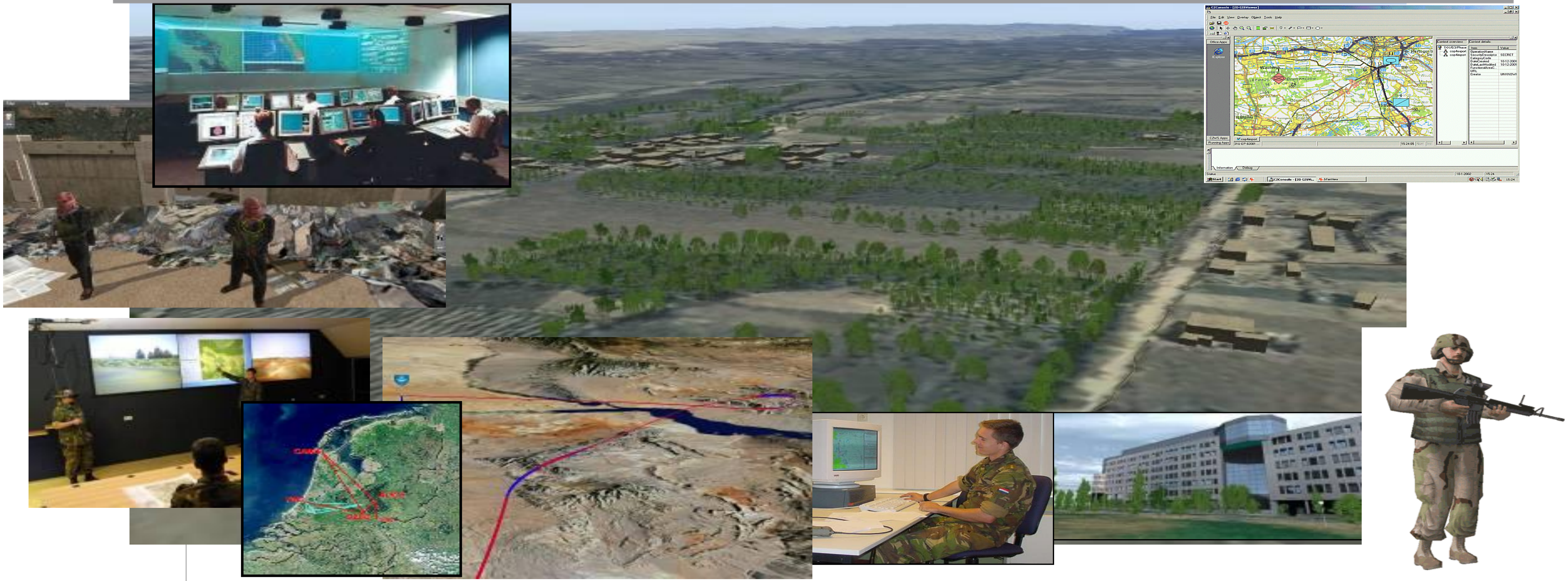
“From days to hours”

SBM: Sketch-a-LIVING-World (SALW)

- Integrated Content
- Accessible Authoring

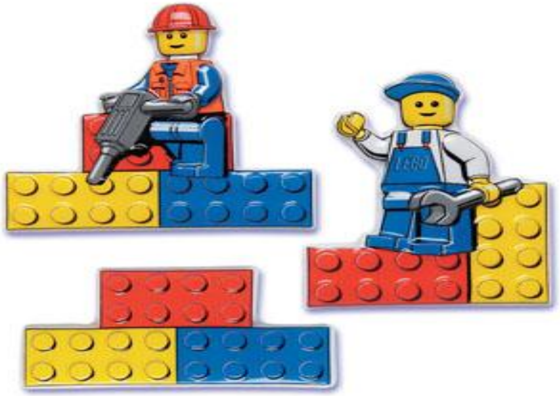
TNO innovation for life

SSE: Provide Integrated MSG expertise for cost-effective Simulation




Statements based on experience

- No single simulation can solve all your problems
- Monolithic simulations are hard to re-use: Size does matter, Smaller is better.
- Interoperable components of suitable granularity provide maximum flexibility

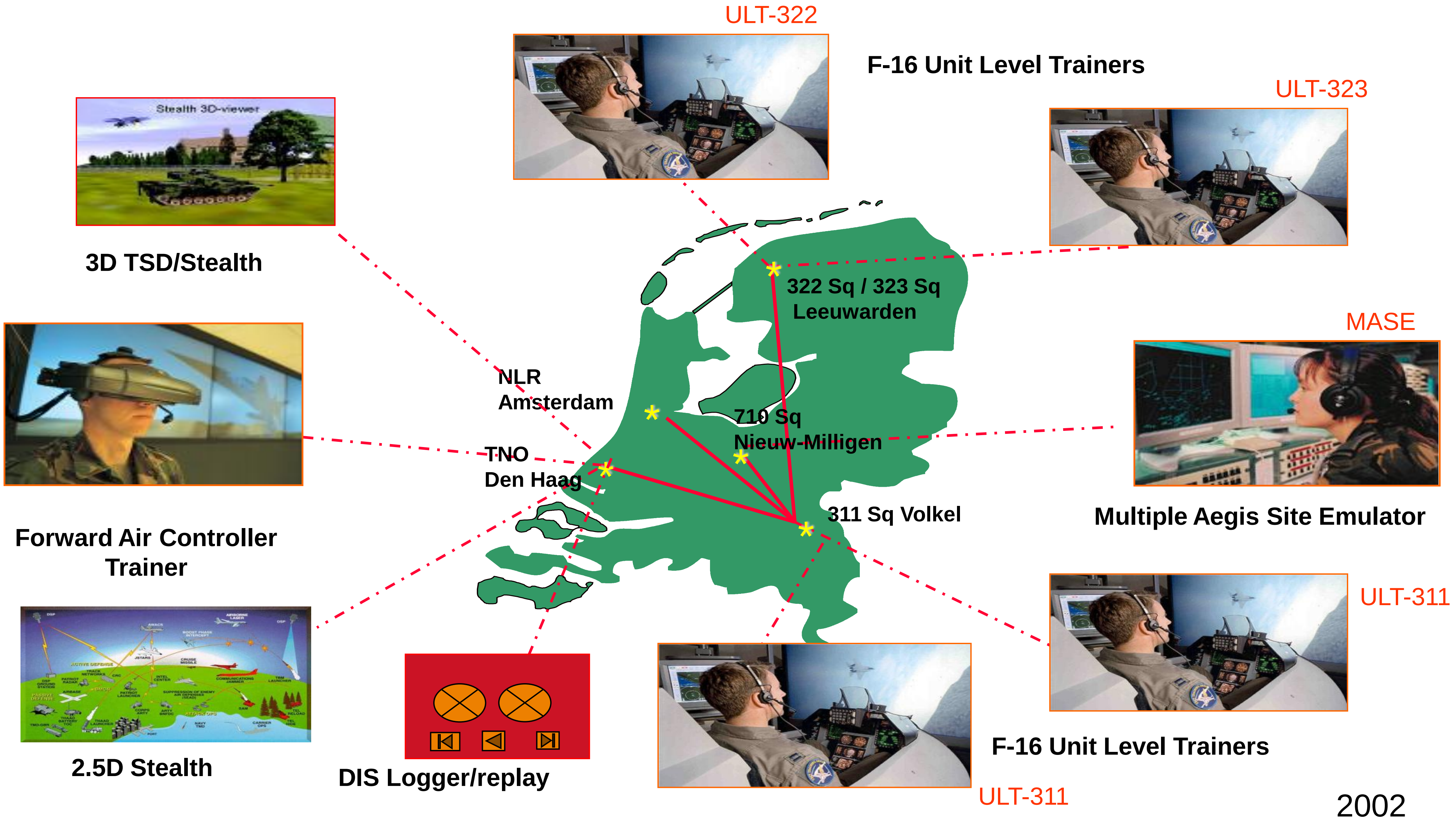


Distributed vs Monolithic Simulation

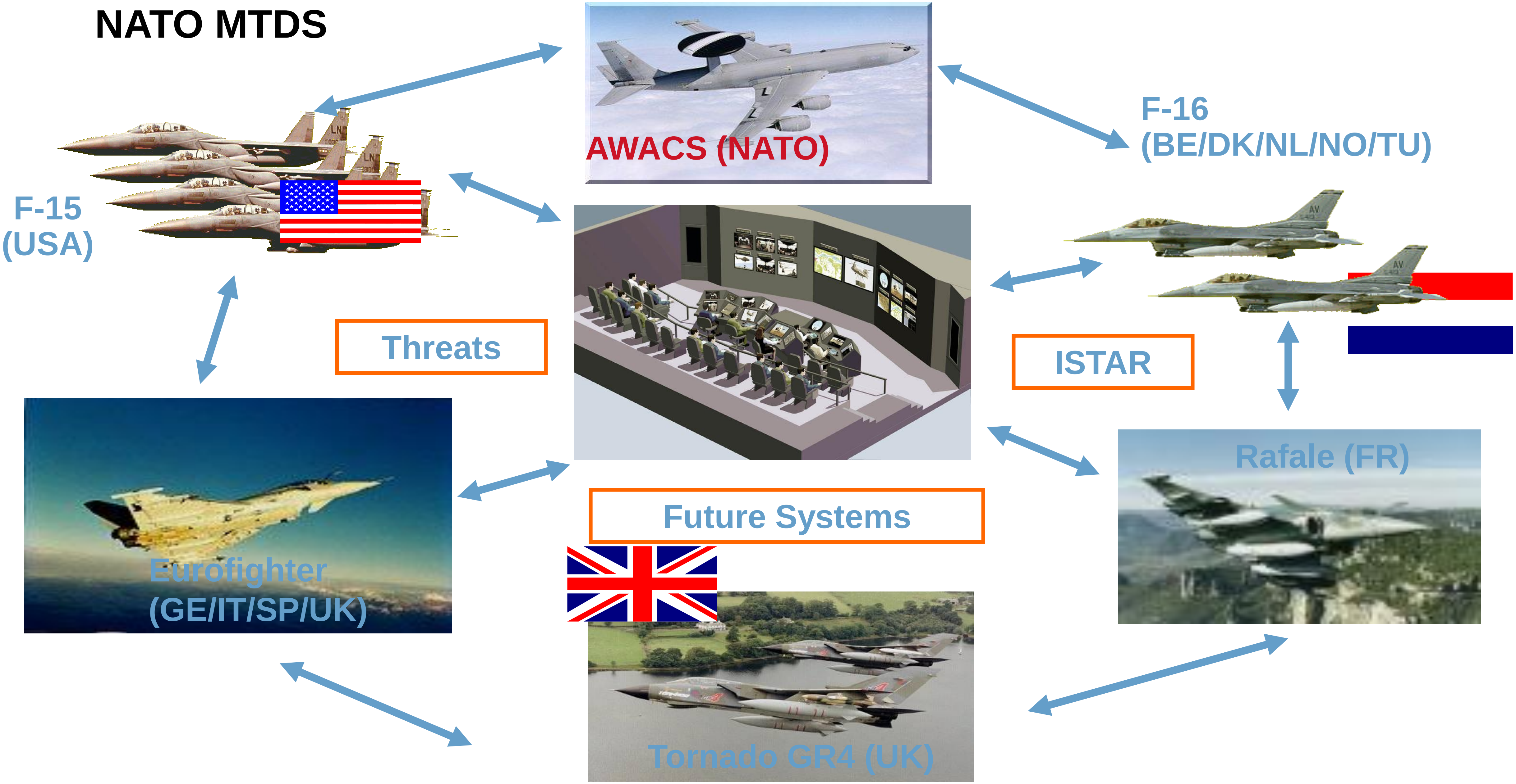
- **Available Training systems are re-used**
  - Local Training remains possible
  - Travel savings

- **Flexible combinations possible**
  - National Training Needs
  - Bi-lateral Training (security levels)
  - Maintenance and incremental upgrades

ULT-JOIND demonstrator



NATO MTDS



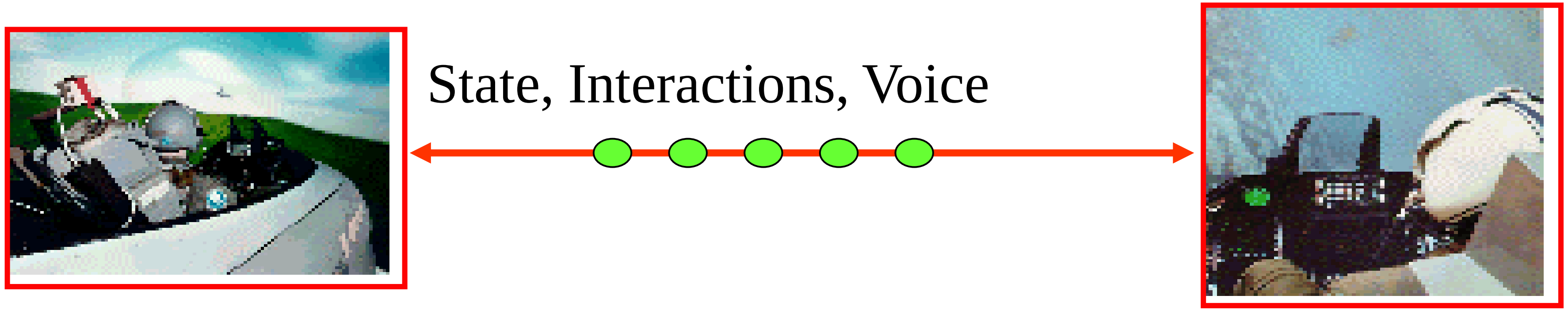
2004

Distributed Simulation Components

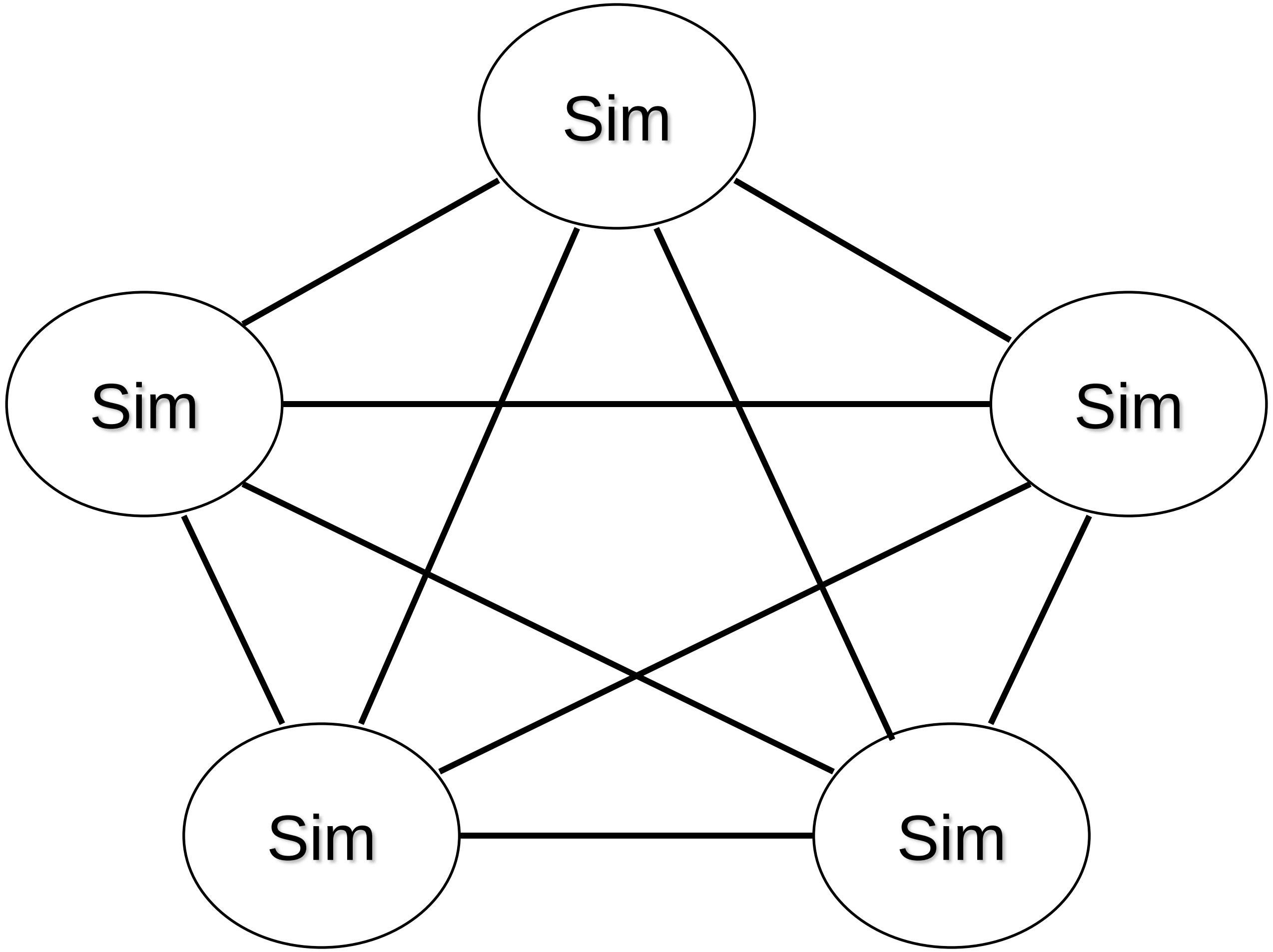
- **Man-in-the-Loop simulators**
  - Aircraft
  - Vehicles
  - Dismounted units (FAC)
  - C2
- **Computer Generated Forces (CGFs)**
  - Blue Forces
  - Threats (e.g. Fighters, GBAD)
- **Exercise Management Facilities**
  - Scenario development tools
  - Briefing/Debriefing tools
- **Analysis and Assessment Tools**
  - Loggers
  - 3D Viewers
  - Generic Didactic Modules (scoring, CAI)
- **Network Infrastructure**
  - Local
  - Wide Area
  - Security/Encryption

Interoperability

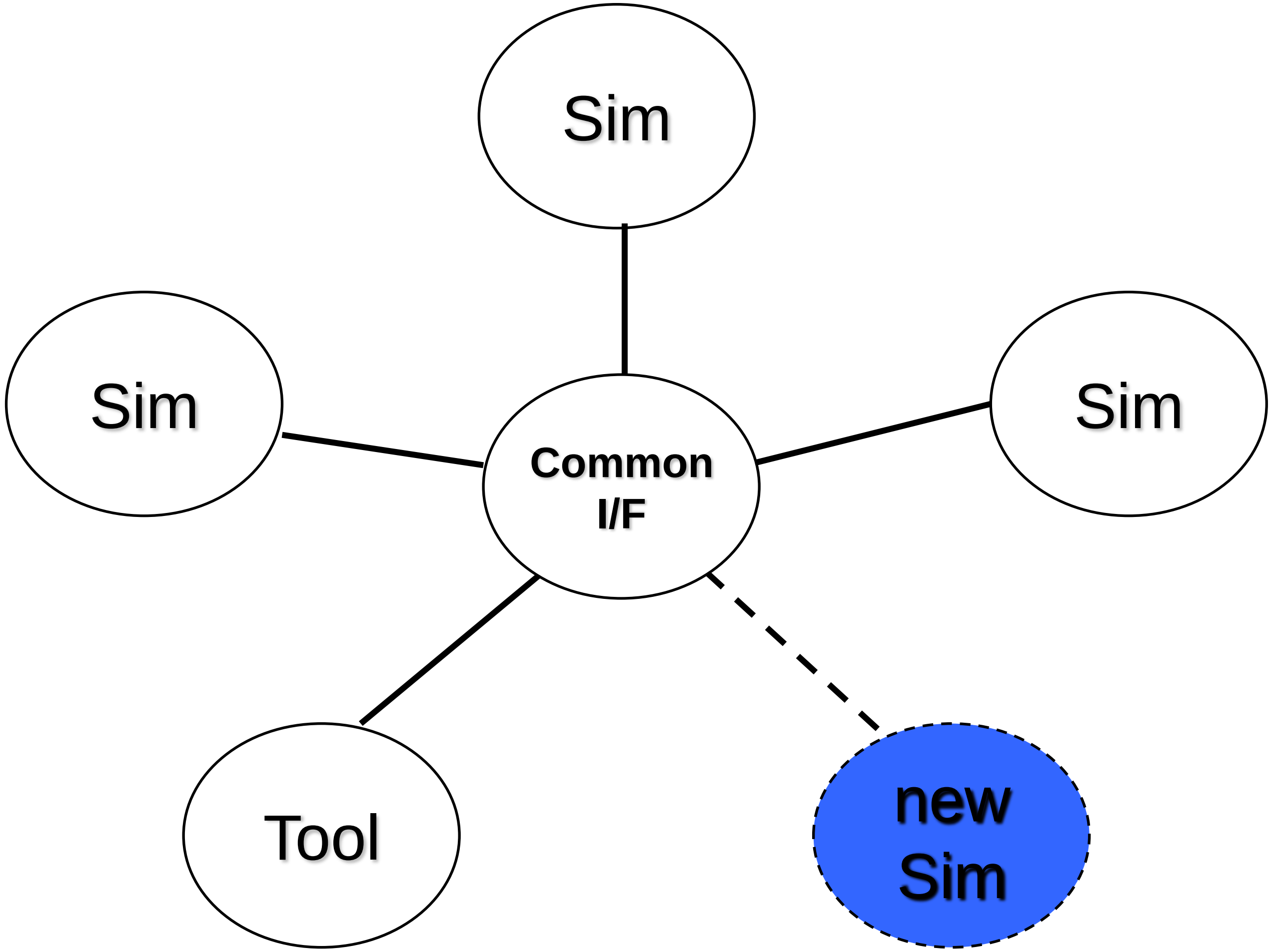
- **Definition: The ability of Simulations to provide services to and accept services from each other**



Interoperability of Sim assets



Interoperability of Sim assets



The Interoperability Challenge

- **Bits&Bytes vs Meaning**
  - “23”: 23 what ? Rounds of ammo, ft altitude, bottles of beer ?
  - “You are dead”: “No way, You’ve missed me”
  - “You are 50% dead”: “So what, I can still fight”
  - “I can see you, but you can’t see me”

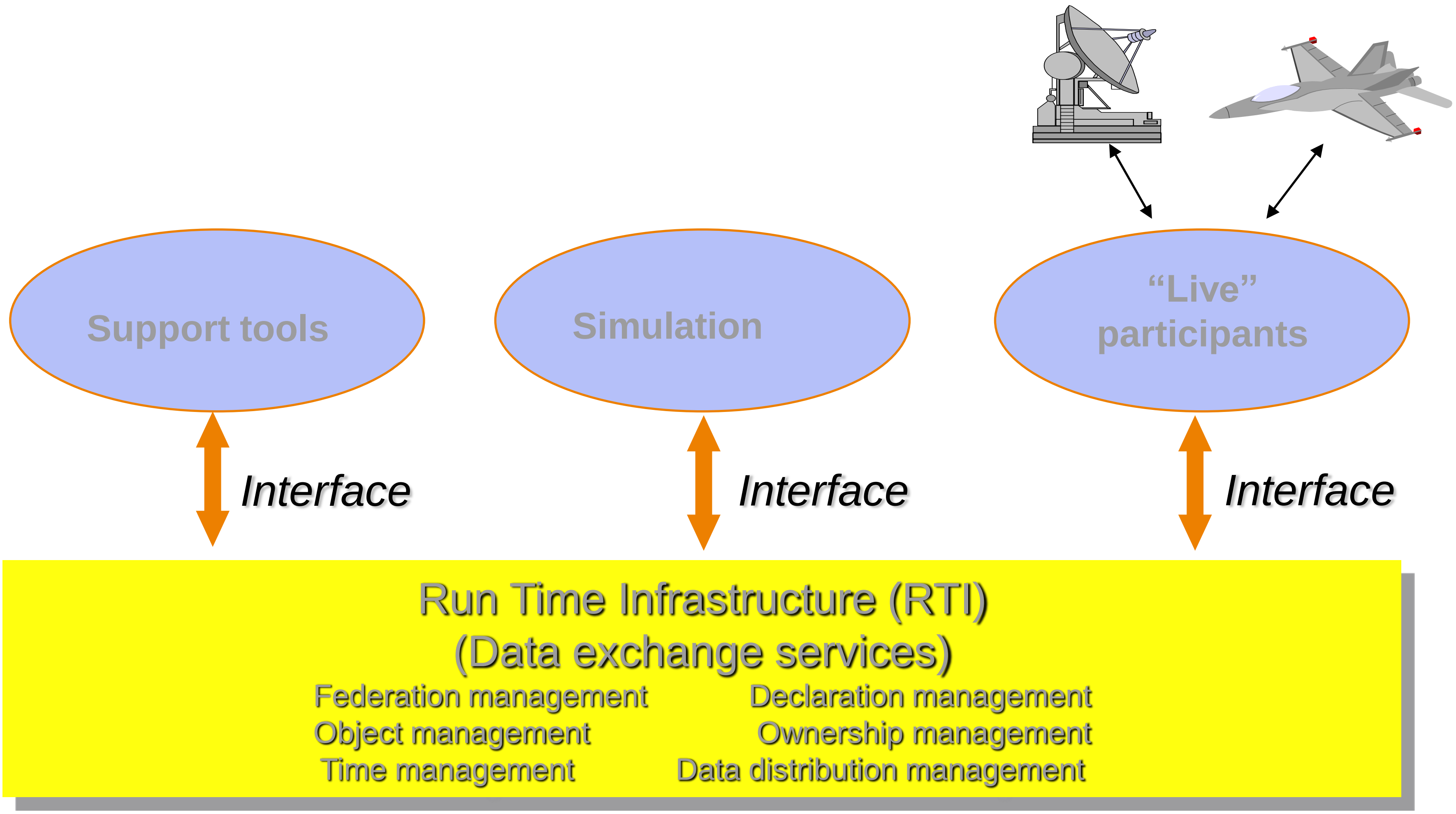
- **Challenges**
  - Standards and Versions (HLA, DIS, …)
  - Vendor Implementations & Compliancy

Modelling & Simulation Standards

- **Advantages**
  - Economy of Scale
  - Comply with legislation
  - Promote Interoperability
  - Promote Common Understanding
  - Introduce Innovations, Transfer Research Results
  - Encourage Competion
  - Facilitate Trade
- **Challenges**
  - Consensus
  - ‘Not Invented Here’ syndrome
  - Vendor Lock-In
  - Maintenance

Modelling & Simulation Standards

The High Level Architecture (HLA)



Terminology

- **Federation:** a set of simulations, a common federation object model, and supporting RTI, that are used together to form a larger model or simulation

- **Federate:** a member of a federation; one simulation
  - Could represent one platform, like a cockpit simulator
  - Could represent an aggregate, like an entire national simulation of air traffic flow

- **Federation Execution:**
  a session of a federation executing together

High level Architecture (HLA)

- **HLA Rules**
  - Must be observed by federates
  - 5 requirements for federations
  - 5 requirements for particular federates
- **Runtime Interface (RTI)**
  - Defines Functional interfaces (service) between federates and the RTI
  - RTI is software, it is not a part of specification
- **Object Model Template (OMT)**
  - Specification of all objects and interactions
  - Federation Object Model (FOM)
  - Simulation Object model (SOM)
  - Management Object model (MOM)

HLA Rules - Federations

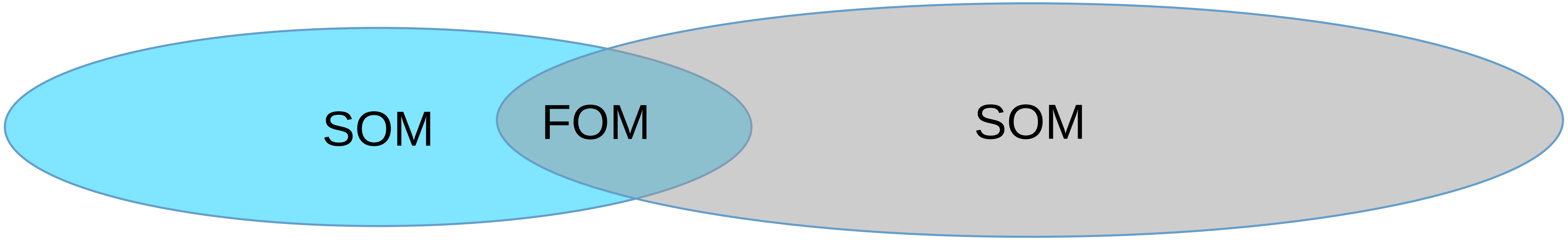
1. Federations shall have an HLA Federation Object Model (FOM), documented in accordance with the HLA Object Model Template (OMT).
2. In a federation, all representation of objects in the FOM shall be in the federates, not in the runtime infrastructure (RTI).
3. During a federation execution, all exchange of FOM data among federates shall occur via the RTI.
4. During a federation execution, federates shall interact with the runtime infrastructure (RTI) in accordance with the HLA interface specification.
5. During a federation execution, an attribute of an instance of an object shall be owned by only one federate at any given time.

HLA Rules - Federates

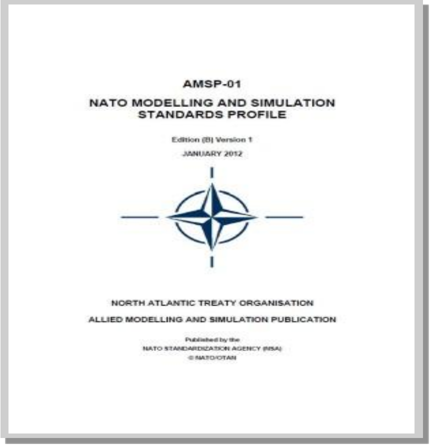
6. Federates shall have an HLA Simulation Object Model (SOM), documented in accordance with the HLA Object Model Template (OMT).
7. Federates shall be able to update and/or reflect any attributes of objects in their SOM and send and/or receive SOM object interactions externally, as specified in their SOM.
8. Federates shall be able to transfer and/or accept ownership of attributes dynamically during a federation execution, as specified in their SOM.
9. Federates shall be able to vary the conditions (e.g., thresholds) under which they provide updates of attributes of objects, as specified in their SOM.
10. Federates shall be able to manage local time in a way which will allow them to coordinate data exchange with other members of a federation.

Object Models

- Object Model Template (OMT)
  - Provides a common framework for HLA object model documentation
  - Fosters interoperability and reuse of simulations
- Federation Object Model (FOM)
  - A description of all shared information (objects, attributes, and interactions) essential to a particular federation
- Simulation Object Model (SOM)
  - Describes objects, attributes and interactions in a particular simulation which *can* be used externally in a federation



M&S Standards Categories


AMSP-01
NATO MODELLING AND SIMULATION STANDARDS PROFILE
Edition (B) Version 1
JANUARY 2012
NORTH ATLANTIC TREATY ORGANISATION
ALLIED MODELLING AND SIMULATION PUBLICATION

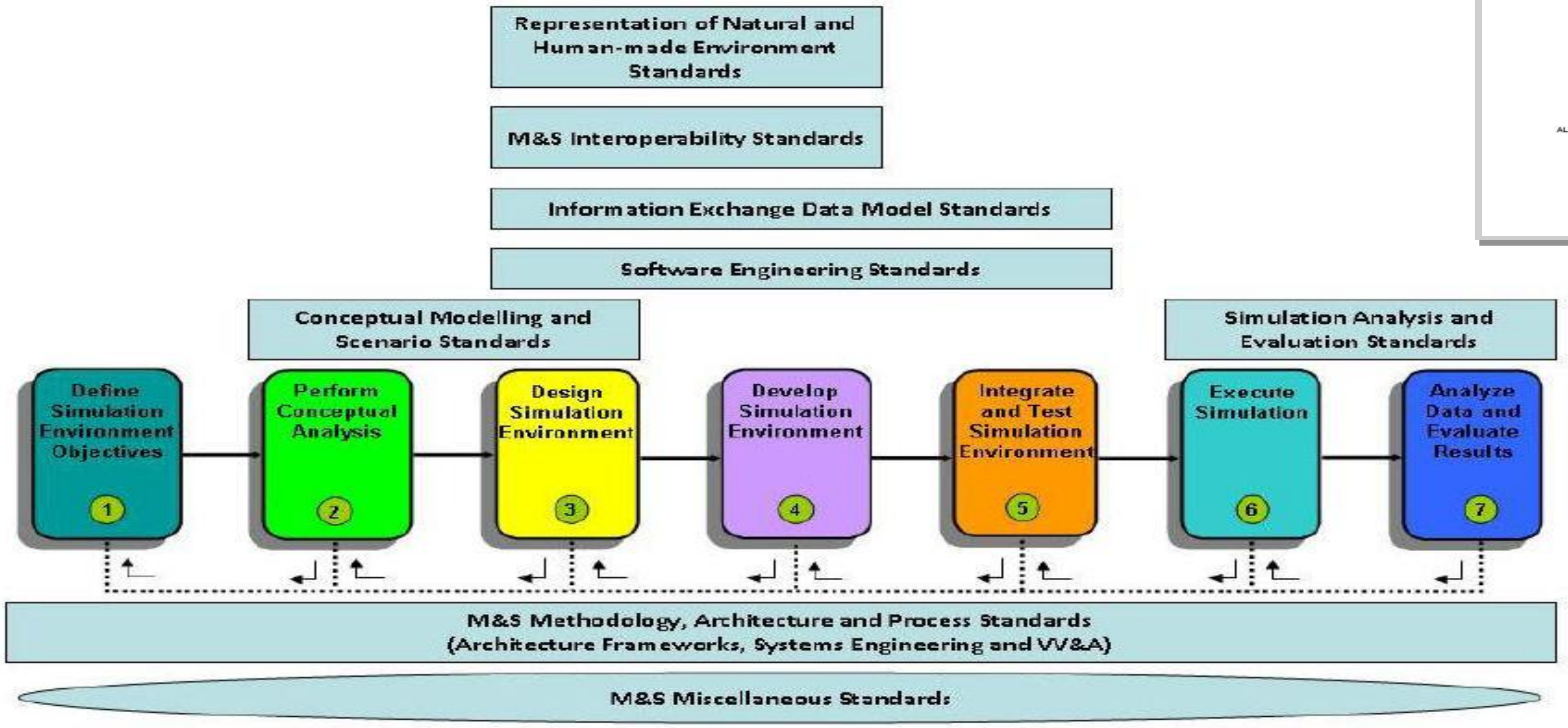


Figure 3-1: The 7-step DSEEP simulation engineering process and the standards categories

S&T organization
Modelling and Simulation Group

SIS Simulation Interoperability Standards Organization
"Simulation Interoperability & Reuse through Standards"

TNO innovation for life

NATO Simulation Reference Architecture


Thursday, February 03, 2011 Text Size

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ALLIED COMMAND TRANSFORMATION

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Viper 51 Meets Rattlesnake 4 In The Virtual World

"Viper 51 this is Rattlesnake 4, let me know when you clear the IP (Initial Point) for your run".
"Roger, Rattlesnake 4".

The pilot of Viper 51 was flying his F-16 at 300 knots just 200 feet off the ground with six 500-pound MK-82 high-drag bombs under his wings.

At this speed and altitude the trees blur into one green mass as he scans the terrain.

"Cleared IP." The Forward Air Controller (FAC) has only seconds to visually acquire the aircraft. One moment it will be a dot on the horizon and the next it will flash overhead.

Rattlesnake 4 has been a FAC for years and has many combat missions in ISAF. He takes one last look at the terrorist vehicles checking also with the ROVER UAV feed to make sure they have not moved, and that there are not any non-combatants near.

"Tip up", calls Viper 51. The F-16 begins a pull up manoeuvre to gain altitude. As he levels out he sees the targets as his aiming dot on his heads-up display creeps across the ground toward the vehicles.

"Rattlesnake 4, tally target."
"Viper 51, cleared hot."

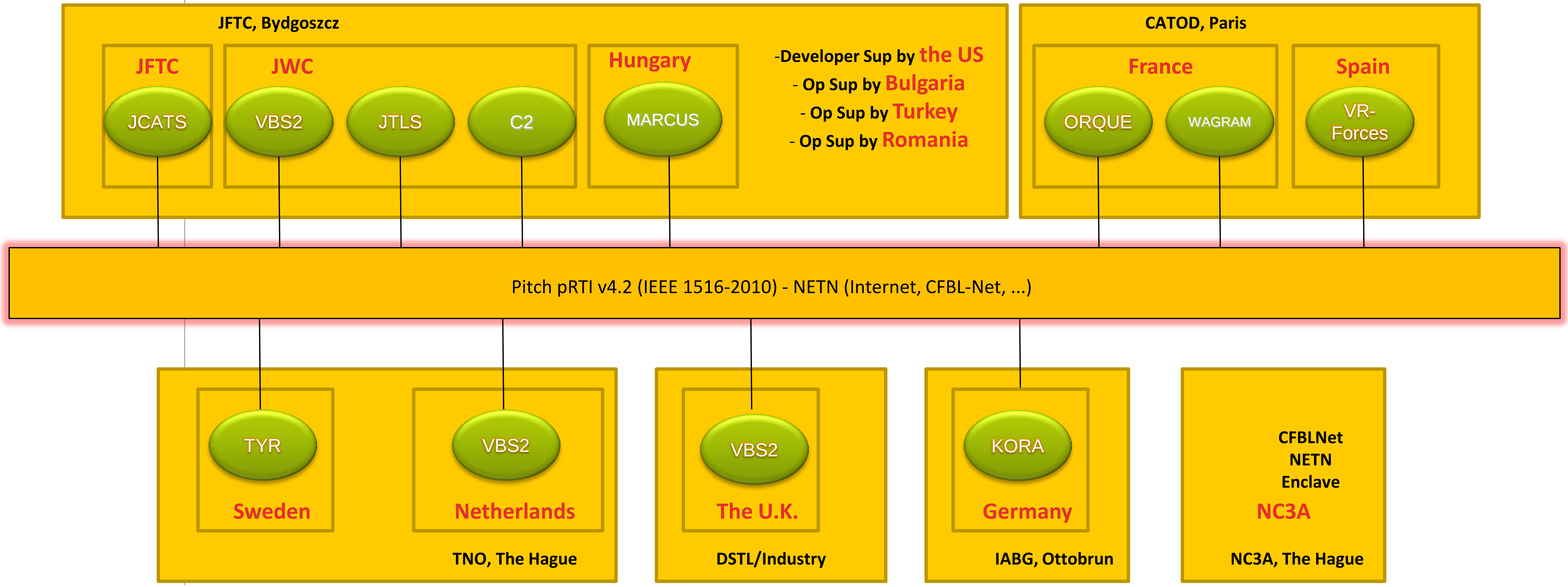
Viper 51 barely gets his clearance to drop before leaving the target area. He drops the bombs as he pulls a high G turn to escape the weapon's fragmentation envelope. The explosion destroys all three vehicles; a successful high-threat low altitude target engagement.

This event did not occur in some far off land on a battlefield between two unnamed mountains. Instead, it took place all around Europe. The UAV pilot was located in Great Britain's Defence Science and Technology Laboratory. The Dutch pilot was flying his F-16 on a desktop simulator at TNO in The Hague, The Netherlands. The FAC was conducting his mission at NATO's Joint Force Training Centre, Bydgoszcz, Poland, wearing a virtual reality helmet. All of them were wrapped in a virtual environment created by the NATO Live, Virtual and Constructive simulation infrastructure. ACT, NC3A, The Netherlands and Great Britain put together this experiment hosted in part by JFTC.

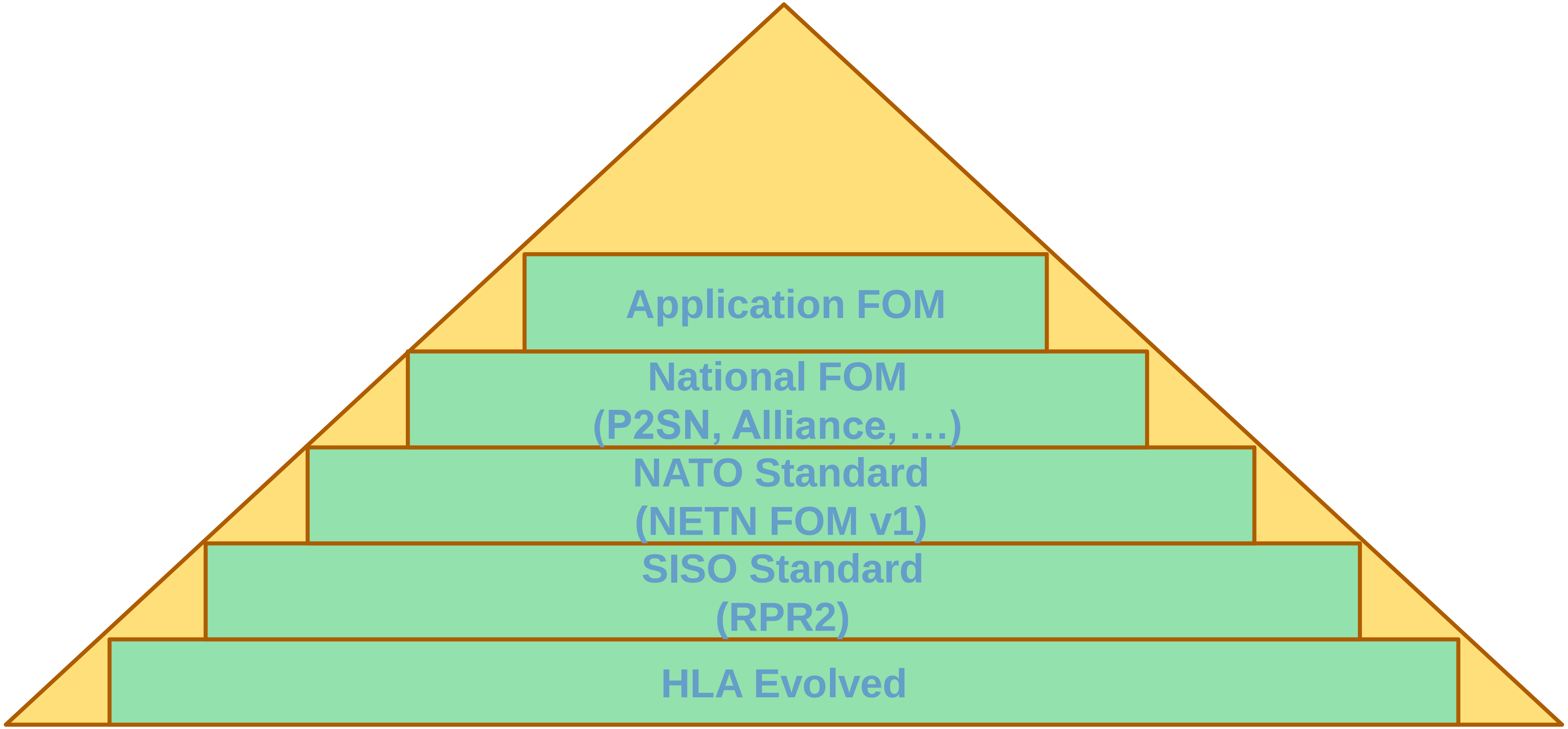
Some comments from the forward air controllers, after the event, included, "doing simulated exercises before the initial live run is critical for making these more productive and for decreasing the number of failed runs". And, "practice of procedures with pilots of the different nations is essential for being ready for real operations. For example, it is critical to deal with different accents or to handle particular ways to describe objects"

"I think this is a huge step forward to improve the training for FACs and air support pilots engaged in multinational operations," said U.S. Navy Commander David James, Fratricide Prevention Integrated Program Team leader. He continued, "Distributed multinational training events such as the one demonstrated here are crucial for pre-deployment and mission rehearsal preparations in order to produce the desired effects for the Alliance in a timely and accurate manner."

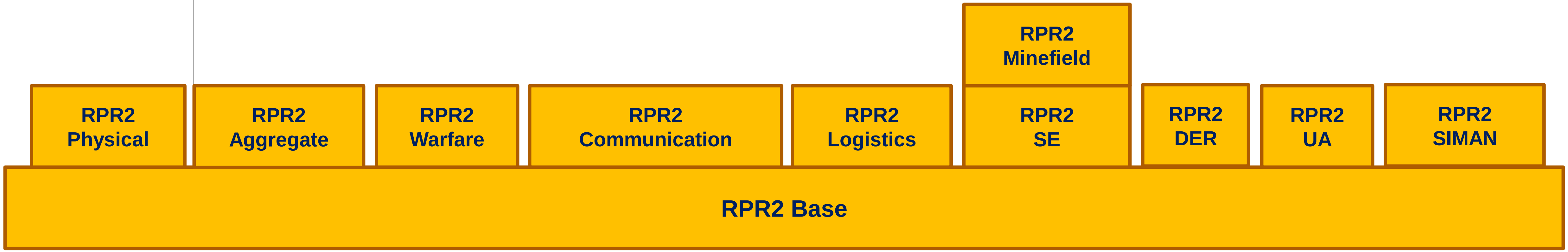
High level Architecture (HLA)



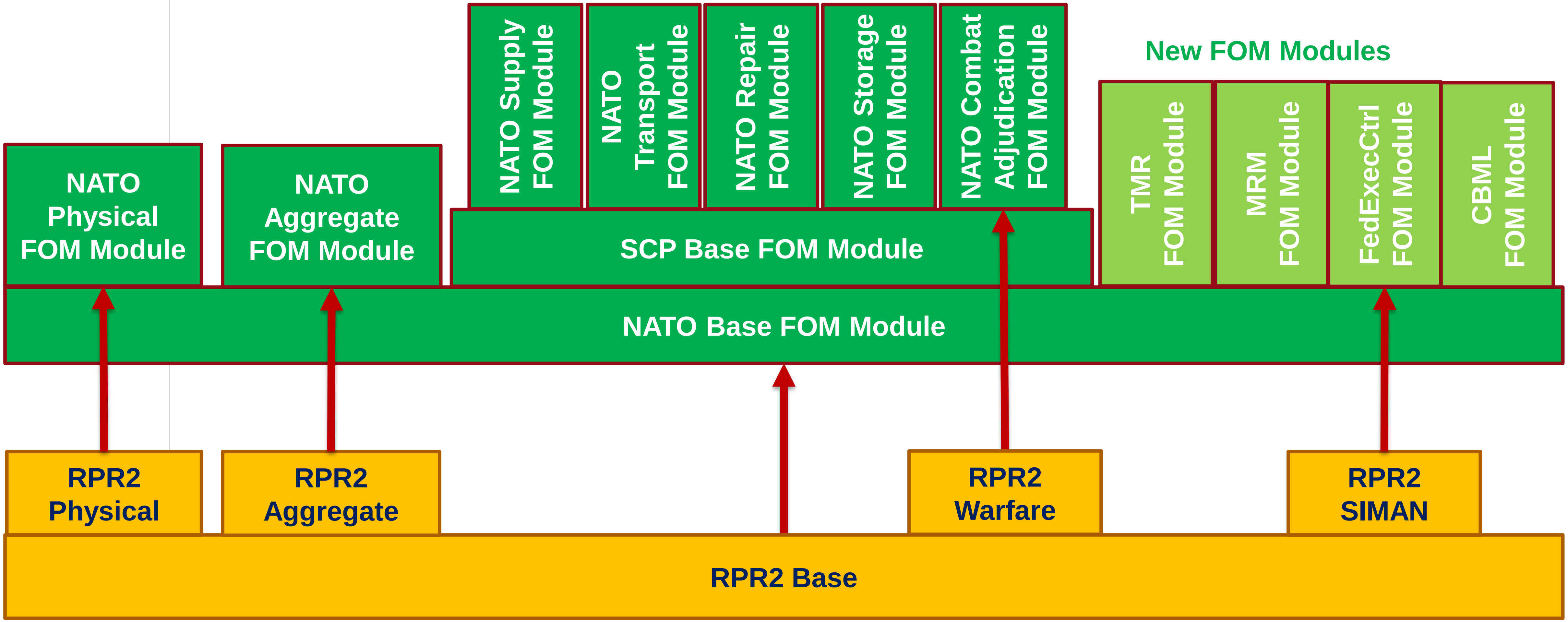

FOM: Technical Baseline



RPR2 FOM Module Dependencies



NATO FOM Module Dependencies

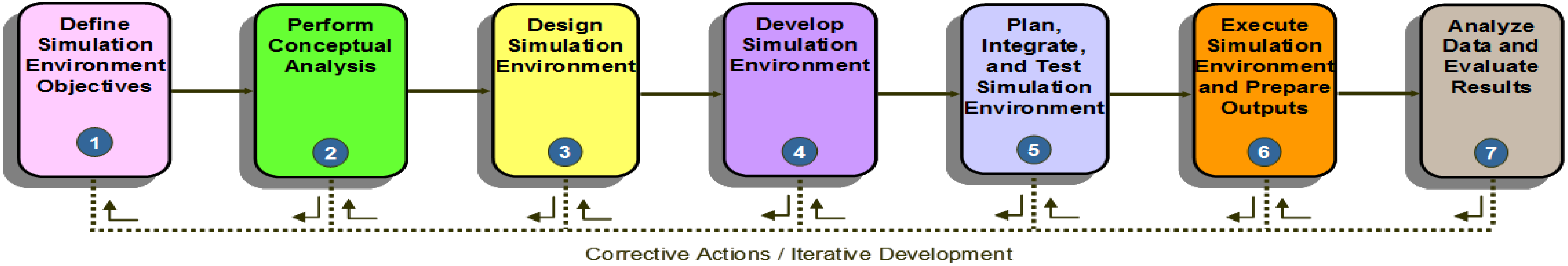


Distributed Simulation Engineering and Execution Process (DSEEP)

Overview

T.W. van den Berg

Distributed Simulation Engineering and Execution Process (DSEEP): a recommended practice



- IEEE 1730-2010: A seven step **engineering process model** for the development and execution of a distributed simulation environment
- Each step is broken down in activities and tasks, with activity inputs and potential outcomes
- Generally applicable, Evolving further by input from the user community

1. Define simulation environment objectives

Define and document a set of ***needs*** *to be addressed through the development and execution of a simulation environment and transform these needs into* ***object***

Start with **Use Case Model** to show real world activities

System Of Interest: Command and Control processes between actual ship, with actual operators and systems

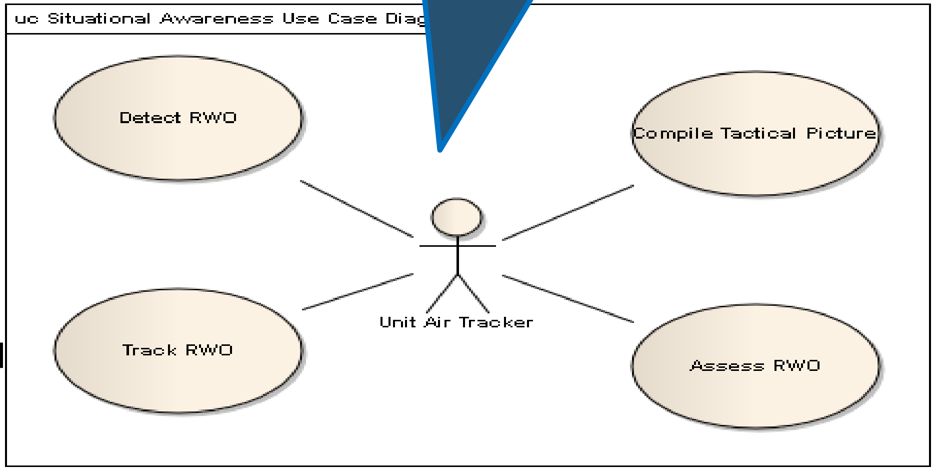
Objective: quantify and evaluate proposed improvements to support acquisition decisions, using Monte Carlo simulation for analysis

MOEs: Time to identify and classify real world objects, …

ission area, …

jectives

iveness/Performa

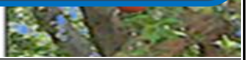


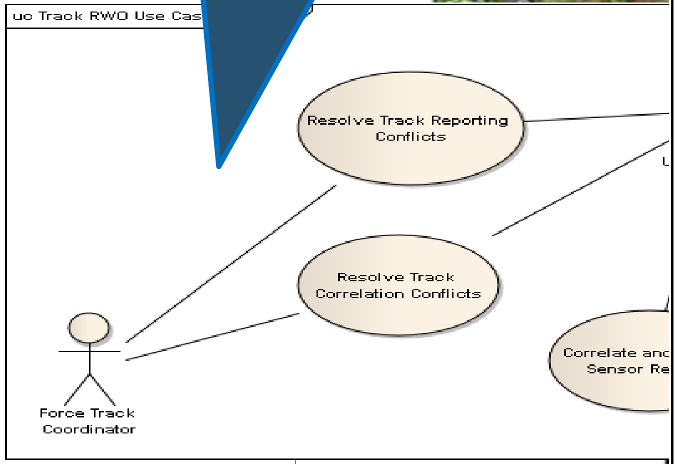
2. Perform

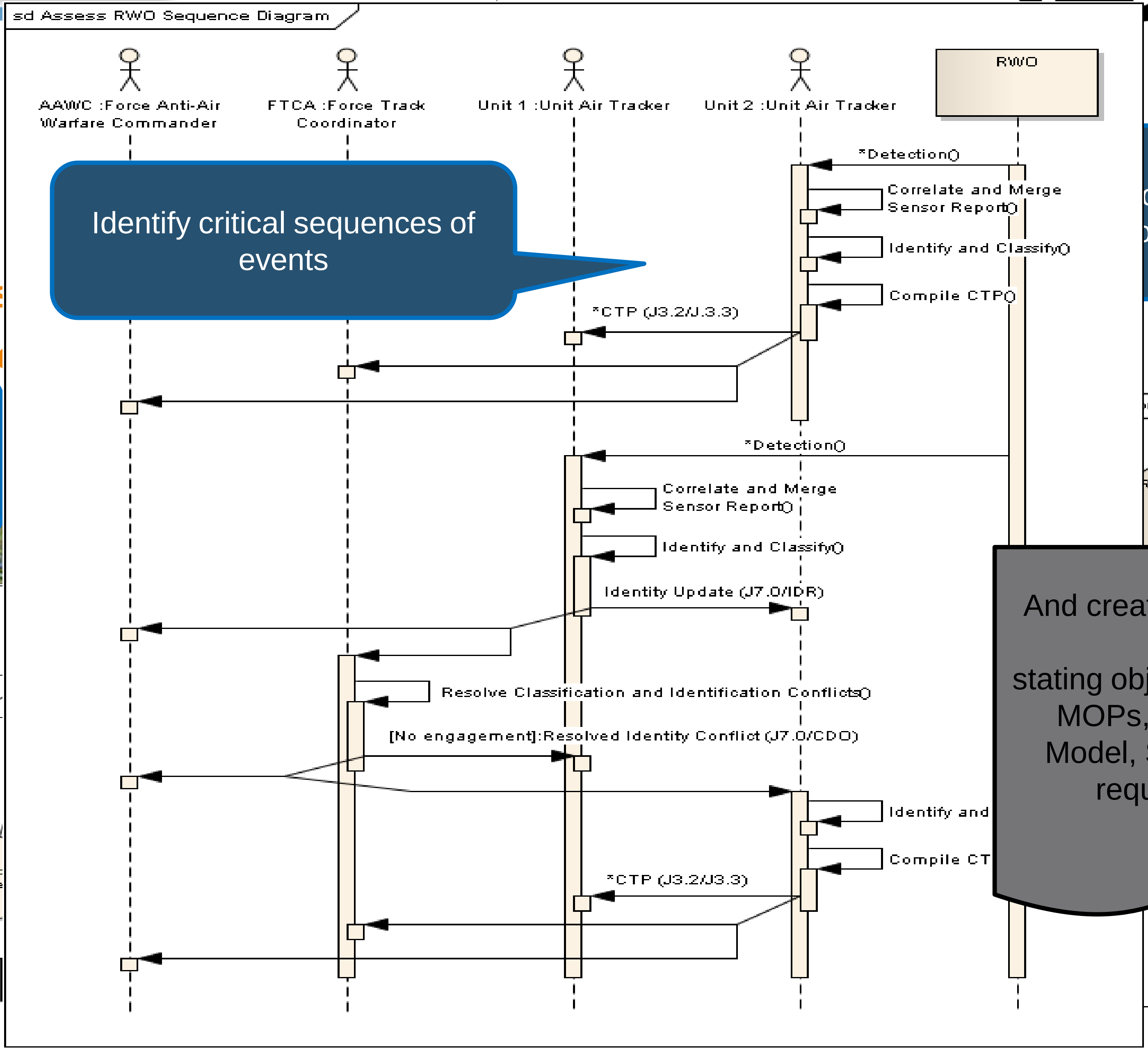
Develop ***repres*** *…*

develop the ***sc*** *…*

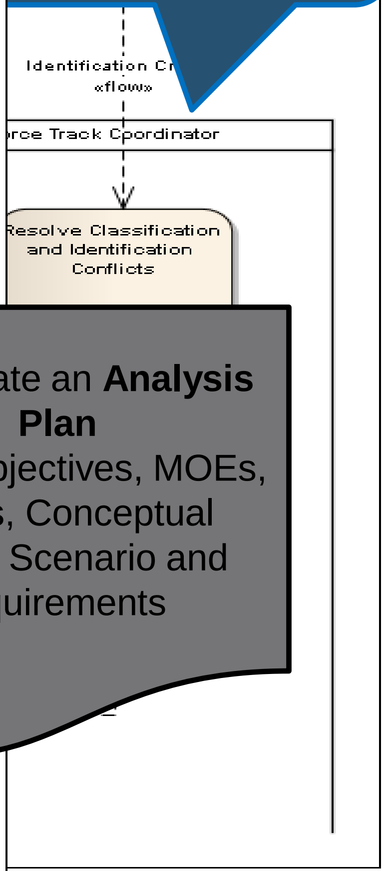
Elaborate **the Use Case Model** to show more real world activities







Identify critical sequences of events



…operational activities …rmation exchanges

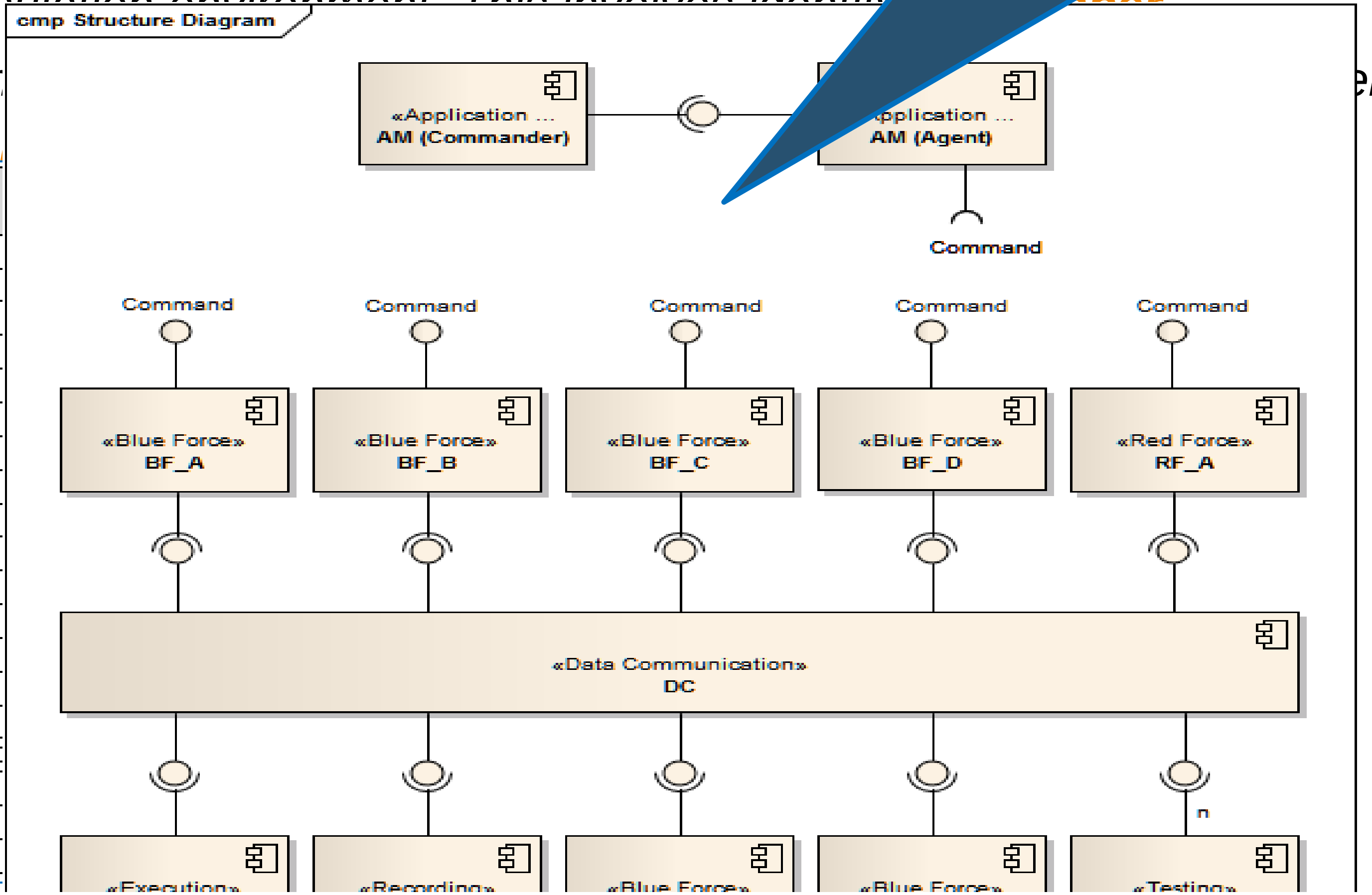
And create an **Analysis Plan** stating objectives, MOEs, MOPs, Conceptual Model, Scenario and requirements

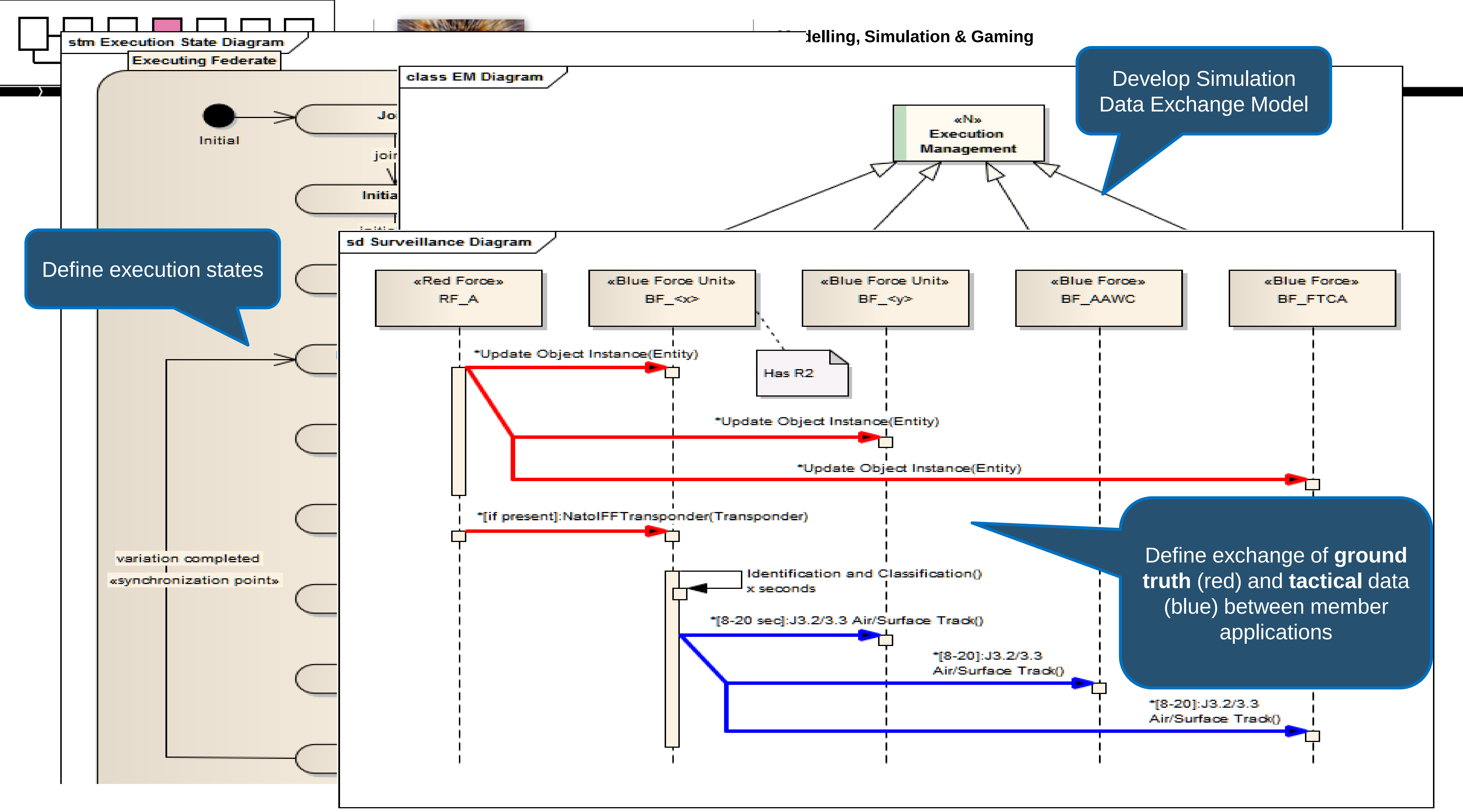
3. Design simulation environment

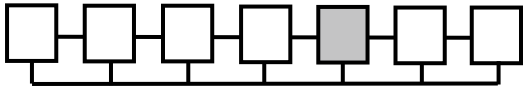
Define **physical structure** of simulation environment and **allocate requirements** and **responsibilities** to represent entities from conceptual model

Perform **trade off analysis** between member applications and requirements

Id	Description
1	Situational Awareness
1.1	Detect RWO
1.2	Track RWO
1.2.1	Resolve Track Reporting Conflicts
1.2.1.1	Send J7.0/IDR
1.2.1.2	Receive J7.0/IDR
1.2.1.3	Send J7.0/CDO
1.2.1.4	Receive J7.0/CDO
1.2.2	Resolve Track Correlation Conflicts
1.2.3	Correlate and Merge Sensor Reports
1.2.4	Correlate Track Updates
1.2.5	Decorrelate Tracks
1.3	Asess RWO
1.3.1	Identify RWO
1.3.2	Classify RWO
1.3.3	Resolve Classification and Identification Conflic
1.4	Compile Tactical Picture
1.4.1	Send J3.2/J3.3
1.4.2	Receive J3.2/J3.3

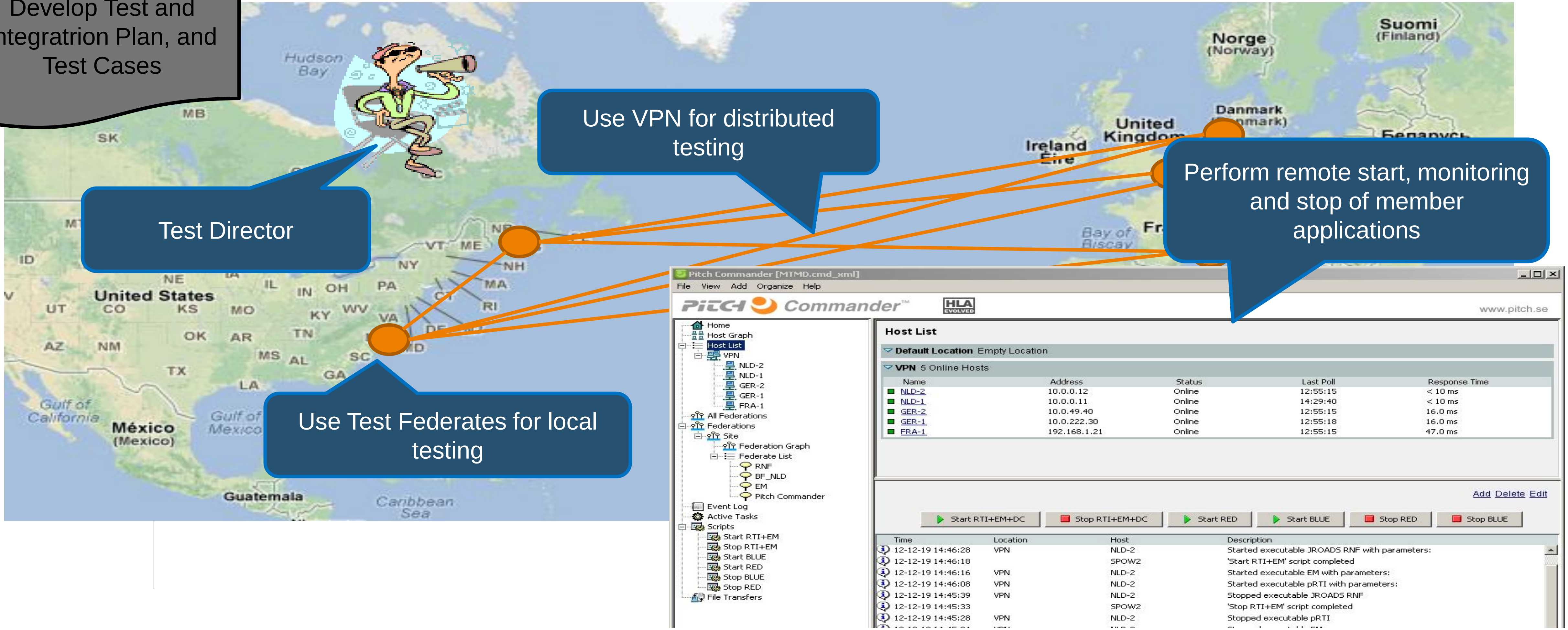



delling, Simulation & Gaming
stm Execution State Diagram
Executing Federate
Initial
class EM Diagram
«N»
Execution
Management
Develop Simulation Data Exchange Model
sd Surveillance Diagram
Define execution states
«Red Force»
RF_A
«Blue Force Unit»
BF_<x>
«Blue Force Unit»
BF_<y>
«Blue Force»
BF_AAWC
«Blue Force»
BF_FTCA
*Update Object Instance(Entity)
Has R2
*Update Object Instance(Entity)
*Update Object Instance(Entity)
*[if present]:NatoIFFTransponder(Transponder)
variation completed
«synchronization point»
Identification and Classification()
x seconds
*[8-20 sec]:J3.2/3.3 Air/Surface Track()
*[8-20]:J3.2/3.3
Air/Surface Track()
*[8-20]:J3.2/3.3
Air/Surface Track()
Define exchange of ground truth (red) and tactical data (blue) between member applications



5. Integrate and test simulation environment

Develop Test and Integratrion Plan, and Test Cases



Use VPN for distributed testing

Test Director

Perform remote start, monitoring and stop of member applications

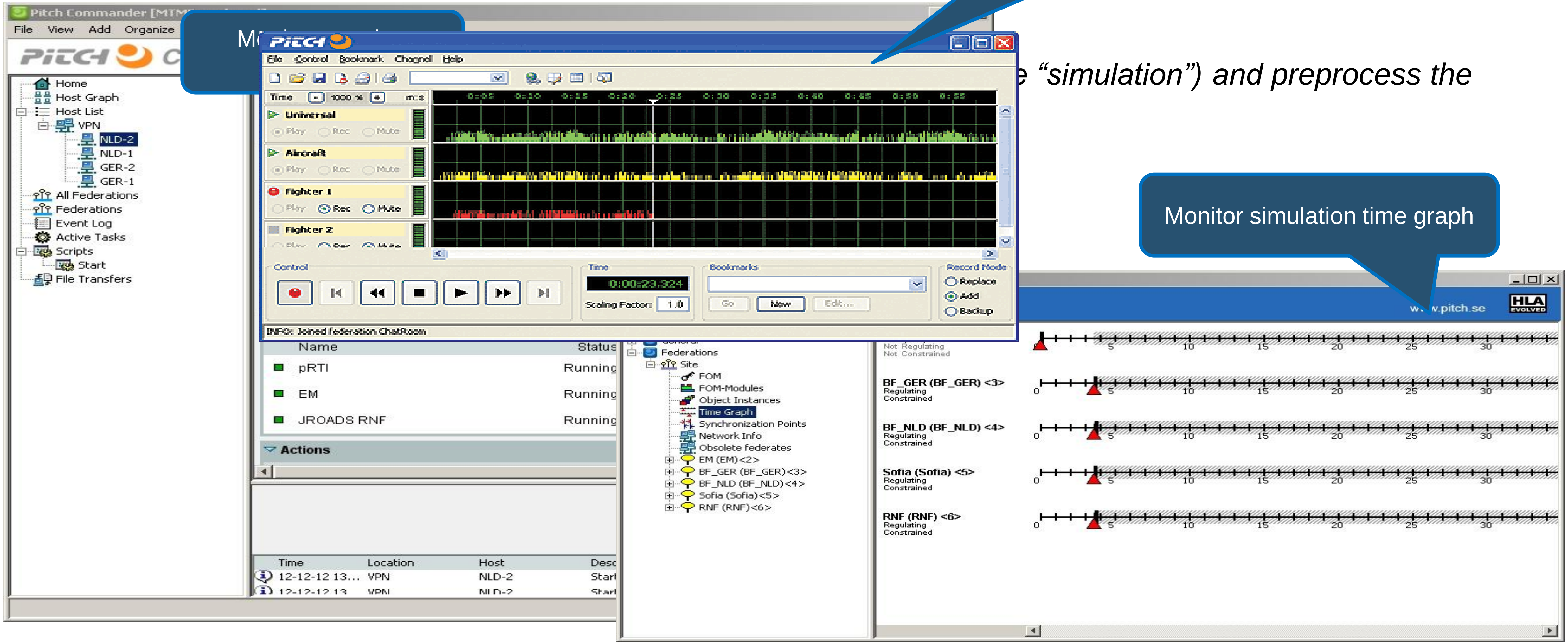
Use Test Federates for local testing

6. Execute simulation

And record data

e “simulation”) and preprocess the

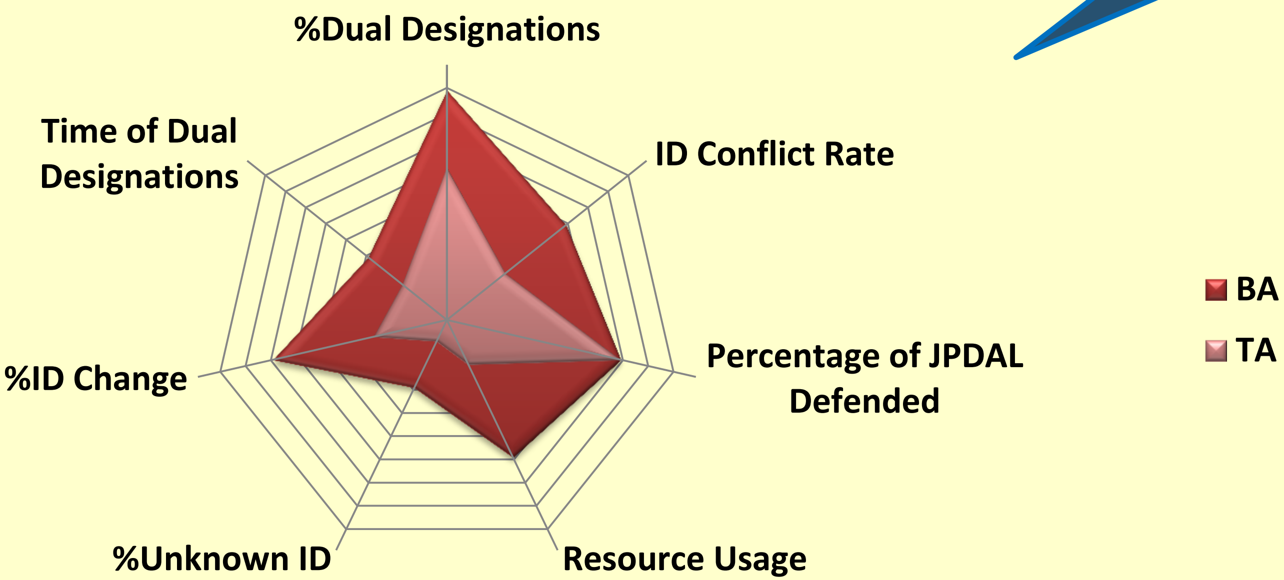
Monitor simulation time graph



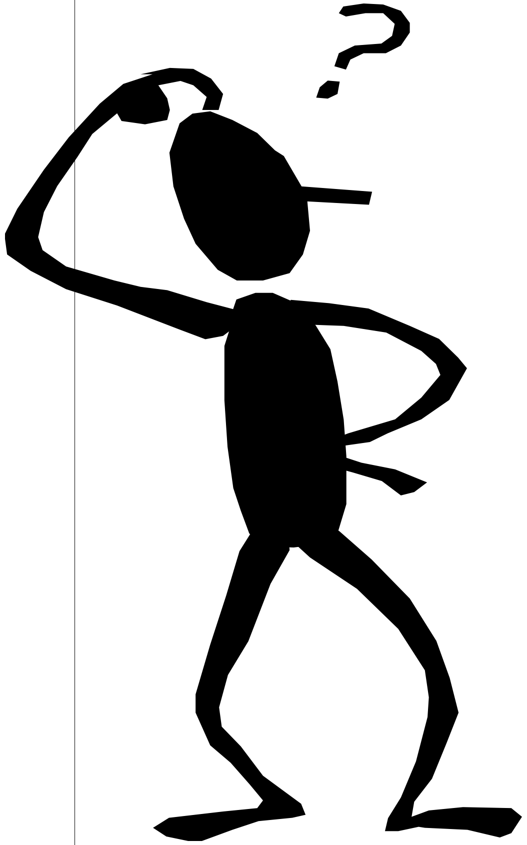
7. Analyze Data and Evaluate Results

Analyze and evaluate data acquired during the execu ... onment, and report the results back to the user/sponsor

Process and analyze data



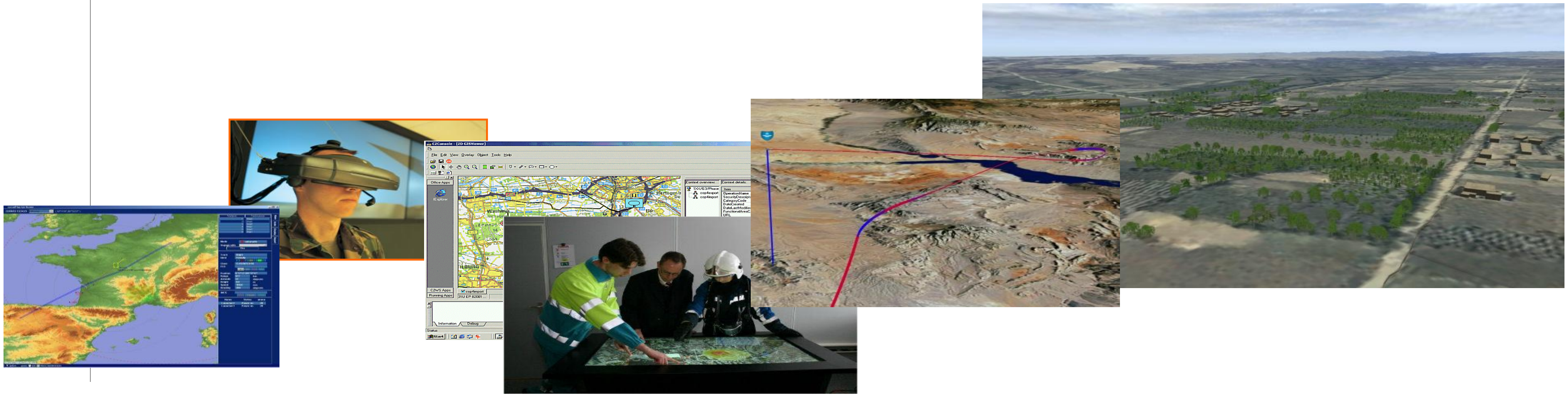
Promoting Standards: Is it working…



- Advantages
  - Economy of Scale
  - Comply with legislation
  - Promote Interoperability
  - Promote Common Understanding
  - Introduce Innovations, Transfer Research Results
  - Encourage Competion
  - Facilitate Trade
- Challenges
  - Consensus
  - Not-Invented-Here
  - Openness / Vendor Lock-In
  - Maintenance

Modelling, Simulation and Gaming

- M&S are complimentary areas of problem analysis and solution synthesis, which are needed to support the full life cycle of a capability
- A set of coherent principles and standards are required to fully exploit the potential of M&S



For more Information

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For more Information

- SISO website: http://www.sisostds.org
- NMSG website: http://www.cso.nato.int/panel.asp?panel=5


sensoren
vr-forces
pollux
hla
uwt
screenplay
standaarden/tools
gedragsmodellen
wapen
missile
modellen
sensor
jadex
burgerbevolking
vbs2
c2-sim-agents
vuurleiding
verkeersmodel
communicatie
mirecol
live-data
datasets

CIPRNet

Critical Infrastructure Preparedness and Resilience Research Network
www.ciprnet.eu

Modelling and Simulation Techniques for Critical Infrastructure Protection

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Modelling, Simulation and Analysis of Critical Infrastructure Training School (Edition 0)

Deltares Headquarters – Delft (The Netherlands) – 3-4 February 2014

Agenda

- Role of simulation for CIP
- Integrated modelling and simulation
- I2Sim framework
- Federated modelling and simulation
- DIESIS architectural approach

Role of simulation for CIP

Some applications areas

- **General (offline) CI analysis**
  - Investigating (inter)dependencies between critical infrastructures
    - Implicit, indirect and hidden relations
    - Feedback loops and cascading effects
    - Stability analysis and risk estimation
  - Testing existing and benchmarking new CI control methods
- **Improving preparedness**
  - Soft exercises and real-time training
    - Large spectrum of emergency scenarios
- **Operational support**
  - Decision support
    - What-if analysis
    - Intelligent alarm interpretation

Role of simulation for CIP

Cross-sector simulation: challenges

- **Heterogeneous CIs**
  - Different modelling approaches
  - Different time scales and levels of abstraction
  - Identifying CIs dependencies
- **Data acquisition**
  - Sensitive, classified or incomplete data
  - Close cooperation with CI operators
  - Interdisciplinary expertise
- **Heterogeneous software**
  - Use dedicated simulators for particular CIs
  - Technical and semantic interoperability
  - Flexibility and extensibility

Integrated modelling and simulation

Workflow of an integrated approach

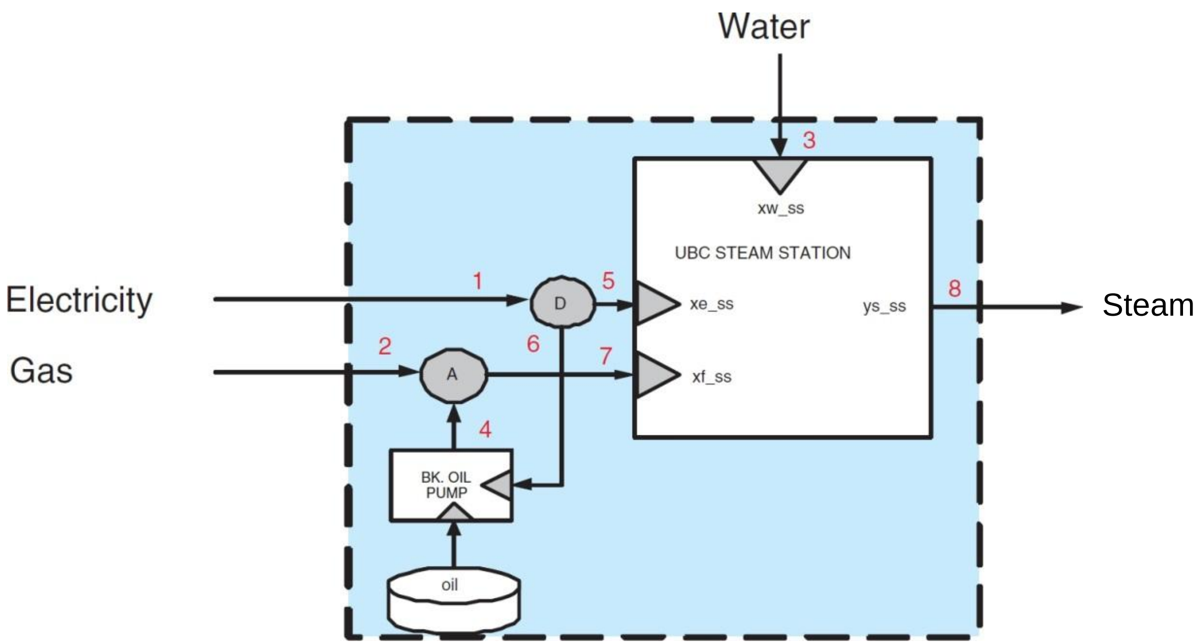
1. Define analysis goal and desired analysis results
2. Choose a proper level of abstraction for each domain
3. Find a suitable common modelling formalism for all involved domains
4. Create models that correctly describe
   - For each domain: relevant elements and their behaviour
   - For each pair of domains: cross-domain relations, services, etc.
5. Implement a modelling and simulation tool for your formalism (for popular formalisms suitable tools may already exist)
6. Run simulations, evaluate and analyse results

Integrated modelling and simulation
I2Sim framework

- I2Sim has been developed at University of British Columbia
- I2Sim is a framework for integrated CI modelling and simulation
- Modelling formalism is a Cell-Channel model:
  - Cells are entities that perform some functions
  - Tokens represent goods or services, provided and consumed by cells
  - Channels transport tokens between certain cells or clusters
  - Clusters are cell groups (reduction of modelling granularity)
  - Control units (distributor/aggregator) change their state according to decision maker layer events
- Linear part of cell functions: Leontief input-output model
- Non-linear I/O-relationships: time-dependent coefficients

Integrated modelling and simulation

I2Sim framework: example cell



*Picture from: Rahman, H. A., et al. I2Sim: a matrix-partition based framework for critical infrastructure interdependencies simulation. In: *Electric Power Conference, 2008. EPEC 2008. IEEE Canada*. IEEE, 2008. S. 1-8.

- For each time step, a set of difference equations for a Cell-Channel model can be provided
- I2Sim simulator solves Cell-Channel network models using MATE solution algorithm
- Example model of a steam station*:
  - A non-linear functional block converts water to steam
  - Inputs: water, gas, electricity
  - Output: steam
  - Control units can be used to switch the backup oil supply unit on and off

Integrated modelling and simulation

Advantages and disadvantages

- **Advantages**
  - Consistent and transparent modelling, well-defined semantics, well-known solution algorithms
  - For a proper level of abstraction: no redundant computations, relatively good performance
  - Only one single modelling and simulation tool is required
- **Disadvantages**
  - For scenarios with many CIs: potentially large networks, construction of such networks is a major effort
  - All domain knowledge needs to be converted into a model that is not familiar to the involved domain experts
  - On a high level of detail within a CI: formalism may be insufficient for modelling of large non-linear CI parts and/or complex continuous behaviour

Federated simulation

Motivation

- There are several practical problems, only a few of them are:
  - It's a major effort to create new models for large infrastructures or to transform existing models into some universal format as well as to keep them up to date
  - For a complex scenario, it's quite unlikely to find people who have expertise in all involved domains and can implement a holistic model
  - CI carriers typically do not disclose full information about their infrastructure
- Possible solution: federated simulation
  - Reuse existing models and interconnect ready-made simulators (possibly already used by CI operators)
  - Create interaction models that describe interactions between domains and contain only relevant CI elements

Federated simulation

Challenges

- **Semantics**
  - Data integration and conversion
  - Different time models: synchronisation (preservation of causality)
  - Concepts of elements beyond existing models may be required
- **Technology**
  - Heterogeneous software: interfacing simulators
  - Different levels of abstraction: avoid redundant computations
  - Orchestration of different execution concepts of federate simulators
  - Communication and event routing among federates

Federated simulation

General workflow of setting up a federation

1. Define analysis goal and desired analysis results
2. For each domain: find appropriate simulators and models
3. Provide a formal description of dependencies: semantics and concrete relations
4. Find a suitable technical interoperability solution
5. Realise dependencies using formal description and the chosen technology
6. For each simulator: implement federation interoperability interface (if not already available)
7. Run simulations, evaluate and analyse results

DIESIS architectural approach

DIESIS interoperability middleware for federated MS&A

- Designed for heterogeneous interdependent federated CI simulations
  - Federates are not required to support common standards (e.g., HLA)
  - Federates have different time models and different time scales
  - Methodology for arbitrary scenarios, scenario-oriented federation design
  - Flexible modelling, extensibility of federations
  - Service-oriented scenario design
- DIESIS interoperability middleware is based on two concepts
  - Separation of technical and semantic interoperability
  - Lateral coupling of federates

DIESIS architectural approach

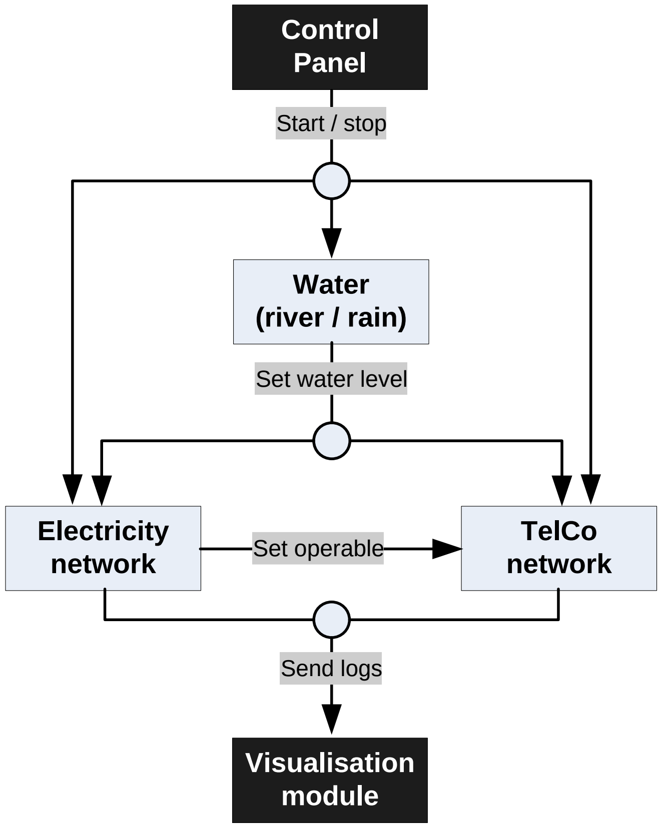
Interoperability layers

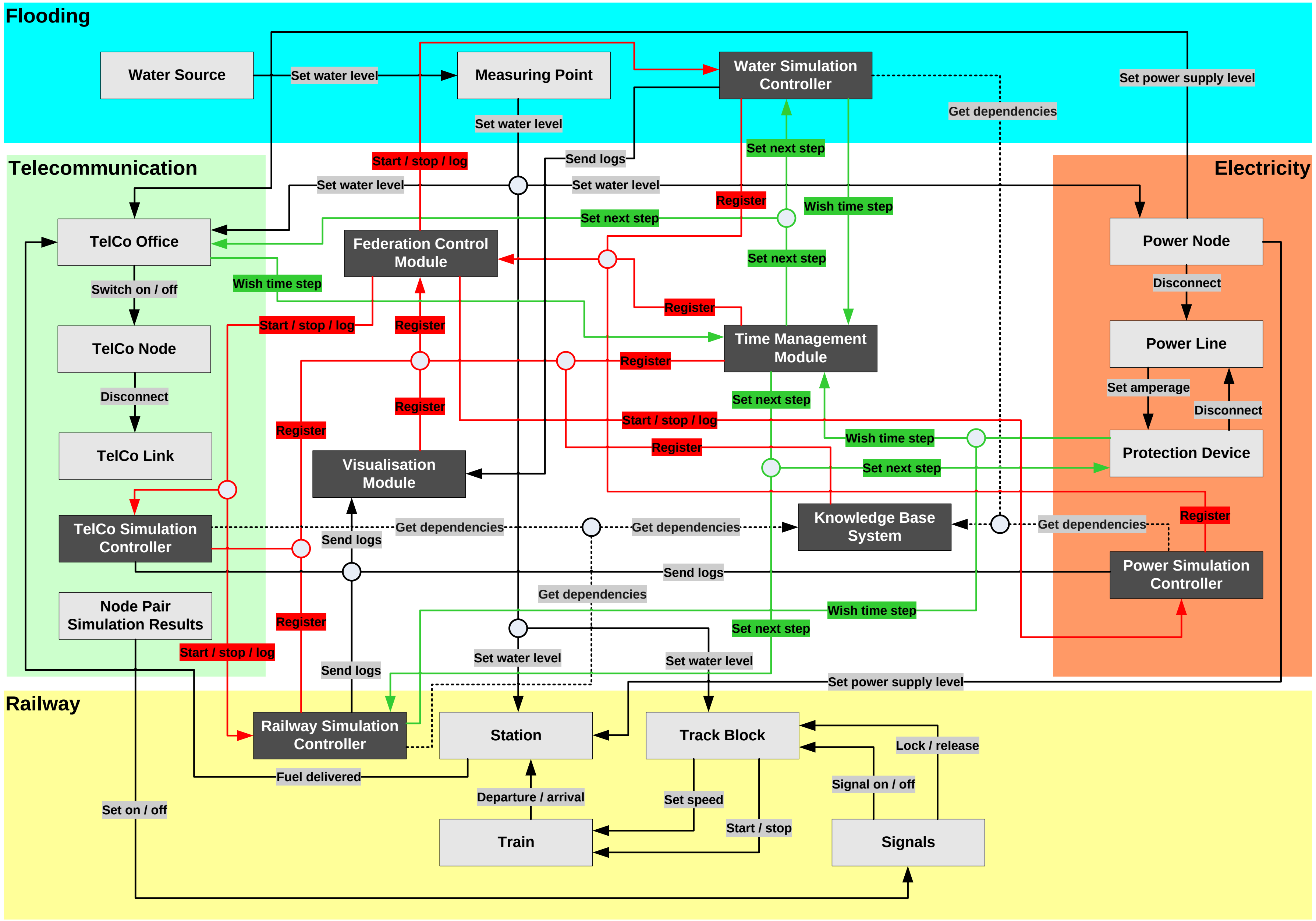
- **Semantic interoperability**
  - DIESIS Knowledge Base System: a general modelling framework
  - CI elements/properties that are involved in cross-domain interactions
  - Concepts beyond particular CIs, static dependency representation (relations), dynamic dependency concepts (behaviour)
- **Technical interoperability**
  - Reusable simulator coupling links, dedicated types:
    - Time links: ensure correct event ordering
    - Data links: exchange state changes (events)
    - Function links: mutual function calls
    - Control links: manage runtime behaviour

DIESIS architectural approach

Scenario-oriented design: conceptual phase

- Enunciate general requirements and the goal
  - Which domains are involved and how do they interact?
  - What do we want to investigate?
- Provide an informal, human-readable, computation-independent model that captures all basic concepts related to interactions
  - Identify agents and services, construct a service network
  - Describe both abstract and technical elements




Flooding
Water Source
Set water level
Measuring Point
Water Simulation Controller
Set water level
Get dependencies
Set power supply level
Telecommunication
Start / stop / log
Send logs
Set next step
Electricity
Set water level
Set water level
Register
Wish time step
Set next step
TelCo Office
Federation Control Module
Power Node
Set next step
Switch on / off
Wish time step
Disconnect
Register
Start / stop / log
Register
Time Management Module
Power Line
TelCo Node
Register
Register
Set amperage
Disconnect
Disconnect
Set next step
Register
Start / stop / log
Register
Wish time step
TelCo Link
Visualisation Module
Register
Protection Device
Set next step
Knowledge Base System
Register
TelCo Simulation Controller
Get dependencies
Get dependencies
Get dependencies
Send logs
Send logs
Power Simulation Controller
Node Pair Simulation Results
Get dependencies
Wish time step
Register
Set next step
Start / stop / log
Set water level
Set water level
Send logs
Set power supply level
Railway
Railway Simulation Controller
Station
Track Block
Lock / release
Fuel delivered
Departure / arrival
Signal on / off
Set speed
Set on / off
Start / stop
Train
Signals

DIESIS architectural approach

Scenario-oriented design: modelling phase

- Provide a formal, machine-readable representation of the informal model (a database or an ontology)

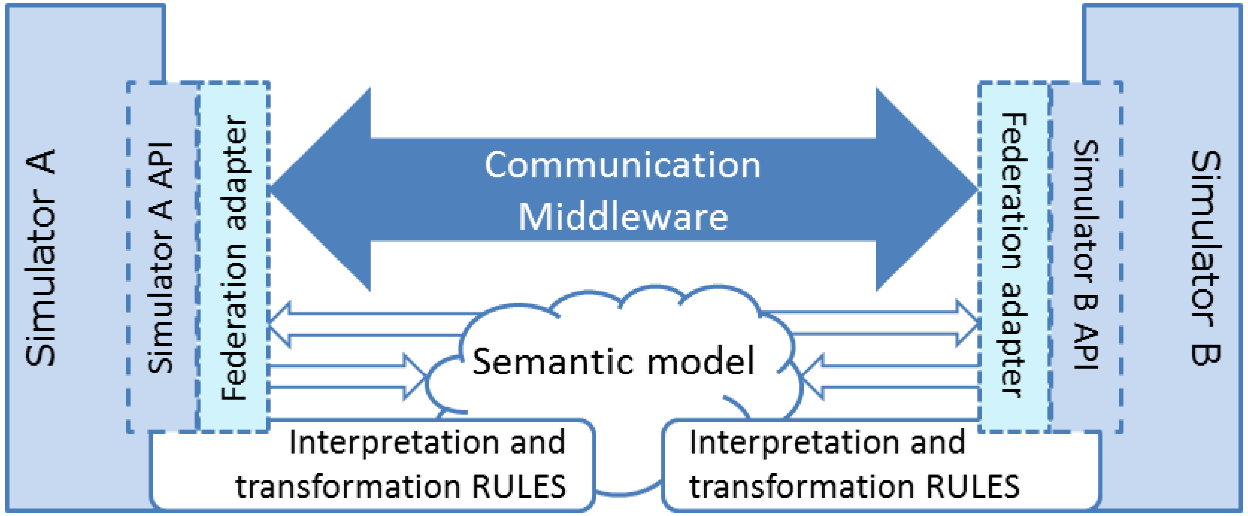
- Conceptual level: add all concepts for elements and relations (database schemata, ontology classes, etc.)
- Instance level: add concrete elements and relations
- Dynamic level: provide description of service behaviour

- Conceptual level: A *power station* provides energy for a *TelCo building*.
- Instance level*: TelCo building* **TB12** receives power from the *power stations* **P20m** and **P18m**.
- Dynamic level: Any kind of equipment inside a *TelCo building* is off if none of the *power stations* linked to it has a property *VoltageLevel* over 80% and the own backup power supply unit is discharged.

DIESIS architectural approach

Scenario-oriented design: implementation phase

- Implement all technological components (see service network)
- Implement communication layer or add interfaces to existing RTIs
- Implement federation adapters for all simulators
- Remove bottlenecks, optimise performance
- Validate simulation results



DIESIS architectural approach

Features and advantages

- Structuring of modelling and development in order to facilitate the process and to minimise efforts
- Modelling at federation level concerns only those elements that are relevant for dependency definition
- No deep insight into structure and behaviour of all (scenario-relevant) domains is required for modelling
- Flexibility: depending on desired results, particular simulators and models can be added, removed or replaced
- Reusability: technical components, models and concepts and can be utilised for various scenarios

Thank you for your attention!

Any questions?

Fraunhofer IAIS

CIPR Net

SEVENTH FRAMEWORK PROGRAMME

CIPRNet

Critical Infrastructure Preparedness and Resilience Research Network
www.ciprnet.eu

Introduction in OpenMI

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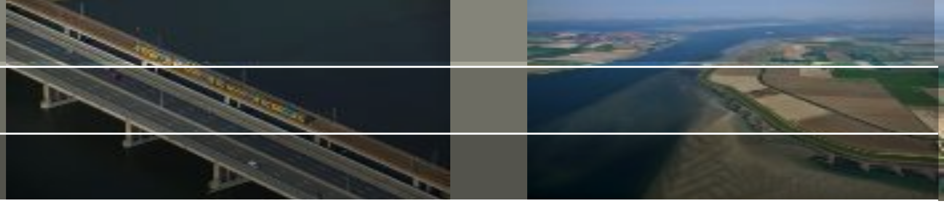
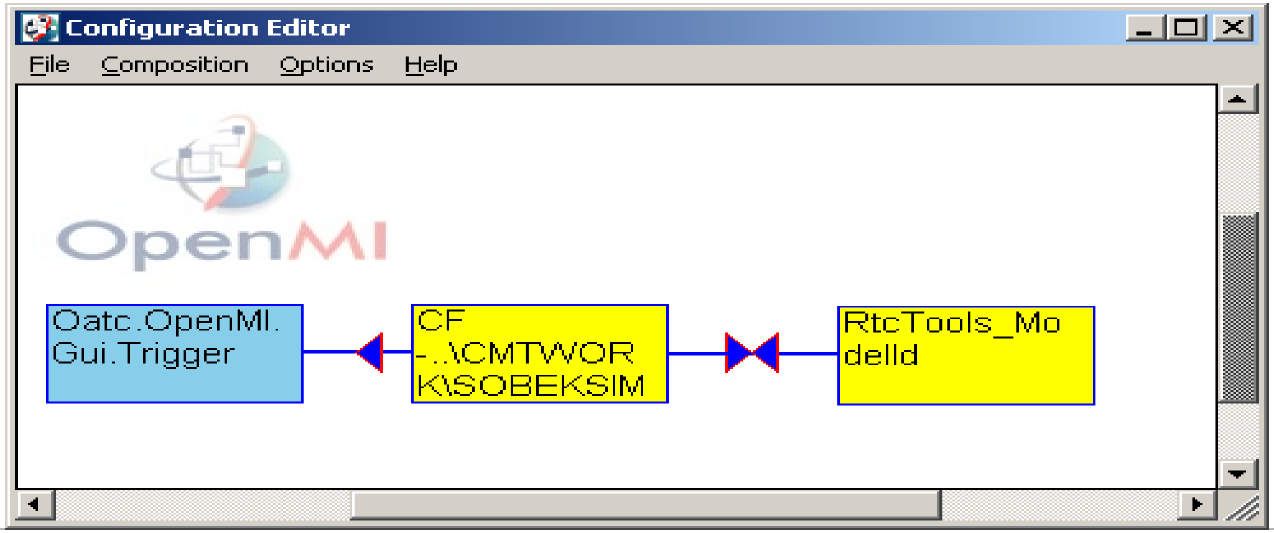


What is OpenMI?

OpenMI is an open model interface standard for hydro-related models developed by the OpenMI Association

- Designed for water-related models
- For legacy code and new code
- Data-exchange during runtime per time step
- Open source
- Used already by several institutions (Deltares, DHI, BAW, RWTH Aachen University, Université de Liège, US Geological Survey, ...)



example:
RTC-Tools and Sobek in the OpenMI configuration editor

Deltares

OpenMI history

HarmonIT - OpenMI v1.0

- OpenMI was developed by 14 organizations from 7 countries in the EU-project HarmonIT in order to facilitate the simulation of interacting processes, particularly environmental processes
- the first version has been released as the OpenMI Standard v1.0 (.Net version)

OpenMI-Life - OpenMI v1.4

- Further development has been performed in the OpenMI-Life project with a consortium of 10 partners from 5 countries
- release of v1.4 (.Net, Java), foundation of the OpenMI Association

Released - OpenMI v2.0

- Several new features are introduced, including a more flexible way of linking, more flexibility in the overall control flow, less difference between temporal and spatial models
- A new user interface (GUI) and a software development kit (SDK) allow users to make their models 2.0 compliant

When to apply OpenMI?

Coupling of models of different processes

- one model for each process
- both processes are of similar relevance
- processes on different time scales

Coupling of models of the same type

- models belong to different institutions
- models are used coupled and uncoupled (maintenance, calibration, local studies)

A quick comparison

- OpenMI: data exchange during runtime per time step
- Delft-FEWS: data exchange after run for a simulation period

Different Types of Coupling

Simultaneous coupling

- the highest level of model coupling
- different processes, including their interactions, are represented in one equation system

Iterative coupling

- exchange data between models during runtime in two directions and iterate the exchange of data until a certain convergence criterion is achieved

External coupling

- data exchange per time step, successively, but without iterations.

→ OpenMI supports iterative coupling and external coupling.

Who should apply OpenMI?

“The long term aim is that the OpenMI should become the European and global standard for model linking in the environmental domain.” (from the OpenMI-life website)

Researchers that develop source code for their studies

- research code can be coupled with OpenMI compliant models

Developers of integrated (hydrological) modelling tools

- coupling of surface/subsurface flood models

Consultants that need dedicated model coupling

- flexible, standardized coupling technique
- use the OpenMI standard for more than one coupling task

Multidisciplinary studies

- CIPRNet - coupling of CI models

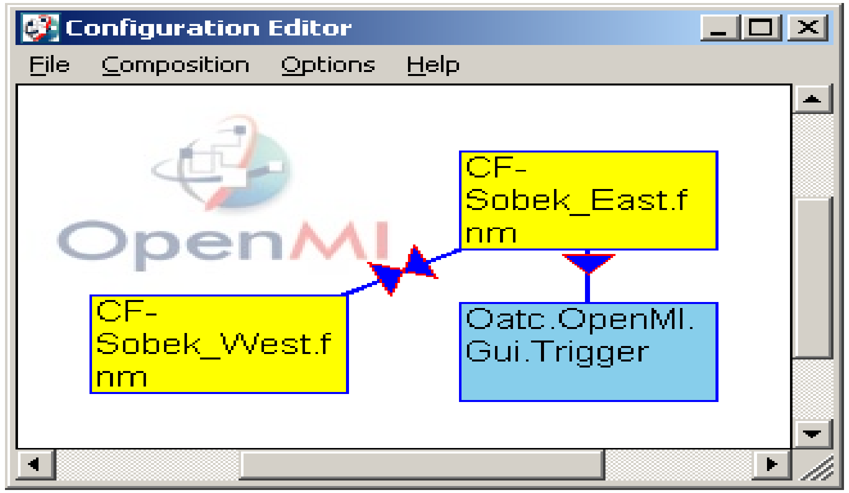
Setting up an OpenMI-Composition

omi-file: the OpenMI-Compliant Component

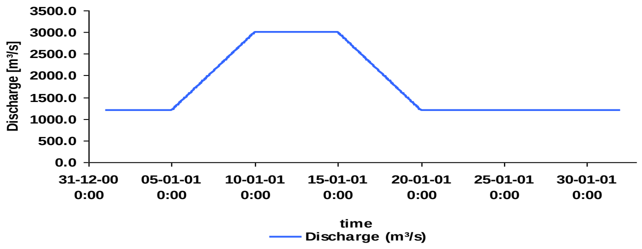
- Where is the DLL with the computational core and OpenMI-Interface?
- Where are the input files?
- What else? (Command line arguments)

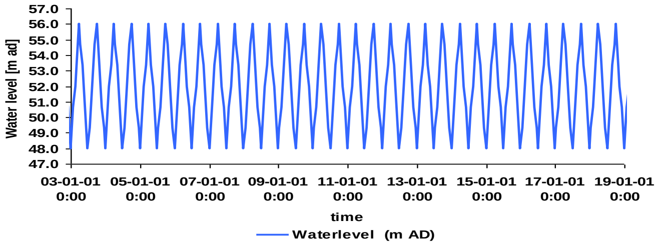
opr-file: the OpenMI-Composition

- Which components (i. e. models)?
- How coupled?
- Which simulation period?
- Where is the Trigger linked with?

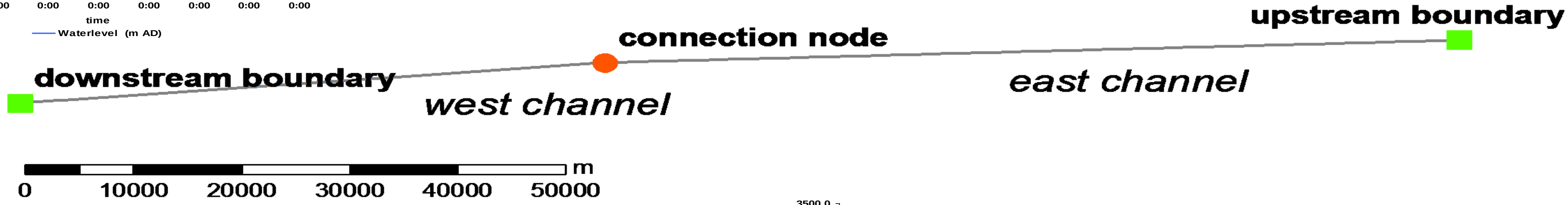


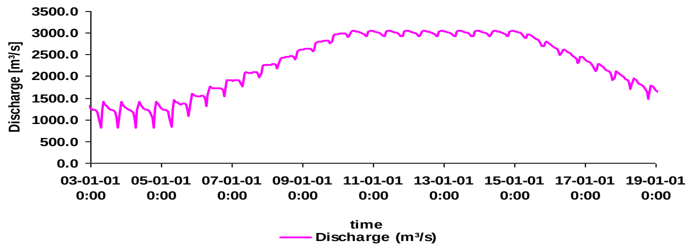
Example case: Sobek-West ←→ Sobek East

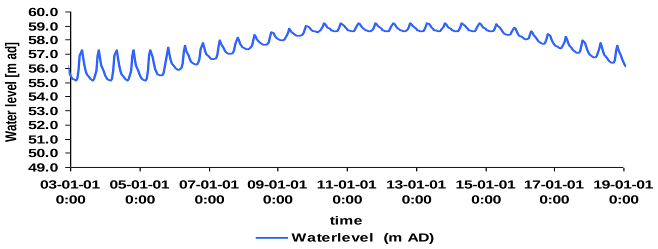




sub-model "channel west"			sub-model "channel east"	
input	discharge	←	output	discharge
output	water level	→	input	water level



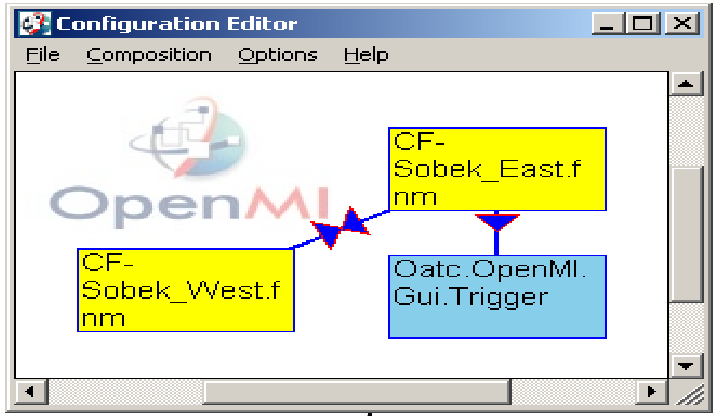




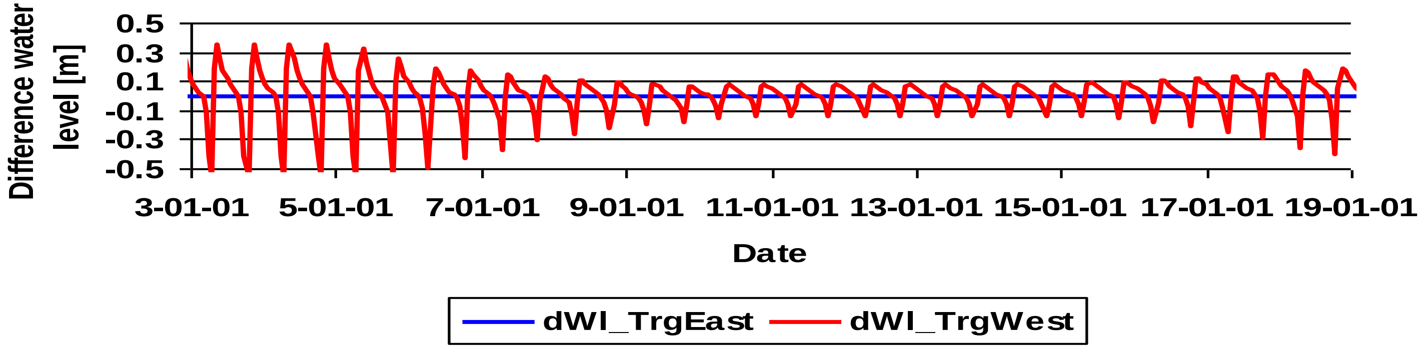
Exchange of results and boundary conditions between multiple models

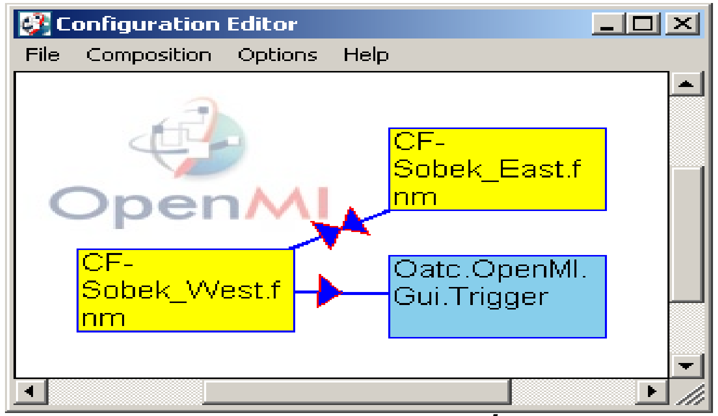
Deltares

External coupling (time-lagged coupling)

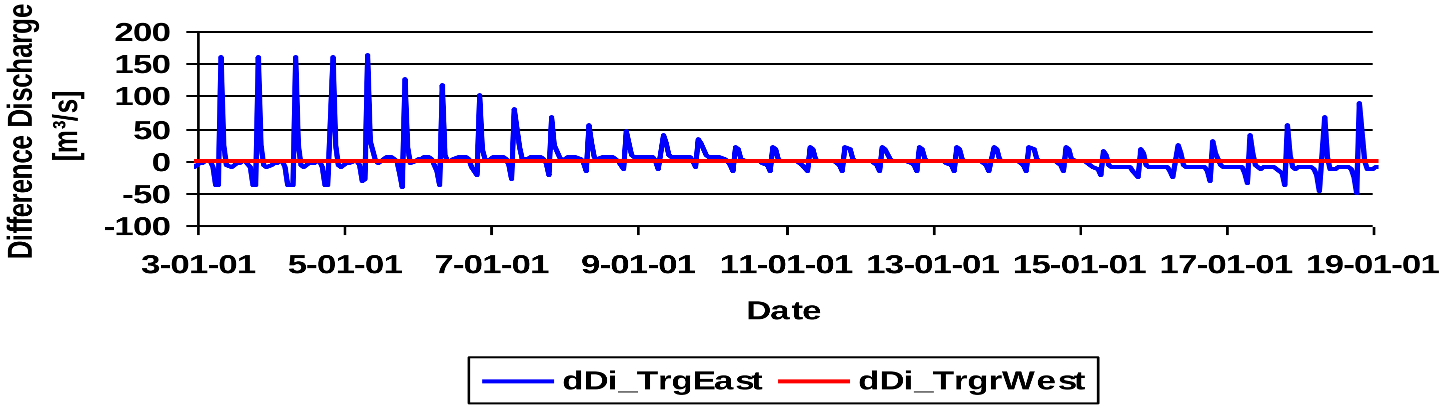


mass conservation



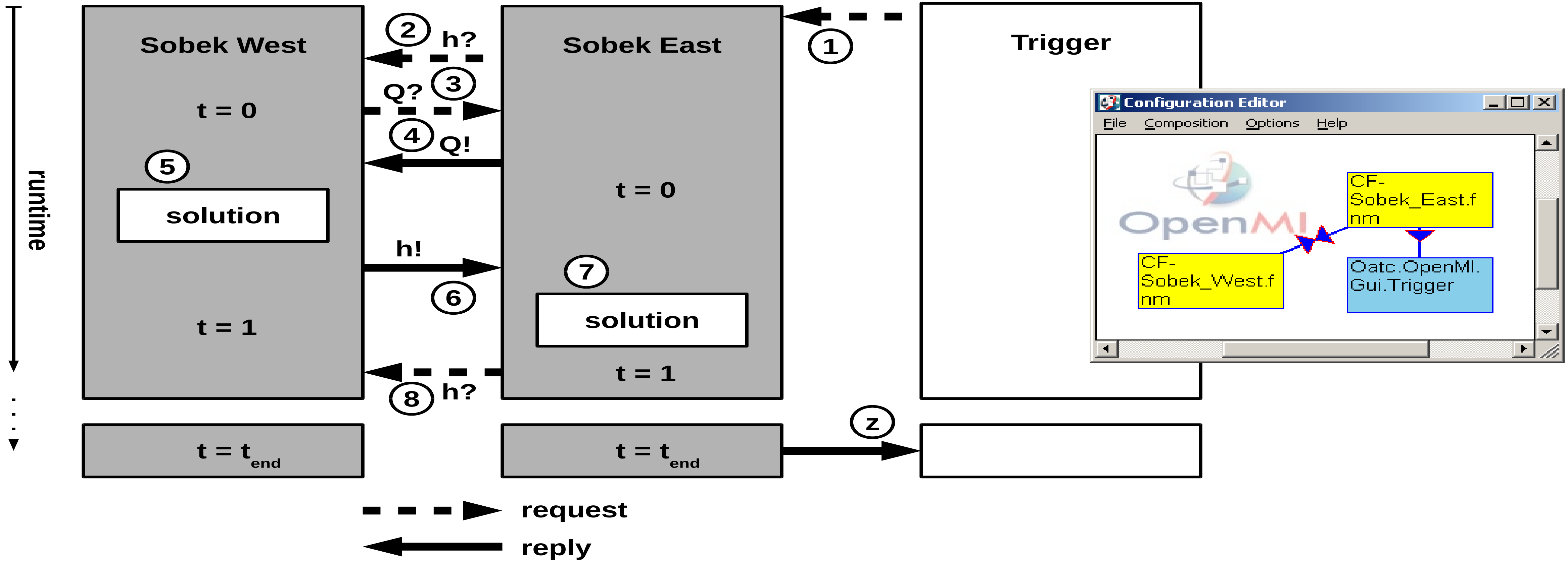


momentum conservation



Position of the trigger impacts the result
external coupling has a time lag

Request-reply-mechanism



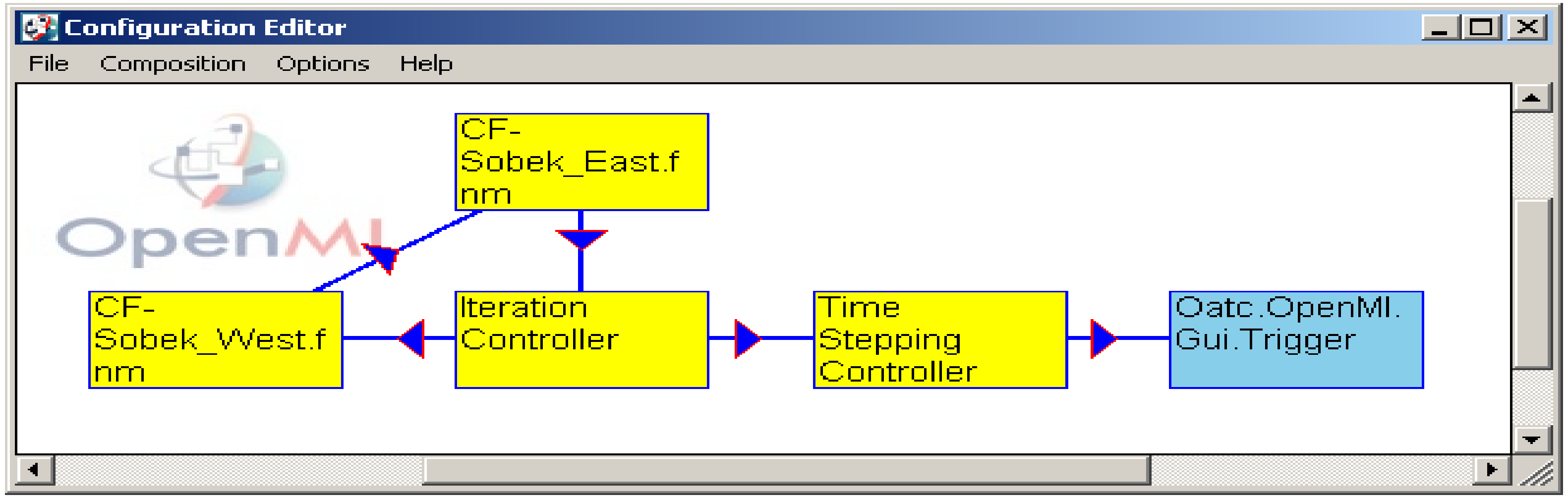
The model component that asks first computes last.

The model that asks gives the guess.

The quantity which is computed first has the same value in both of the models.

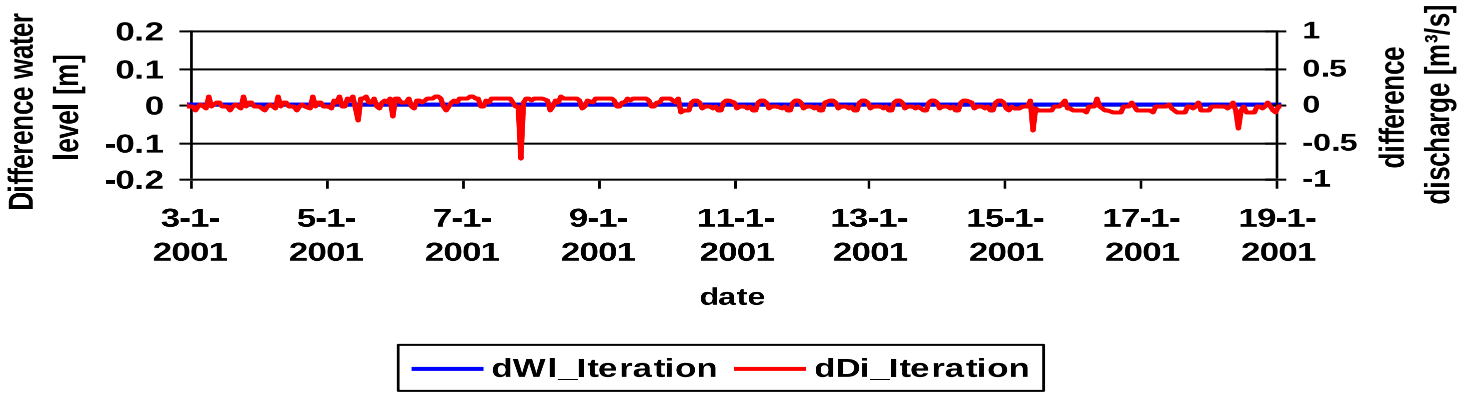
Iterative coupling

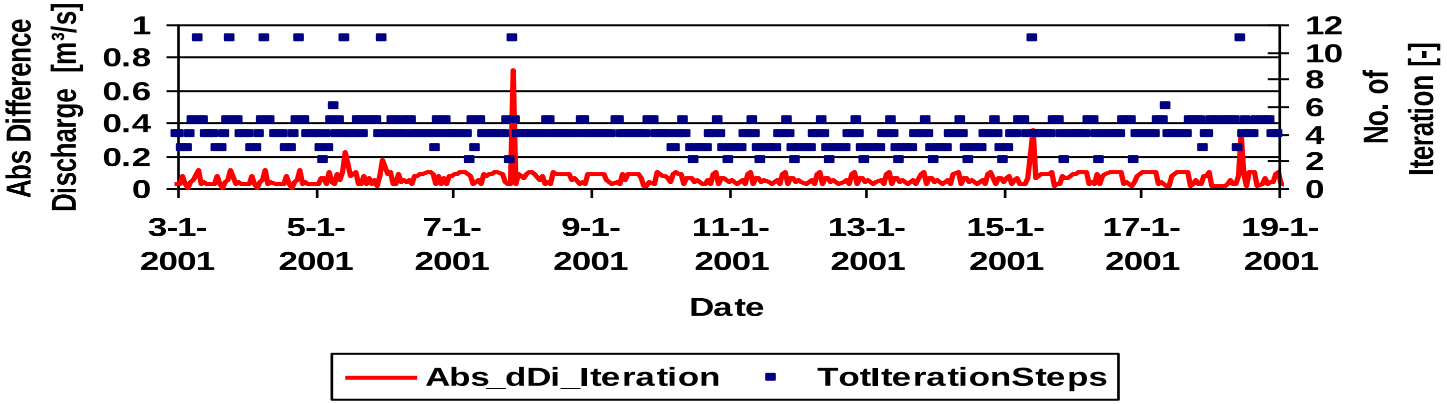
OpenMI compliant component “iteration controller”



objective: reduce difference in discharge by iteration
better momentum conservation
maximum 12 iterations per time step or dQ < epsilon = 0.01

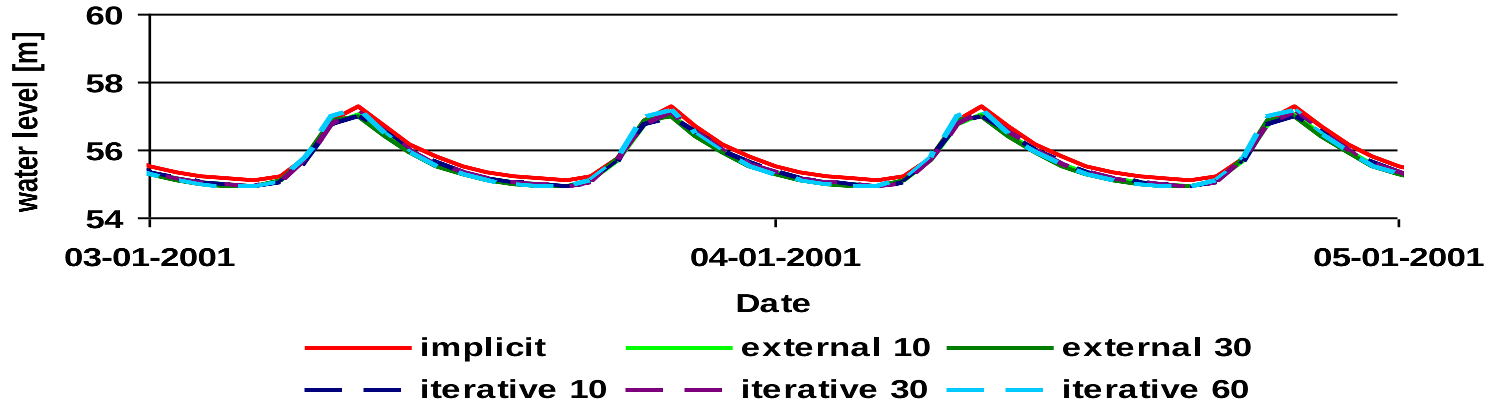
Iterative coupling

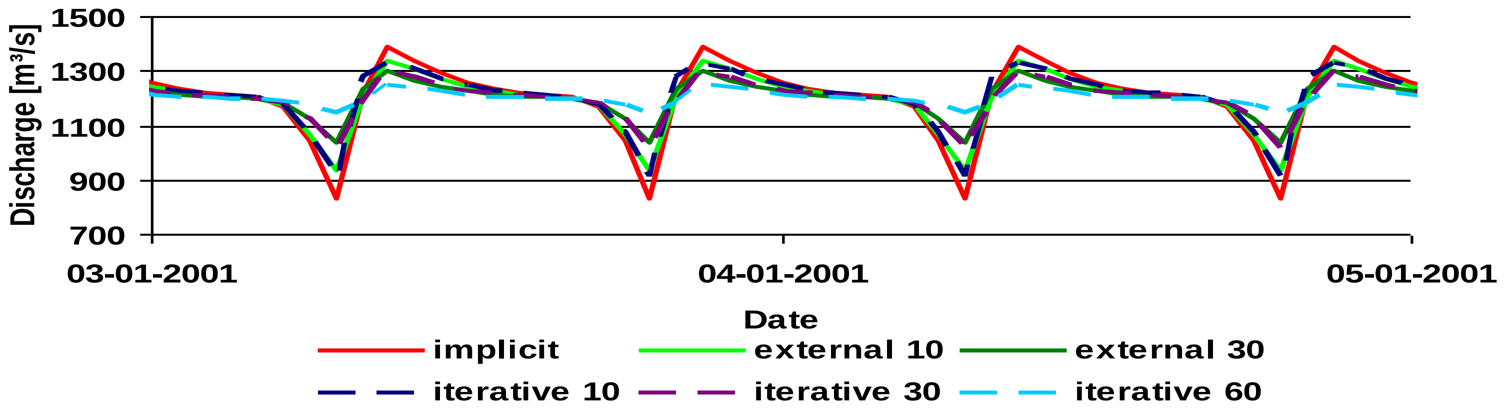




Iteraties increase accuracy by repeating data exchange per time step

Iterative and external coupling: test case results





coupling method (min)	computing time
ternally coupled (10)	30 s
externally coupled (10)	27 s
externally coupled (30)	14 s
externally coupled (30)	12 s
iteratively coupled (10)	192 s
iteratively coupled (30)	50 s
iteratively coupled (60)	43 s
implicit solution	3 s

External coupling as accurate as iterative coupling, but more controllable and less computational expensive

Deltares

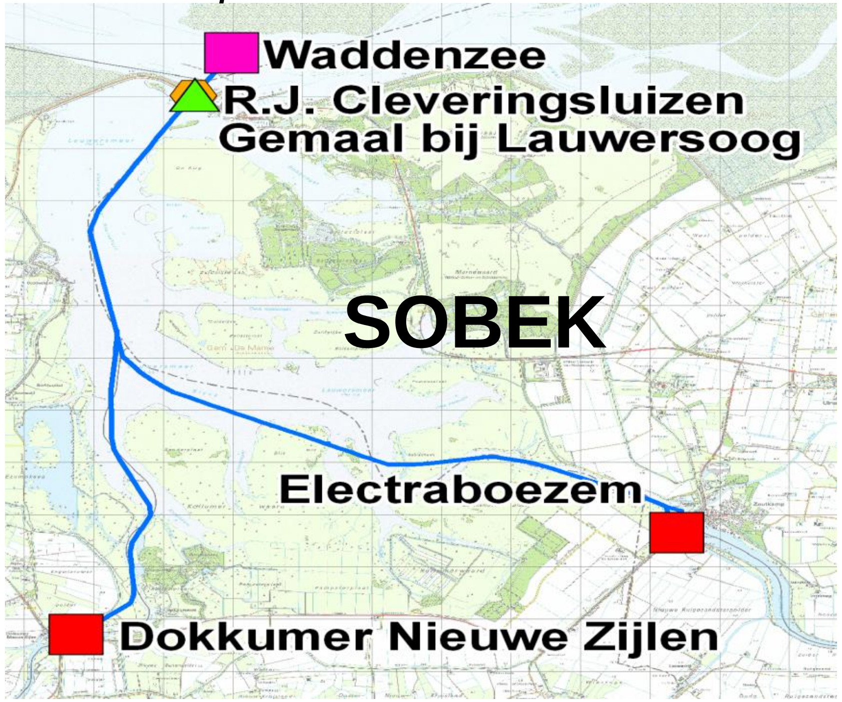
Example: SOBEK ←→ WANDA

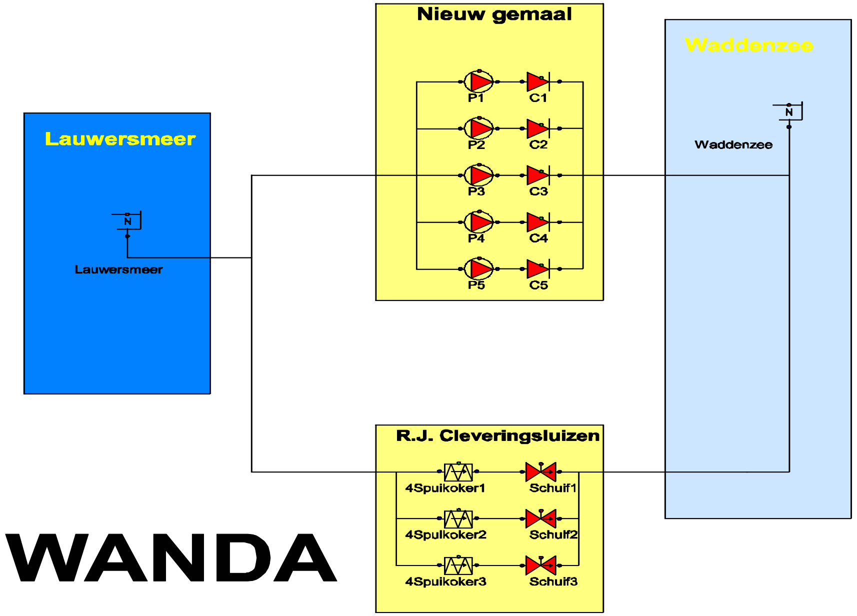
Design of a pump station for lake Lauwersmeer (the Netherlands)

- more extreme rainfall events and rising sea level expected
- drainage of polder areas must be facilitated with a pump station

open channel flow

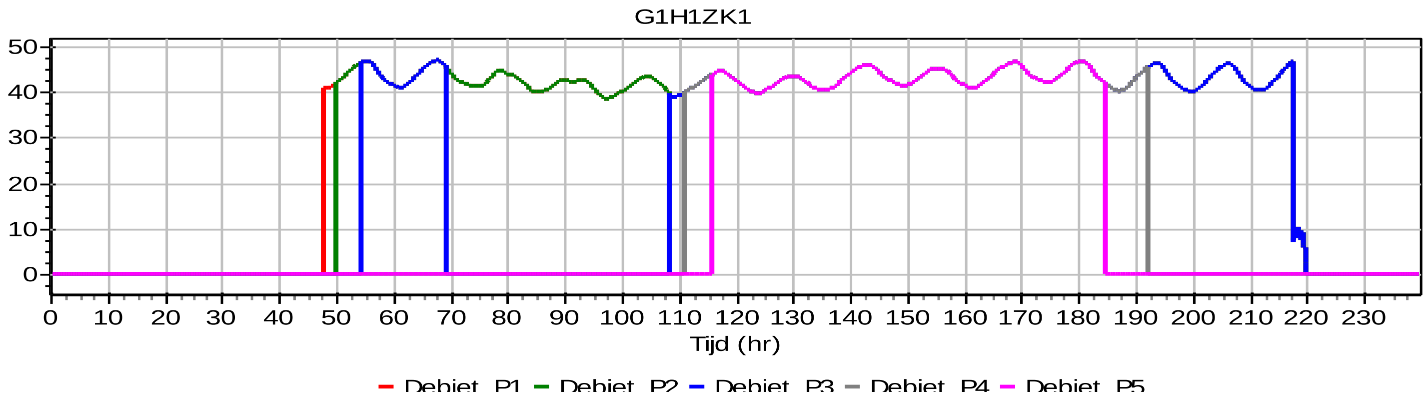
pump and sluice hydraulics



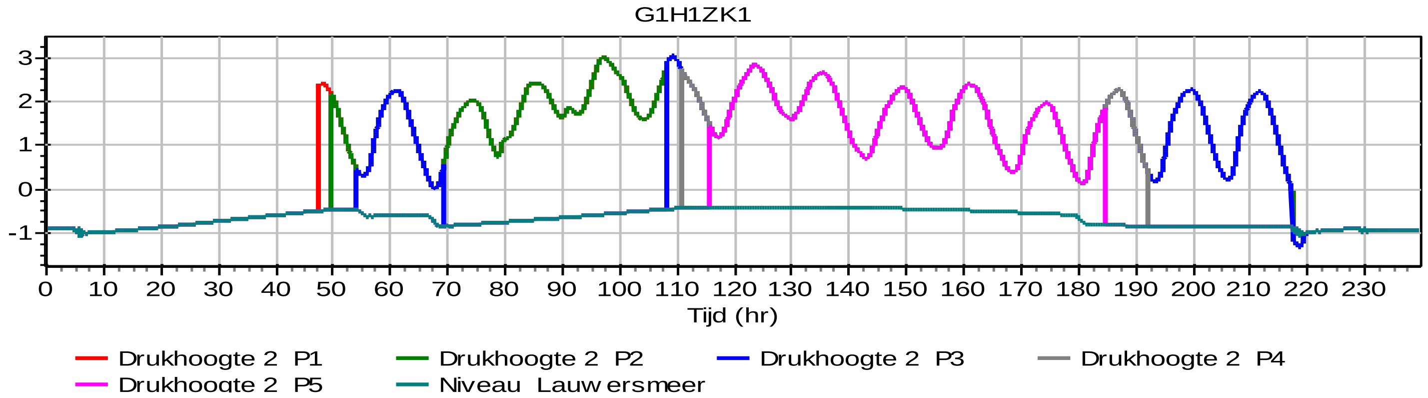


Deltares

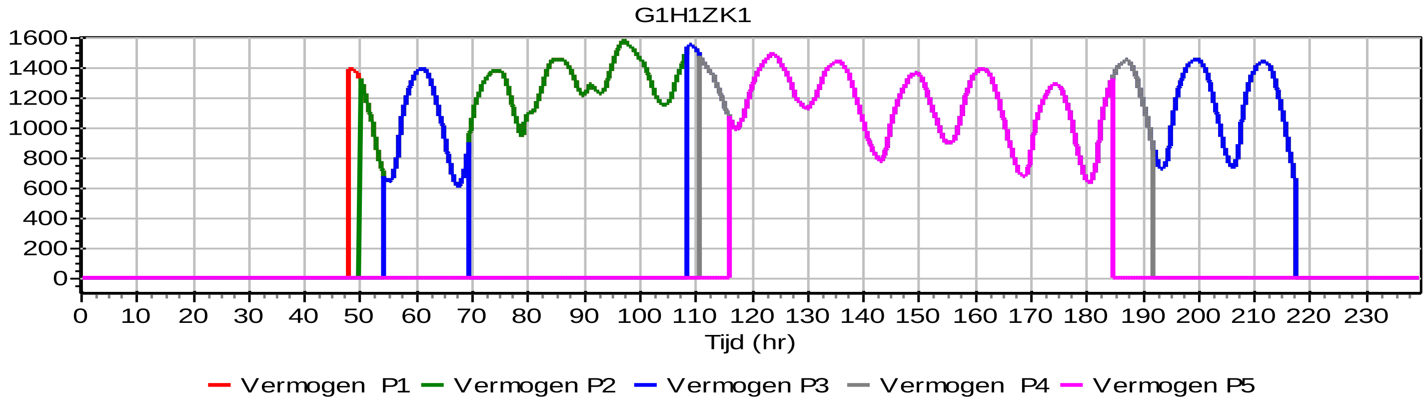
Example: SOBEK ←→ WANDA (2)



discharge from WANDA for SOBEK



Pressure head from SOBEK (tidal influenced)



power consumption from WANDA for design

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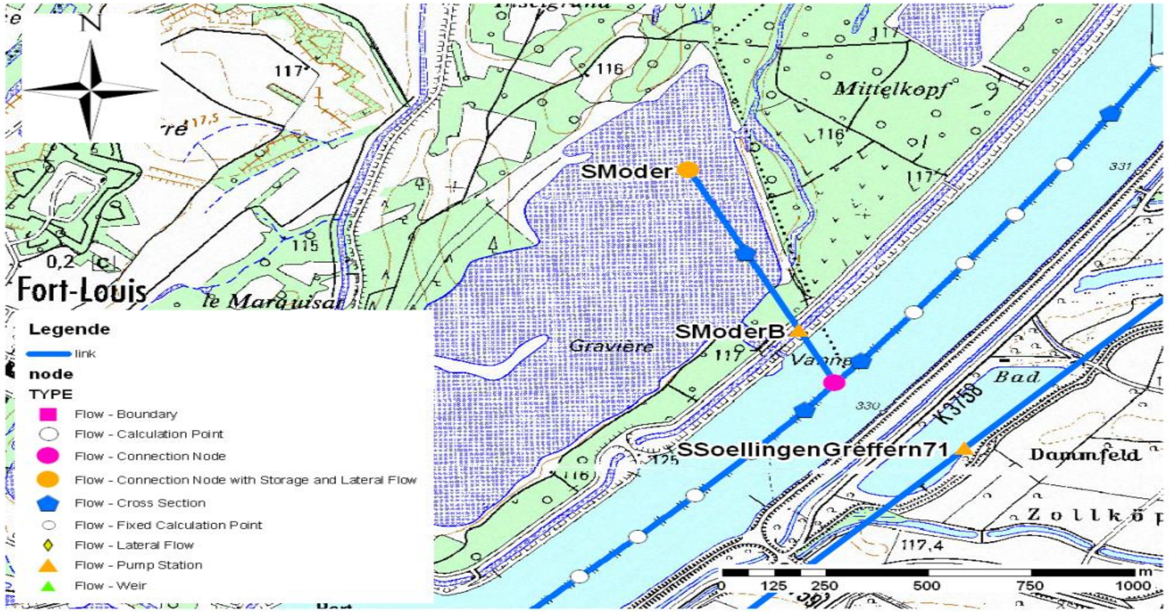
Example: SOBEK ←→ RTC-Tools

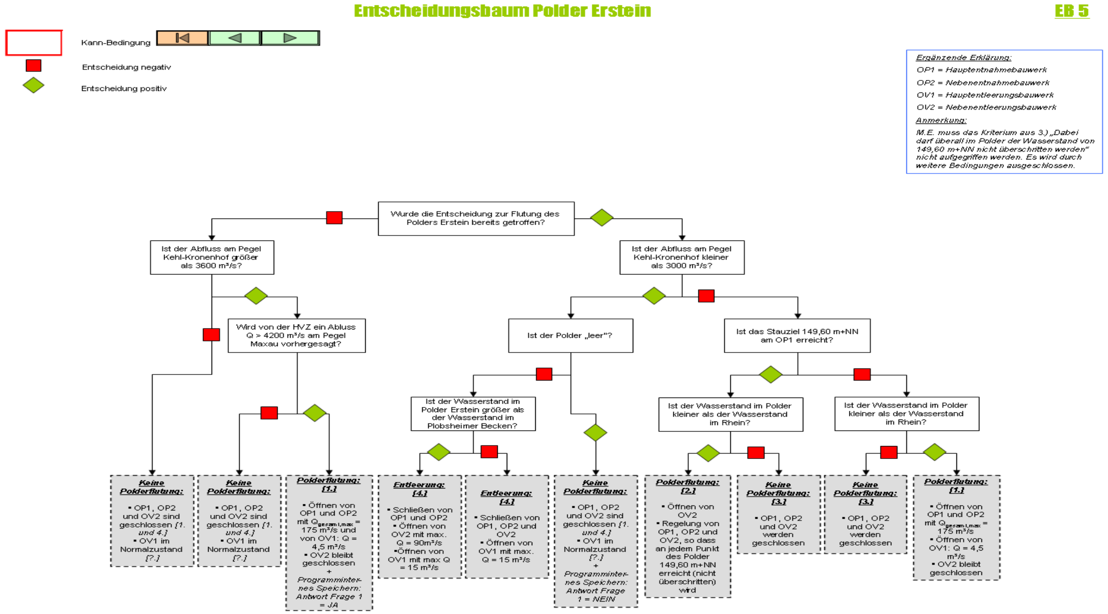
Control of the Oberrhein (upper Rhine) water system:

Decision tree and open channel system

SOBEK: open channel flow

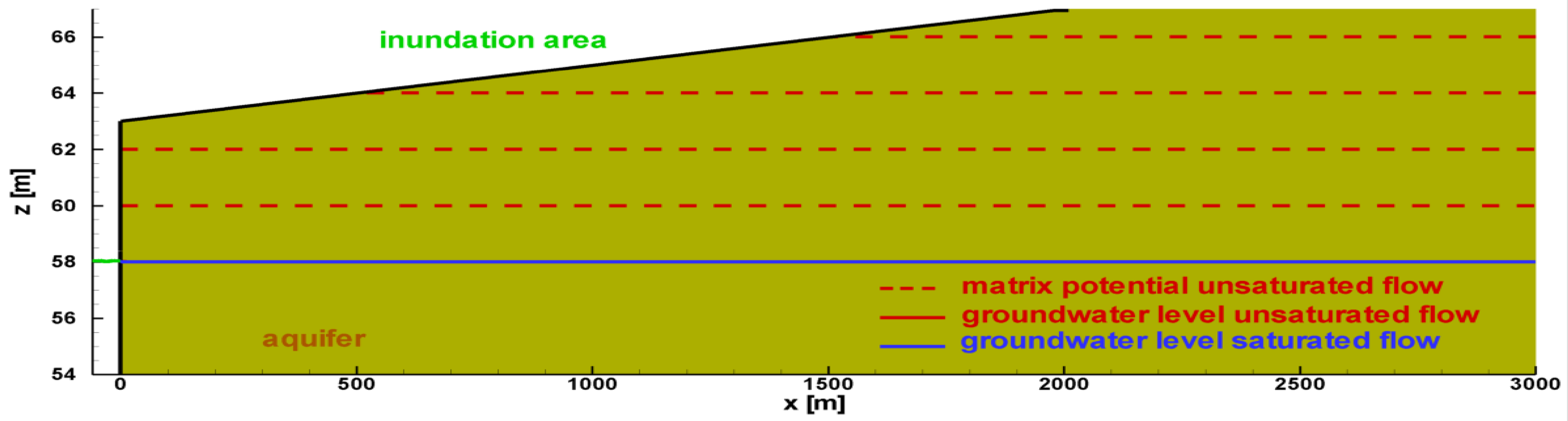


RTC-Tools: human operations (control)



Sobek		RTC-Tools
Channel flow (Q, h)	→	**Water system state**
Control parameter	←	**Control parameter (crest level, turbine discharge)**

Example: Ilmoflood ←→ Feflow

Simulation period: 14 days

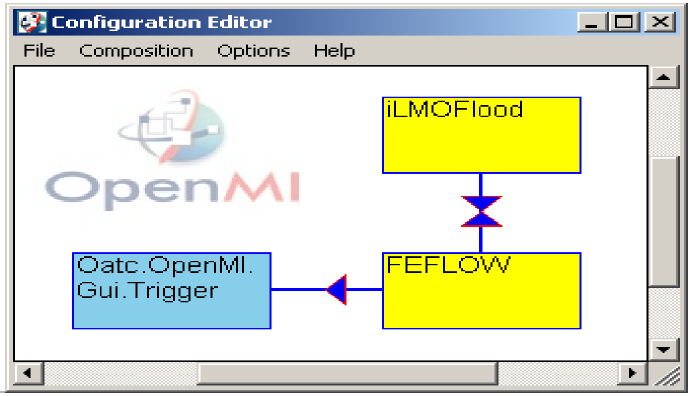
Two coupled simulations:

Ilmoflood ←→ Feflow saturated

Ilmoflood ←→ Feflow unsaturated

coupling:

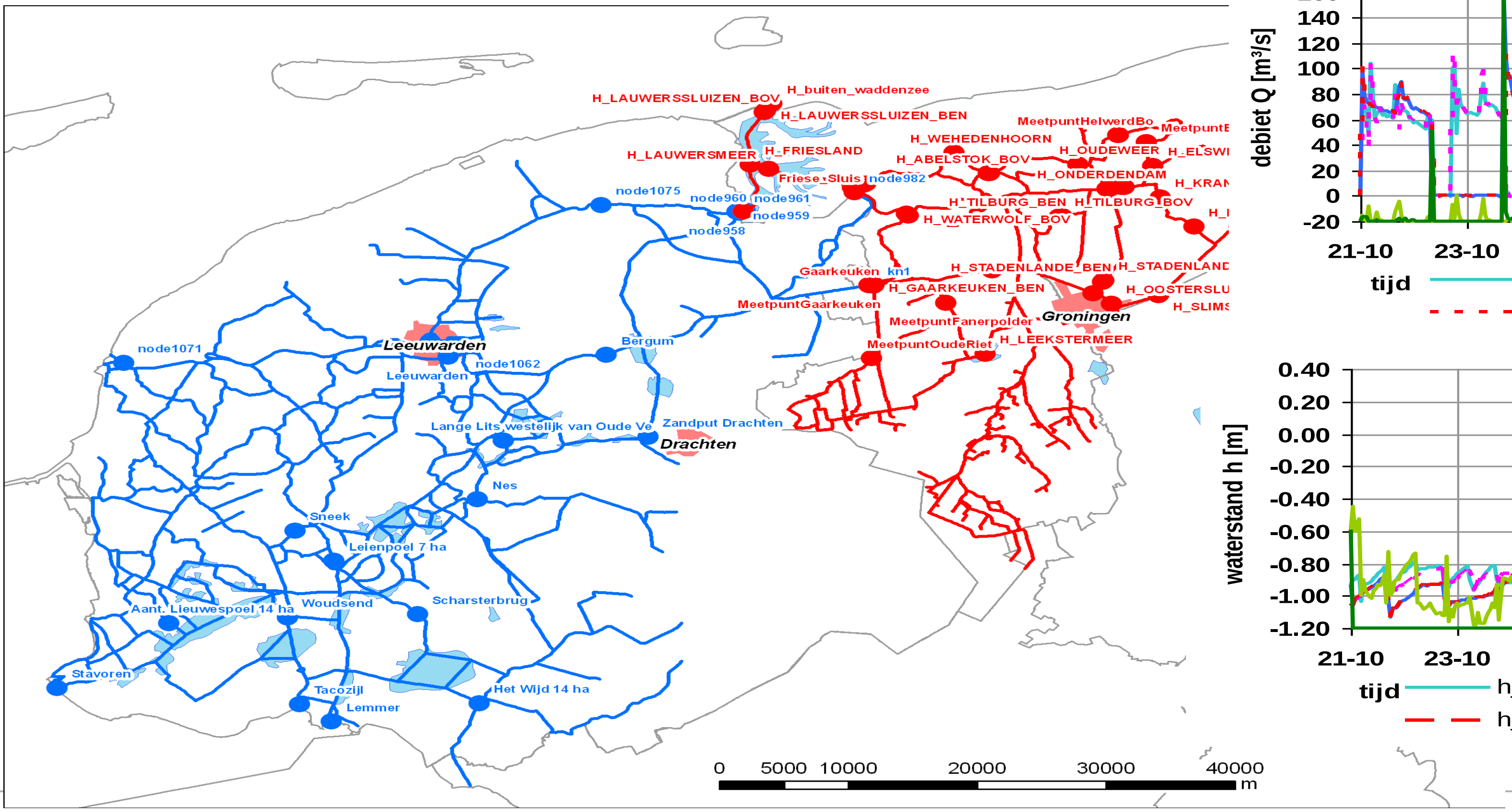
Ilmoflood		Feflow
head	→	**leakage**
flow	←	**flow**

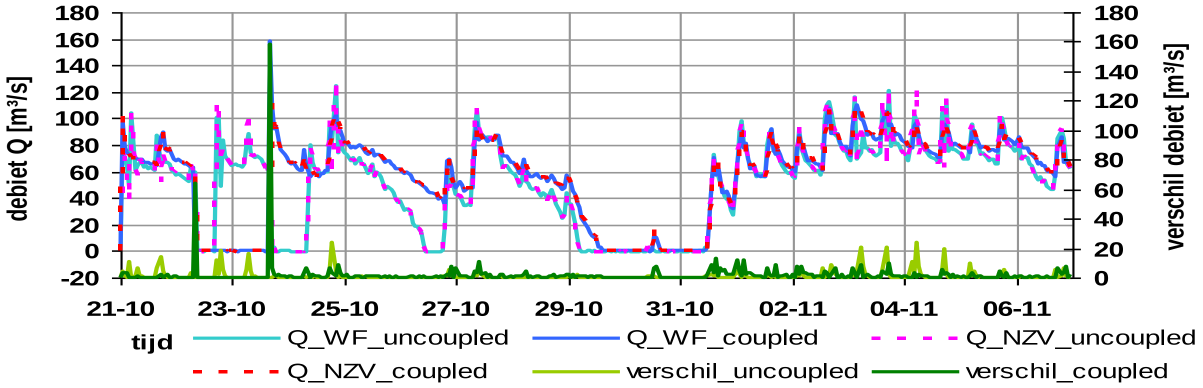


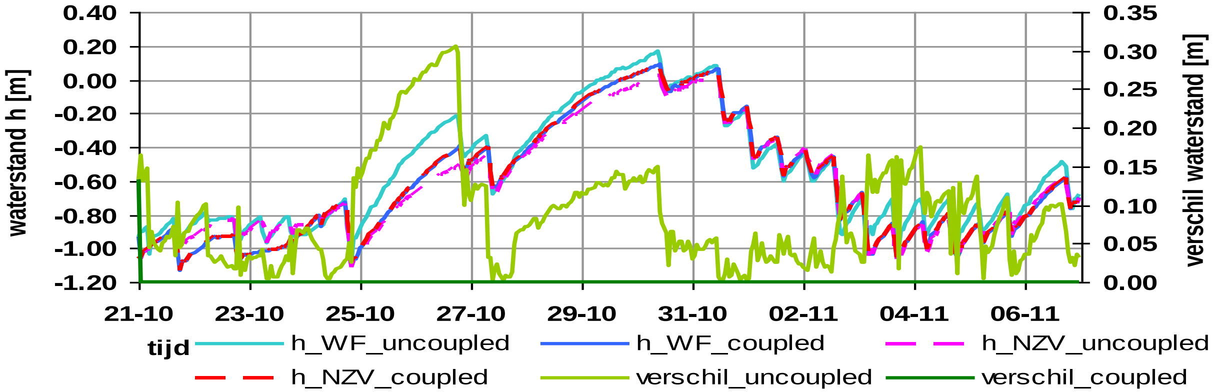
Example: Boezemmodellen

Boezemmodellen Wetterskip Fryslân and Noorderzijlvest coupled at three connection points

One water system, two water authorities

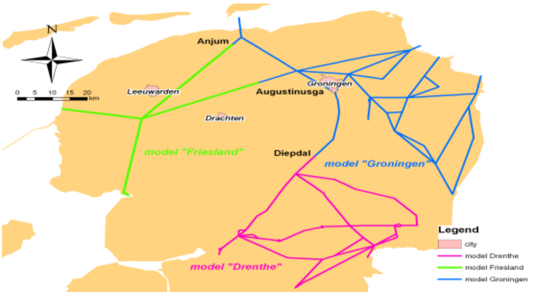


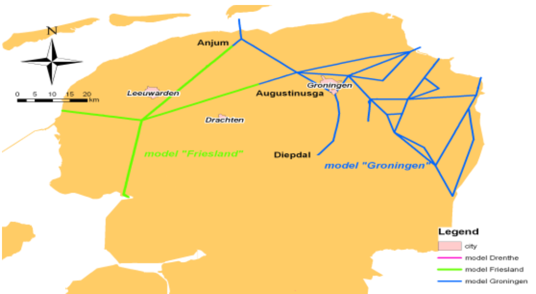


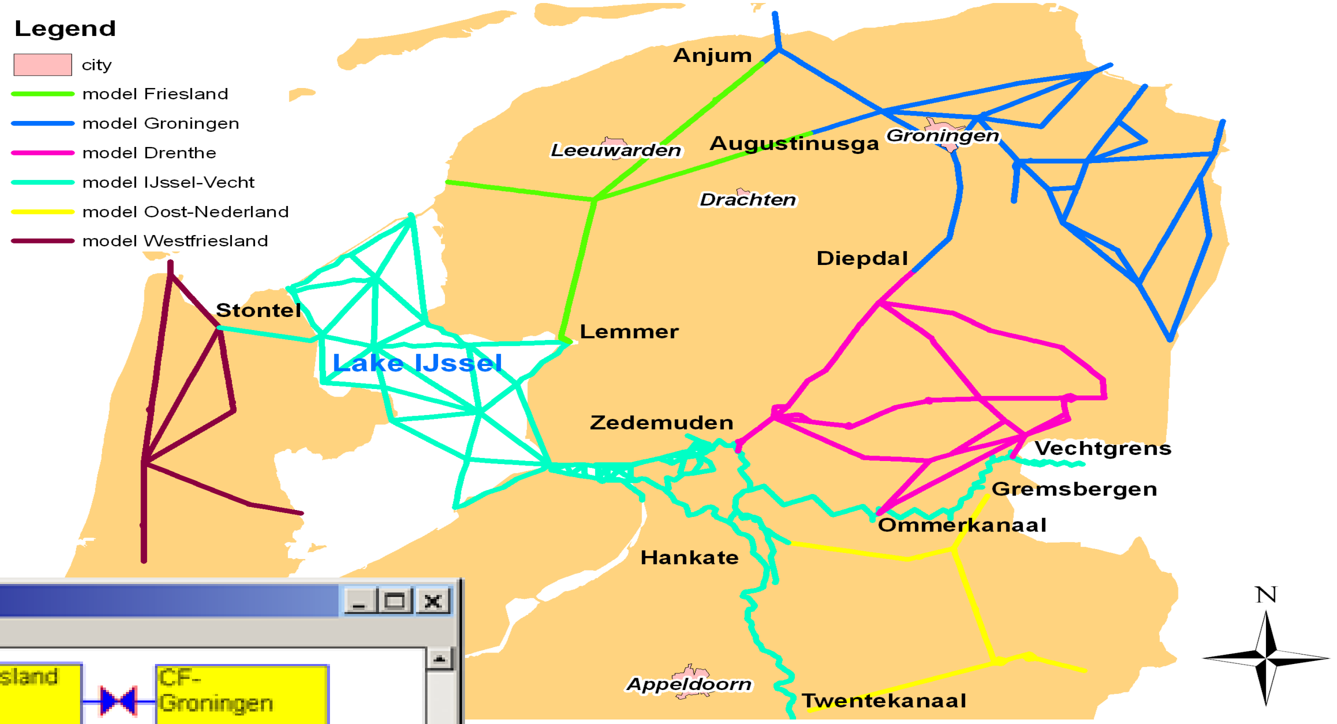


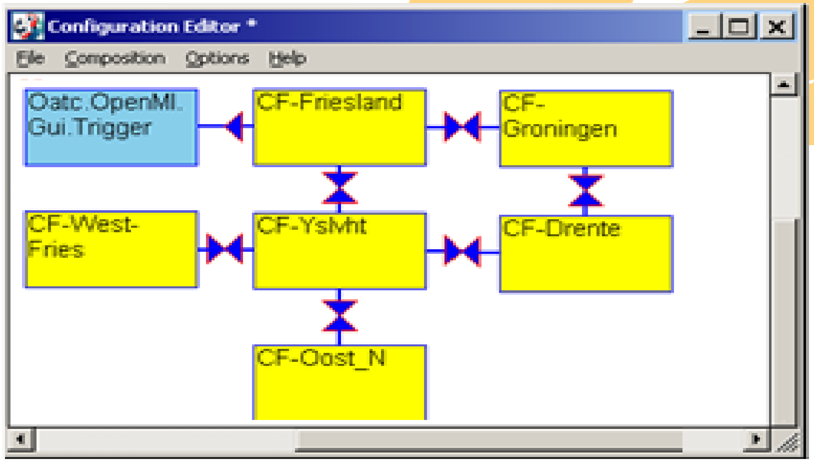
Dutch Large Scale SOBEK model

From 2 to 6 model coupled:

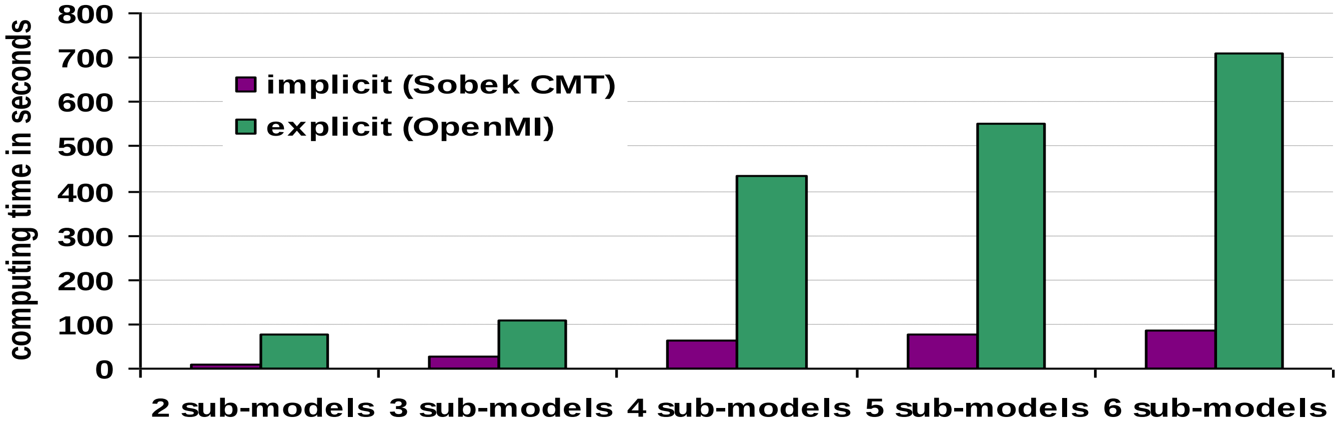








Dutch Large Scale SOBEK model

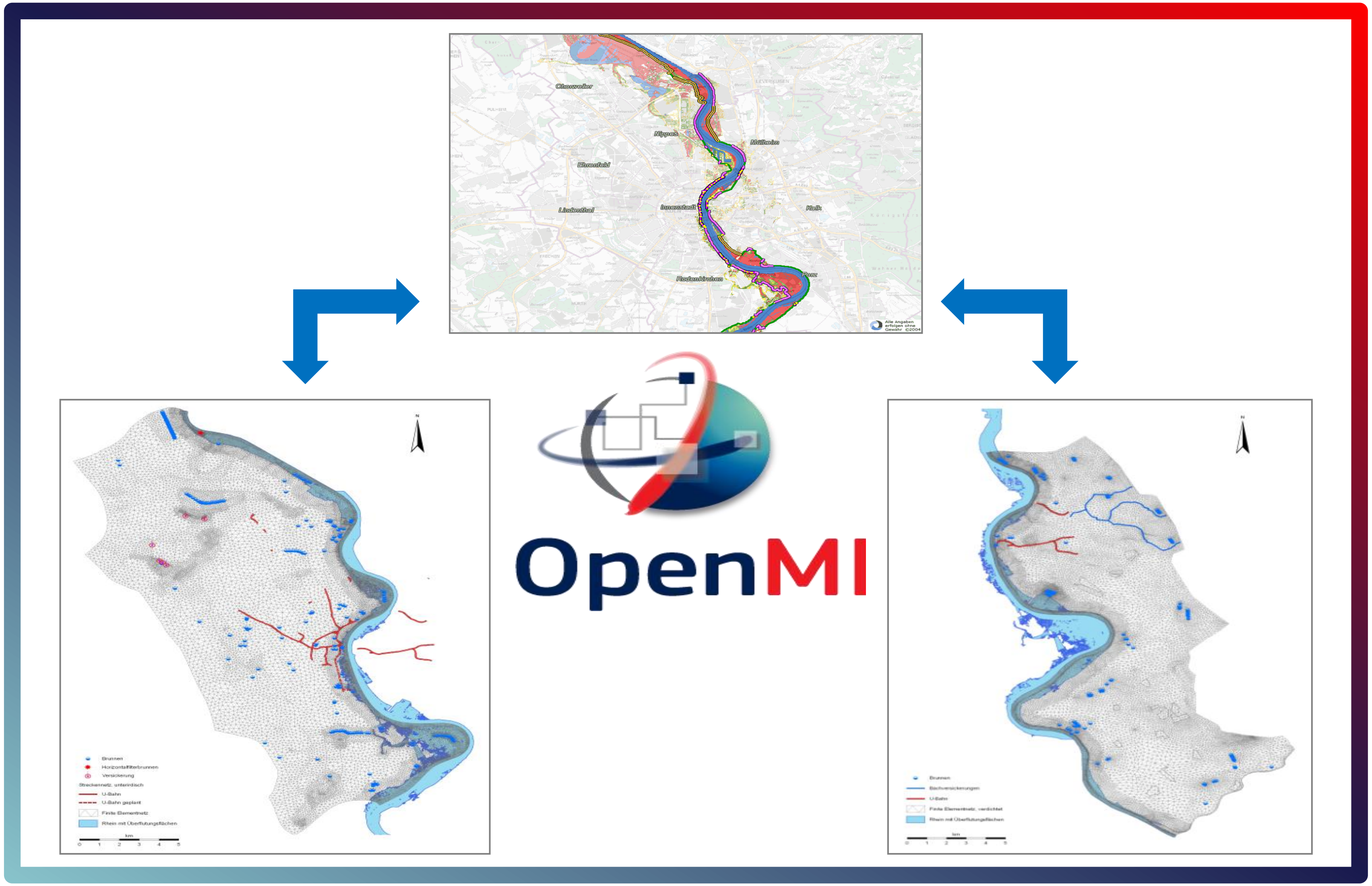


- Water level differences: less than 3 cm
- Discharge differences: less than 1 m^3/s
- Computational effort of explicit coupling increases disproportionally with the number of sub-models

→ implementation of OpenMI standard into Sobek has high potential to increase performance

Deltares

Cologne: subsurface flood hazard modelling



Models

Surface water:

Sobek (Deltares)

Groundwater:

Feflow (DHI-Wasy)

Project contractor

RWTH Aachen University

Deltares

Some things to be considered …

Different exchange items for different coupling tasks

- surface water – subsurface water interaction: grid-based
- rainfall-runoff – channel flow: node based

State-of-the-art code performs better than legacy code

- RTC-Tools (direct access) vs. Sobek (client-server-technique)

Delft-FEWS is *not* model coupling in terms of OpenMI

- FEWS: sequential coupling
- OpenMI: online-coupling on time-step basis, parallel / simultaneous simulation

OpenMI 2.0 provides a loop approach (kind of parallel coupling)

Outlook

High potential for coupled flow simulation across

- country borders (e.g. Germany, The Netherlands)
- institution borders (two neighboured water authorities)
- software producer borders (Deltares-DHI, Deltares-Alterra)

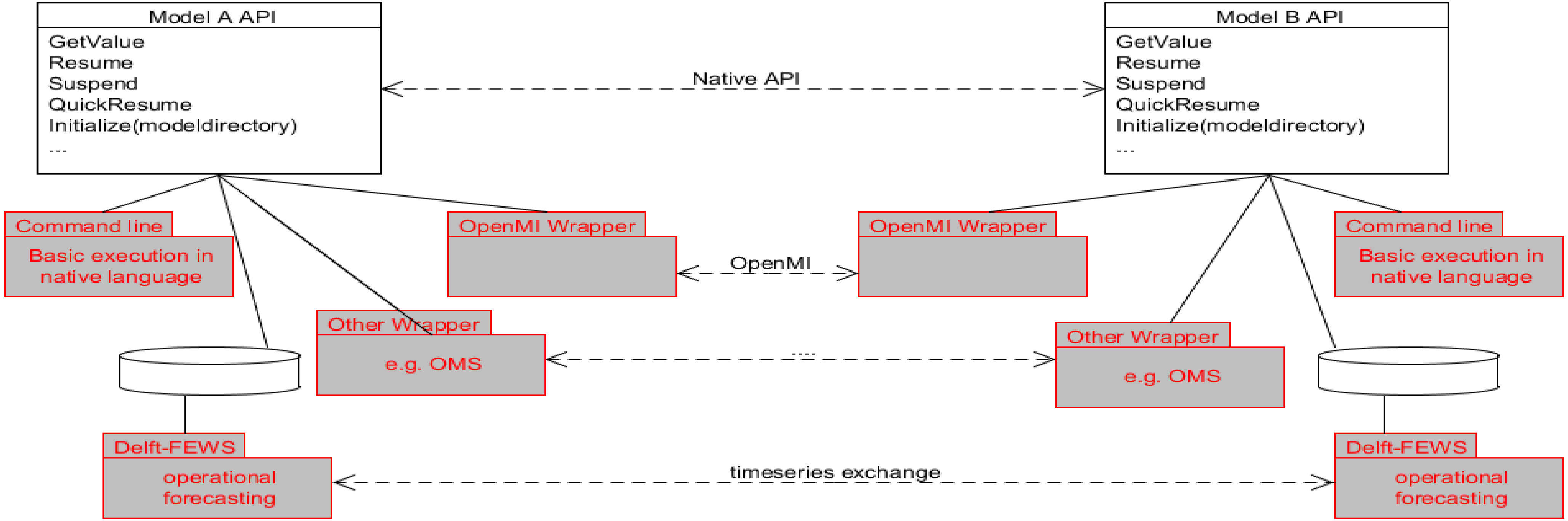
For coupled processes model coupling is already frequently applied:

- DeltaShell, Sobek 2, OpenStreams …
- OpenMI-coupling can be a first step for more: RTC-Tools is now integrated in DeltaShell

Next steps:

- Bring the OpenMI technique to consultants, universities and other disciplines
- Get further on-the-job-experience with OpenMI 2.0
- OpenMI - CIPRNet workshop during the Delft Software Days on 27th October 2014

Current projects: OpenStreams



Further reading

OpenMI Association (www.openmi.org)

- general information about OpenMI and the OpenMI Association
- download and documentation of OpenMI 1.4 and 2.0

Deltares OpenMI public wiki (publicwiki.deltares.nl)

- documentation, how-to tutorials

Publications

- …
- …
- …

Appendix

Appendix

OpenMI-compliant components and experts

OpenMI compliant components

(selection)

- Sobek 2 (Deltares)
- Sobek 3 (Deltares)
- Modflow (USGS)
- Wanda (Deltares)
- Feflow (DHI-Wasy)
- WFLOW (Deltares)
- RTC-Tools (Deltares)
- Waqua (Deltares)

…

Deltares colleagues with OpenMI-experience

Software developers

- Stef Hummel
- Peter Gijsbers
- Edwin Spee
- Gennadii Donchyts
- Bert Jagers

Modellers

- Bernhard Becker
- Jan Talsma
- Quanduo Gao
- Neeltje Goorden
- Geert Prinsen
- Juzer Dhondia
- …

Deltares

CIPRNet

Critical Infrastructure Preparedness and Resilience Research Network
www.ciprnet.eu

Conjunctive modelling with OpenMI

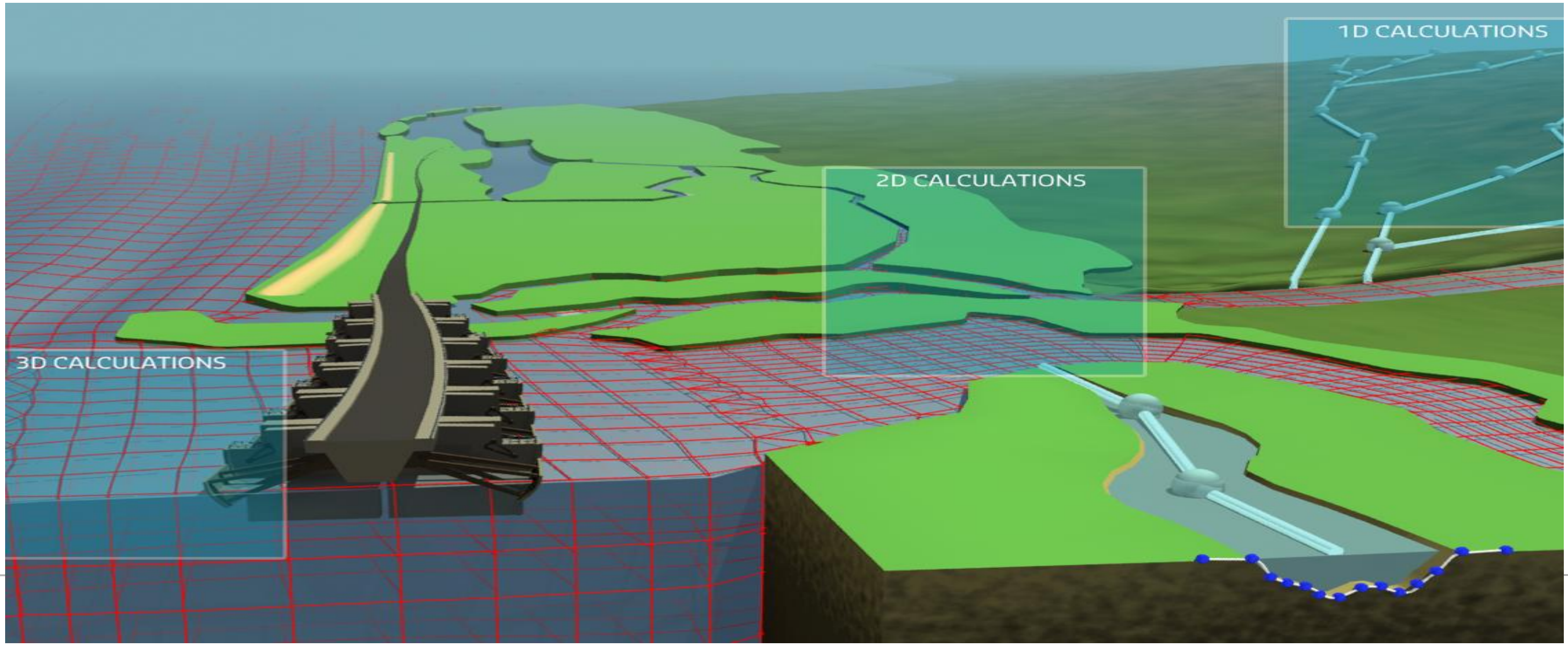
Andreas Burzel and Bernhard Becker (Deltares)
andreas.burzel@deltares.nl | bernhard.becker@deltares.nl

Modelling, Simulation and Analysis of Critical Infrastructure
Training School (Edition 0)

Deltares Headquarters – Delft (The Netherlands) – 3-4 February 2014

What is a model?

Conceptual model: How does a system operate?
Mathematical model: A set of equations
deterministic (physics-based) – empirical – logical
Computer model: Coded equations
Generic model: Simulation software (GUI, input, output)
Site-specific model: Generic model + site-specific data



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What is conjunctive modelling?

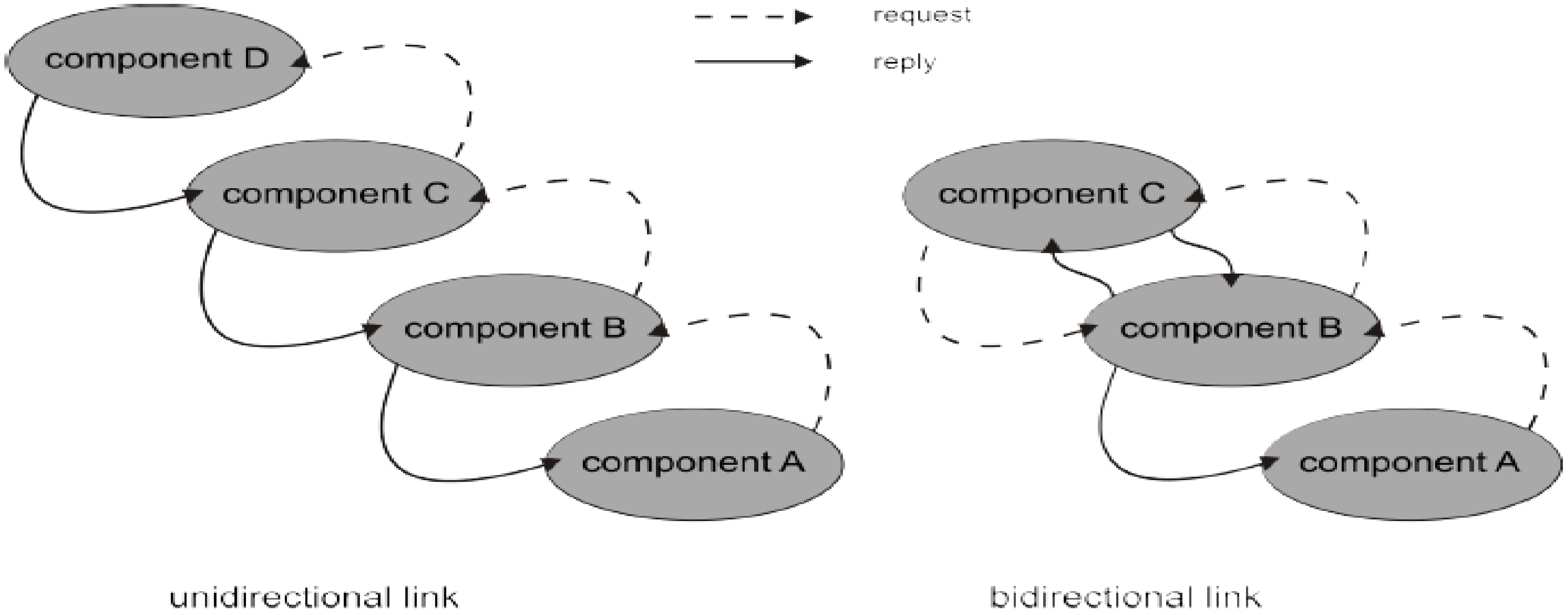
Conjunctive modeling:

- link models to model process interaction

Coupled modeling:
- data transfer in two directions.
- requires data exchange on a time step basis

Uncoupled conjunctive modeling:
- data transfer in one direction
- not necessarily o n a time step basis.

Unidirectional and bidirectional coupling



uncoupled coupled

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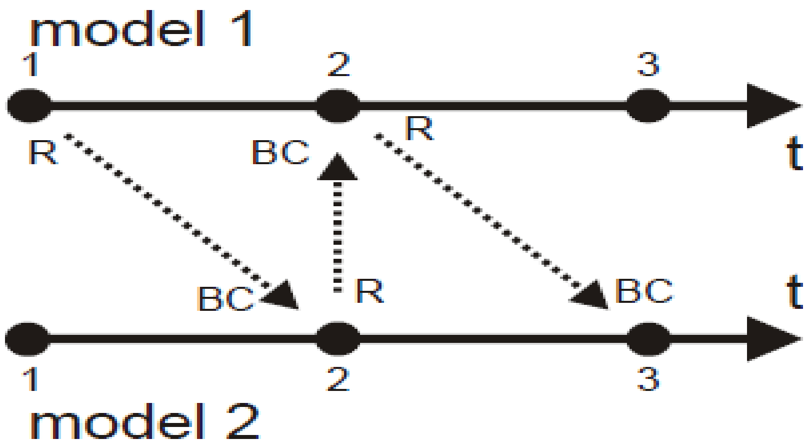
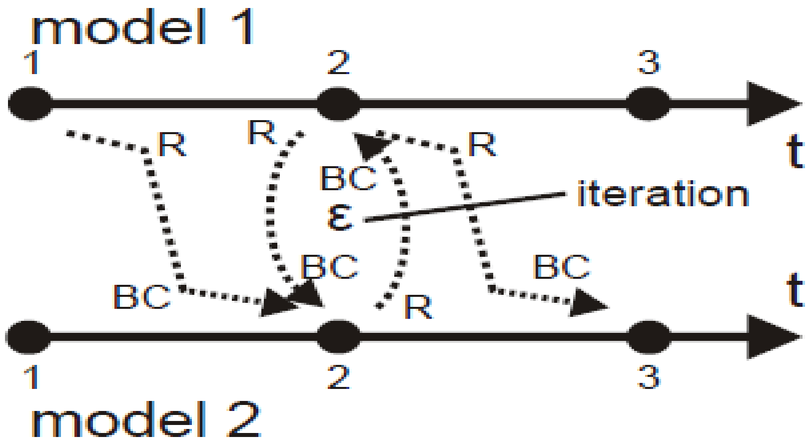
Model coupling



External coupling
-easy to implement
-mass balance errors



Iterative coupling
-advanced
-more accurate
-computationally more expensive

Simultaneous solution: multiple processes in one equation system
-highest level of coupling
-accurate
-time steps resolution must be the same
-equations must be of the same type

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Task: conjunctive modelling

1. Compose a scenario including different possibilities of critical infrastructure failure.
2. Identify models that can represent the relevant processes
3. Draw a sketch of models and their interactions.
4. Discuss benefits of model coupling for your setup against uncoupled modeling.
5. Discuss alternative setups.

Table 1: Relevant processes and corresponding models

no.	process	model
1	rainfall-runoff	hydrological model
2	river flow	1D open channel flow model
3	dike breach	dike breach model
4	hinterland flooding	two-dimensional flood model
5	groundwater head rise (subsurface flood)	groundwater model

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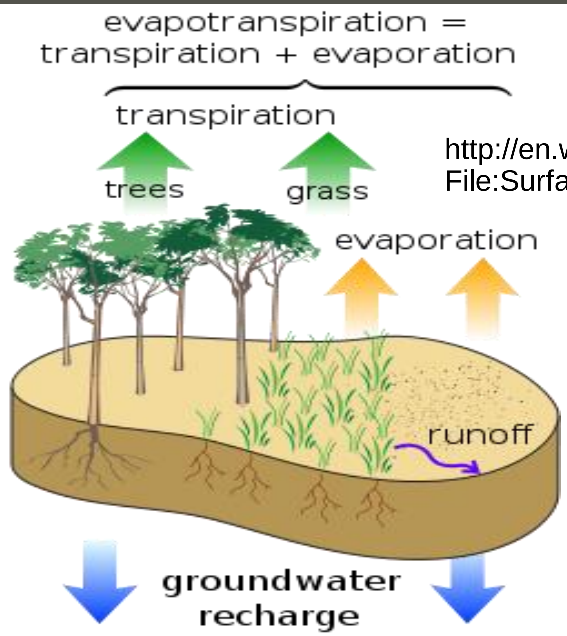
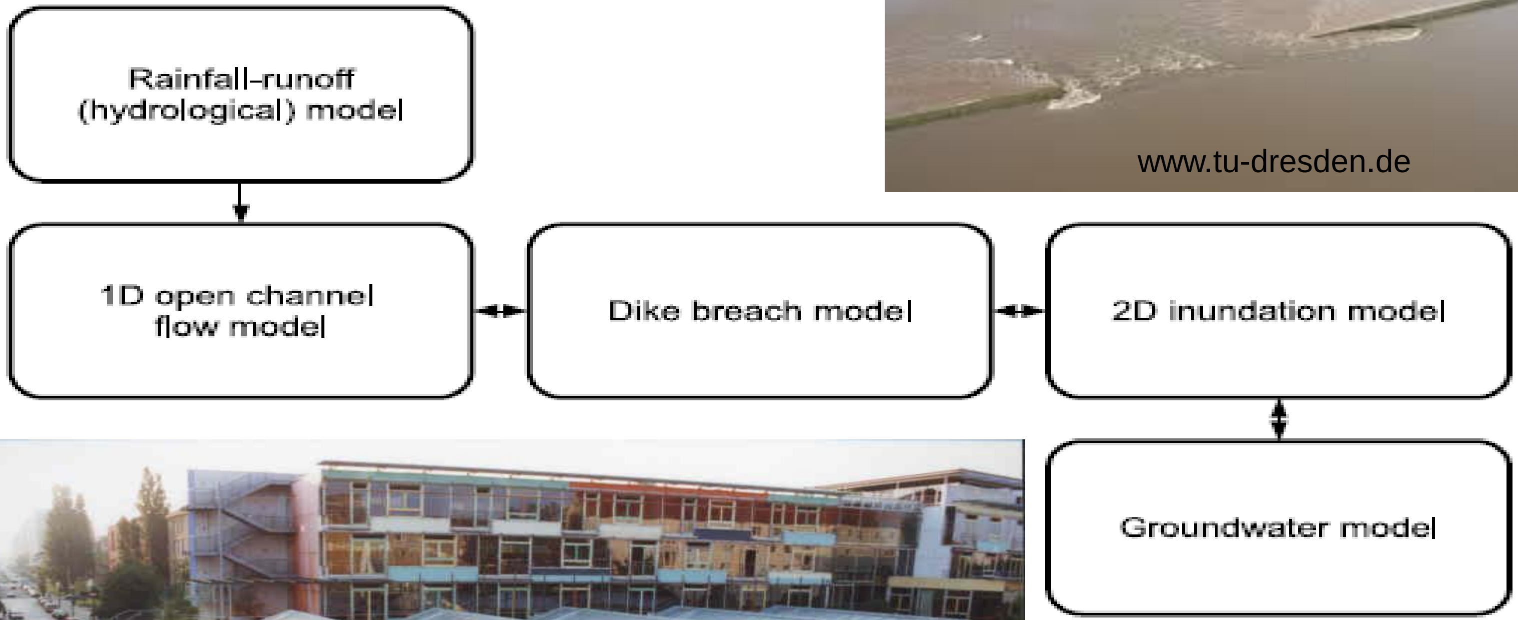
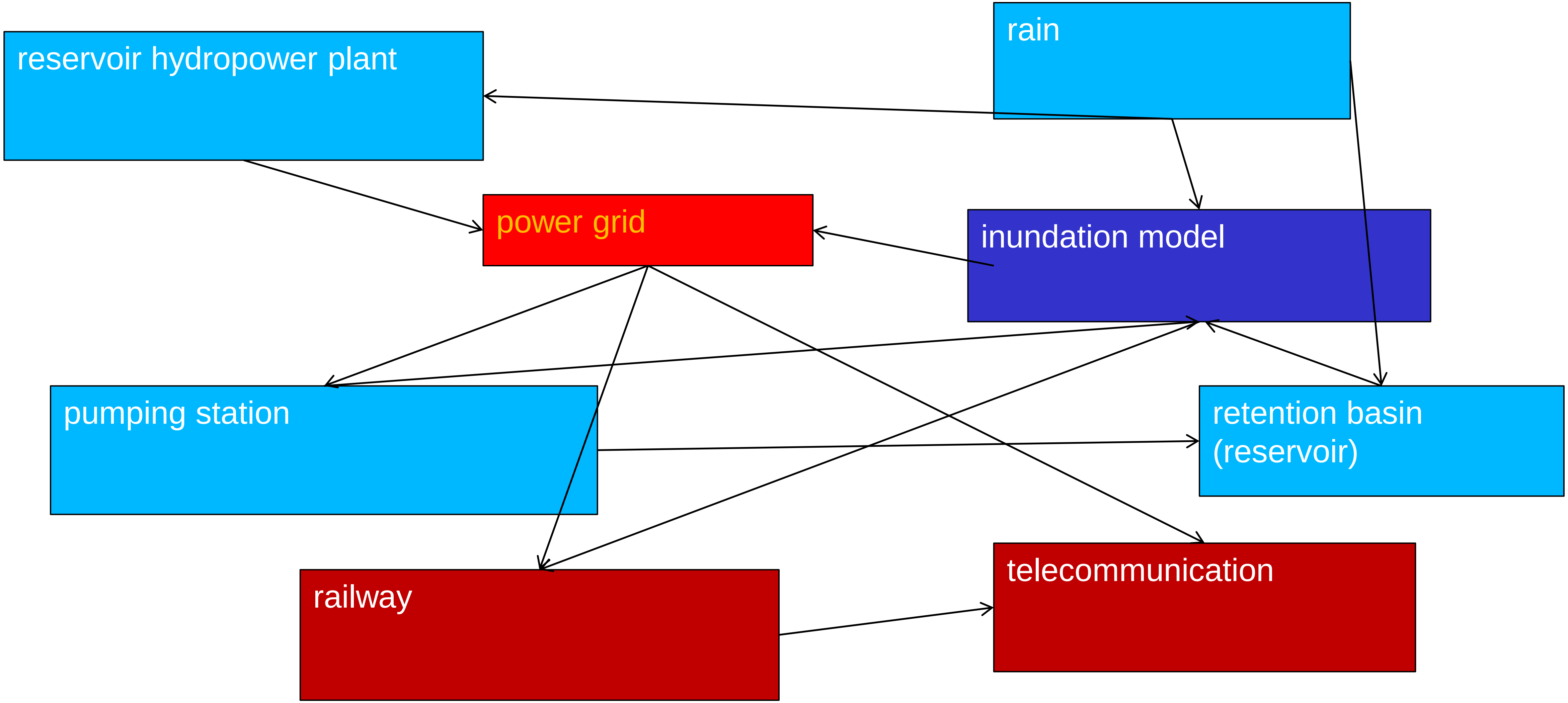
Conjunctive modeling



http://en.wikipedia.org/wiki/
File:Surface_water_cycle.svg

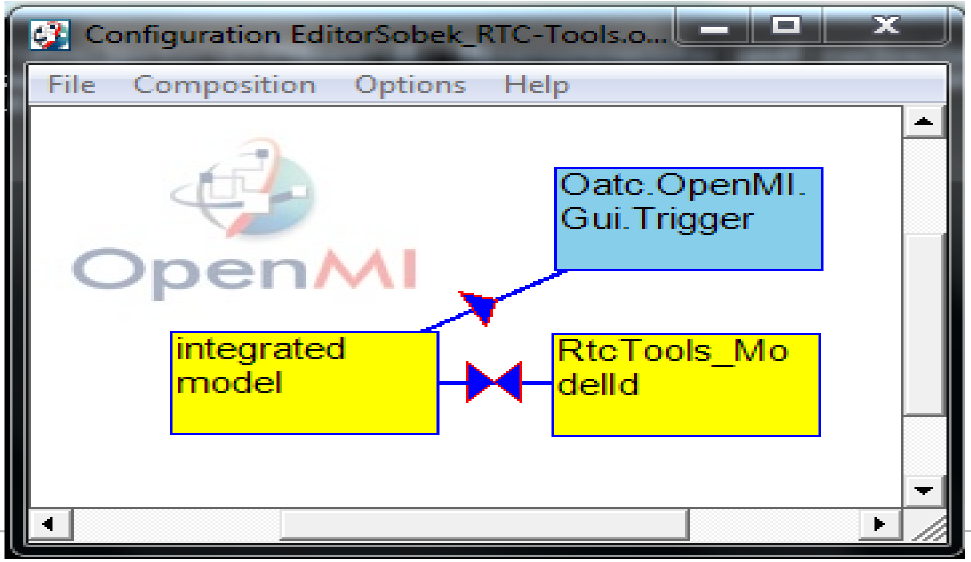


Deltares


reservoir hydropower plant
rain
power grid
inundation model
pumping station
retention basin (reservoir)
railway
telecommunication

Processes and models

	Open channel flow	Human operations (control of hydraulic structures)
Simulation programme	Sobek	RTC-Tools
Output parameters	Water level, discharge	Crest level
Input parameters	Crest level	Water level

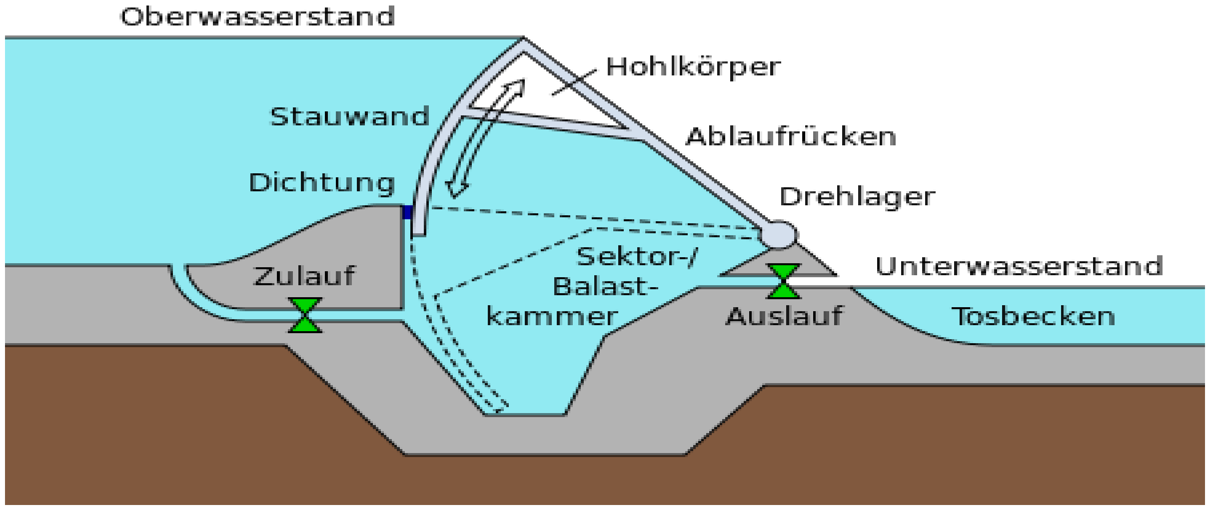


Example: Elbe river, Magdeburg (Germany)

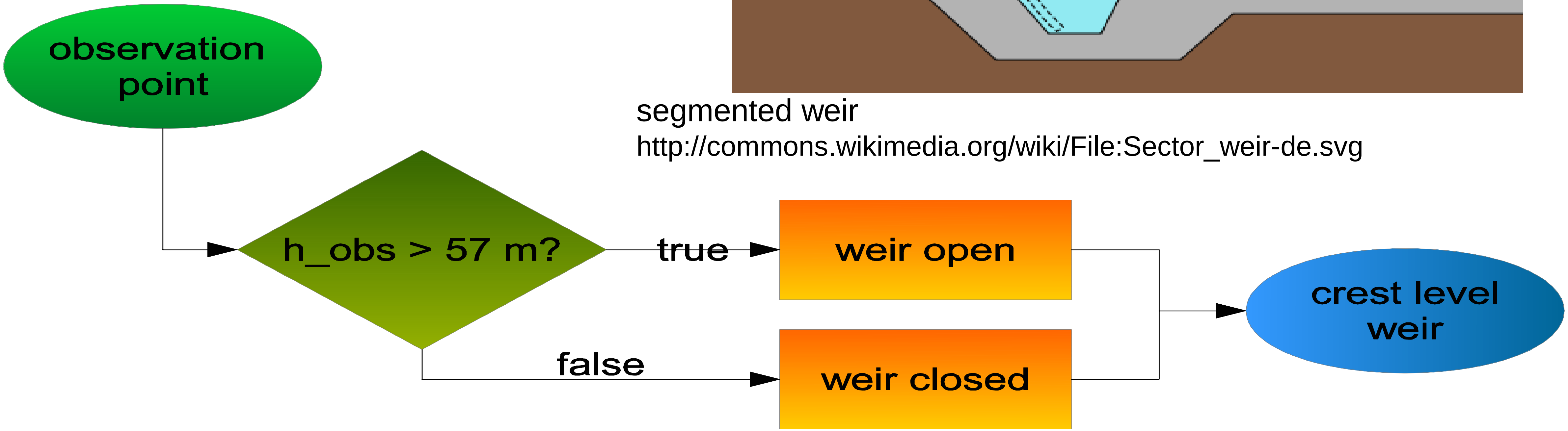
- Main station
- Railway track junctions
- Weir
- Gauges “Magdeburg” “and “Schönebeck
- Old Elbe branch
- Main river channel

Sobek model schematization
physical model (St.-Venant equations)

The real-time control model



segmented weir
http://commons.wikimedia.org/wiki/File:Sector_weir-de.svg



logical/relational model

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Setting up an OpenMI-Composition

omi-file: the OpenMI-Compliant Component

Where is the DLL with the computational core and OpenMI-Interface?

Where are the input files?

What else? (Command line arguments)

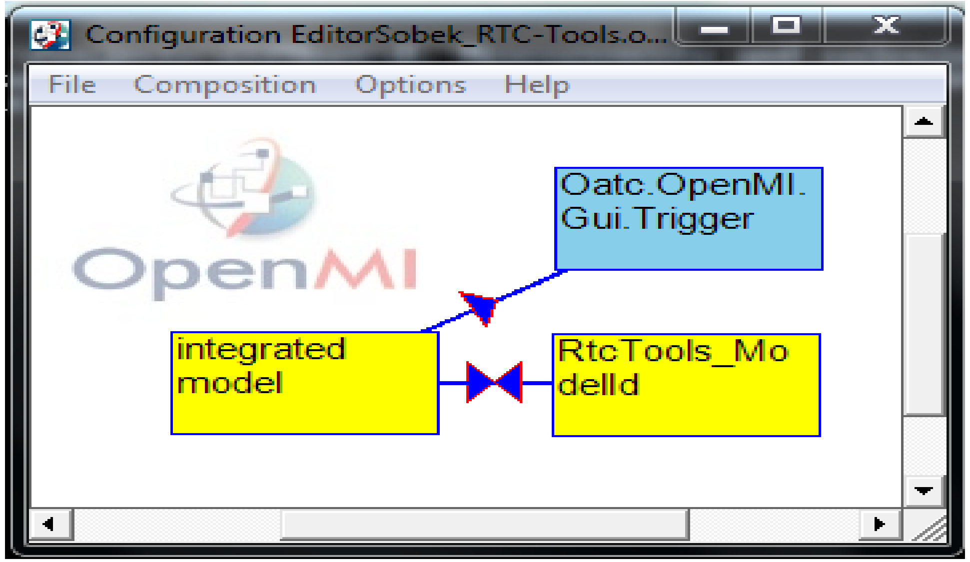
opr-file: the OpenMI-Composition

Which components (i. e. models)?

How coupled?

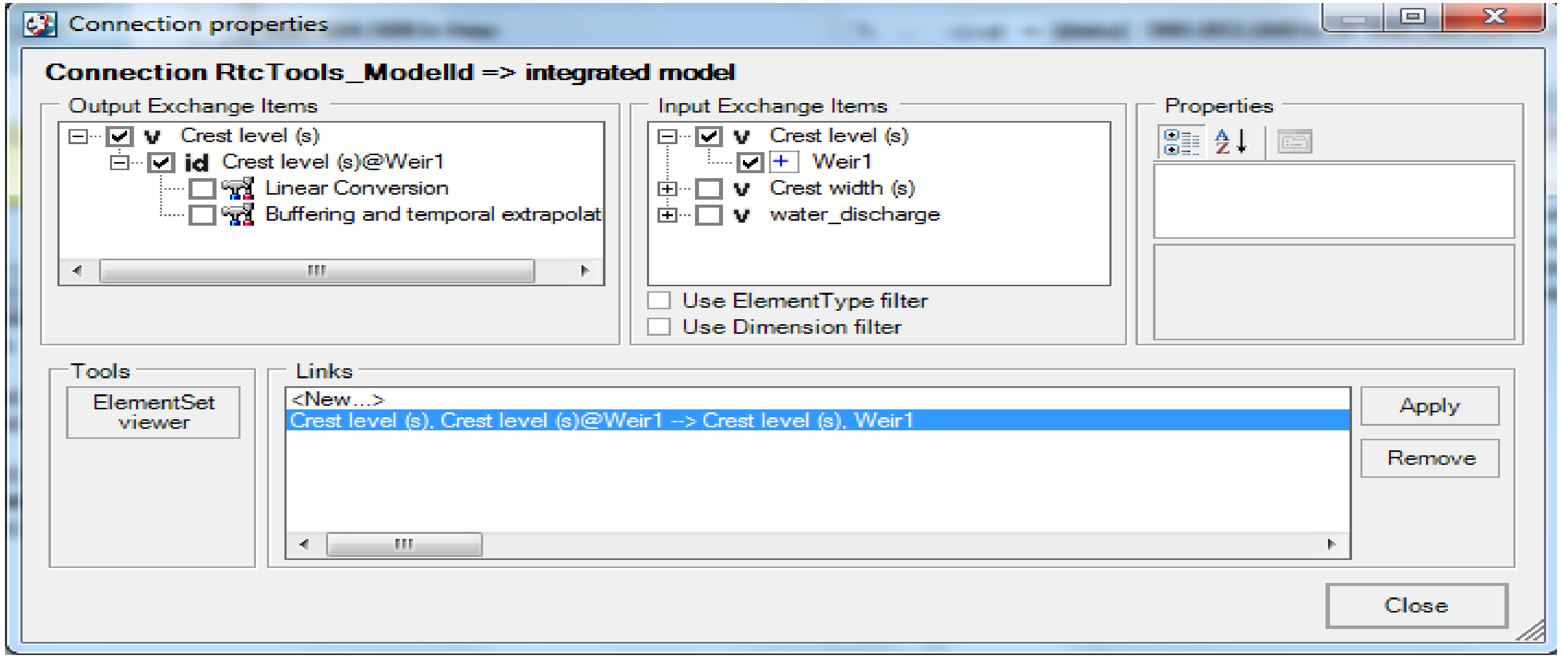
Which simulation period?

Where is the Trigger linked with?

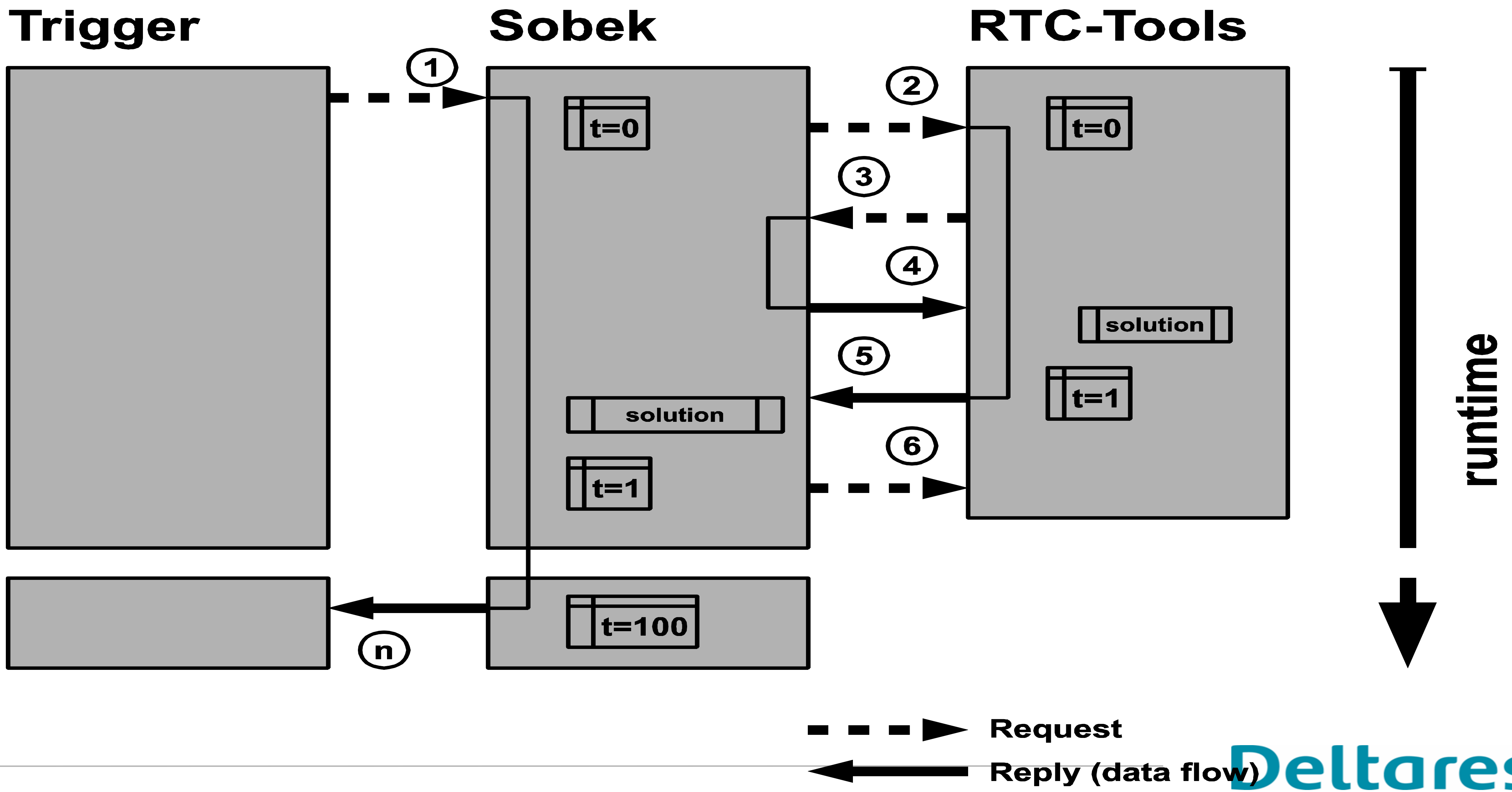


OpenMI Exchange items

What? e. g. water level in metres.
Where? e. g. Gauge Schönebeck
input exchange items: e. g. boundary conditions
output exchange items: e. g. simulation results

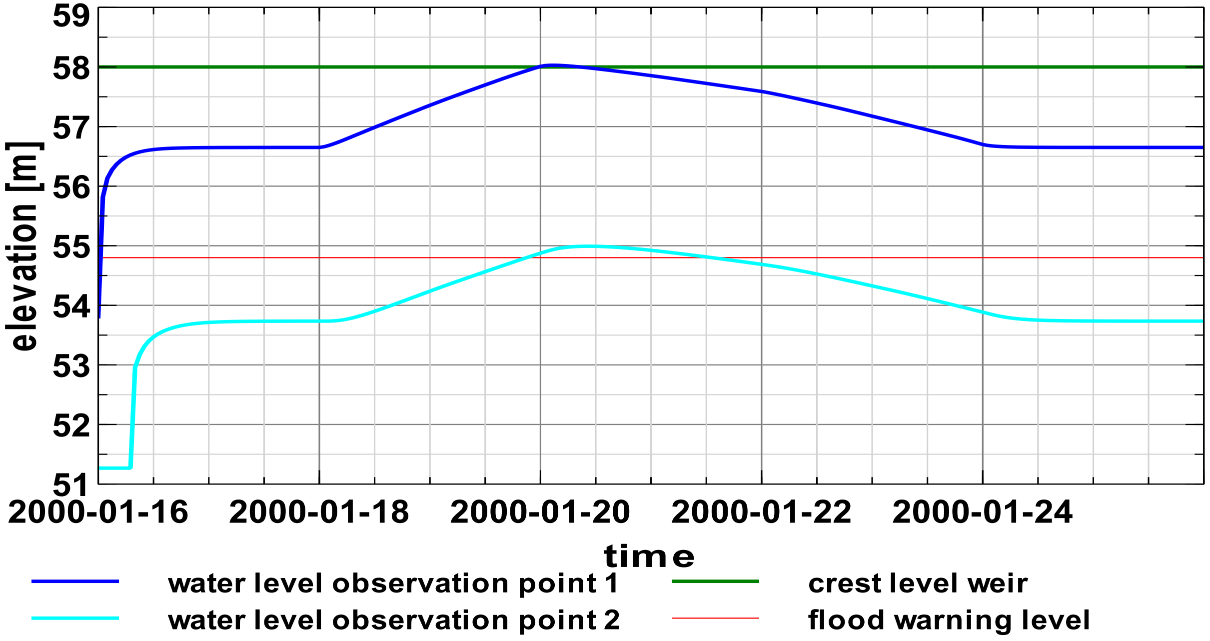


Data exchange mechanism

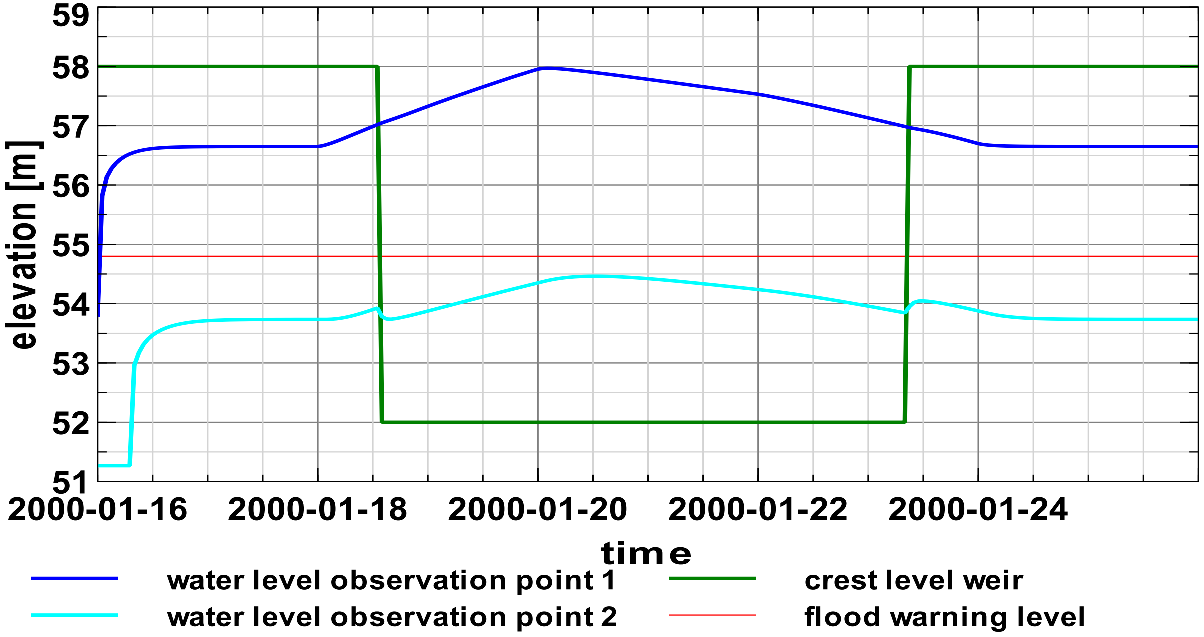


Deltares

Simulation results



Sobek



Sobek and RTC-Tools

Deltares

OpenMI-compliance

DLL with OpenMI-functions

`Initialize()`

- read input files
- populate exchange items (e. g. water level in meters at node number 62)

`GetCurrentTime()`

- returns the current simulation time as Modified Julian Day

`GetValues()`

- returns a simulation result for an OutputExchangeItem

`SetValues()`

- sets a value for an InputExchangeItem (boundary condition)

`PerformTimestep()`

- solves the flow equation for **one** time step

Deltares

Migration to OpenMI compliance

Re-organise the computational core

- `.exe` → `.exe` and `.dll`
- break the big loop over all time steps (t < tend)
- provide internal functions (“native layer”)
  - `ComputeOneTimeStep()`
  - `ReturnListOfNodes()`
  - `ReturnSimulationTimeInSeconds()`

Couple the computational core (engine) with the OpenMI source code (C#) via MSDN PlatformInvoke

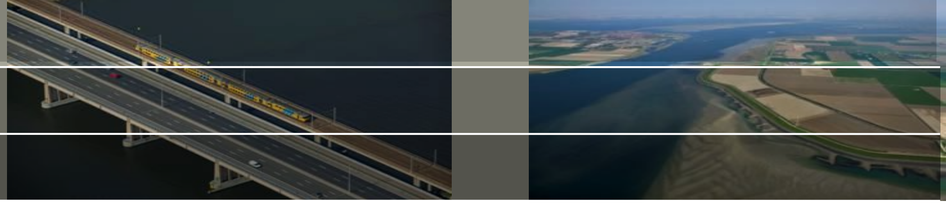
Fill the OpenMI `ILinkableEngine` member functions

The OpenMI association provides tutorials and course material and a handbook.

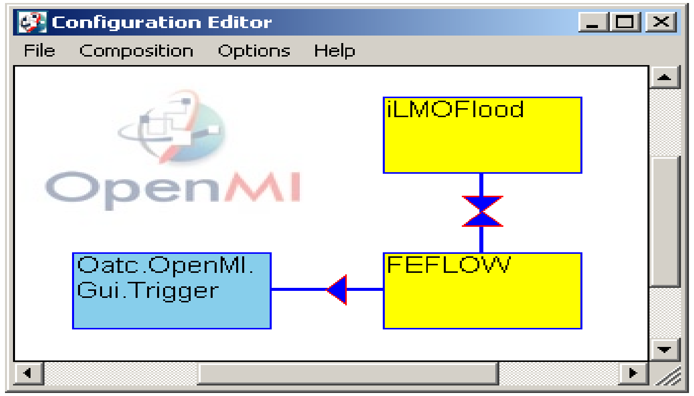
Work load:

- one week for RTC-Tools (experienced developer, “state of the art code”)
- Sobek: features are continuously developed for different cases

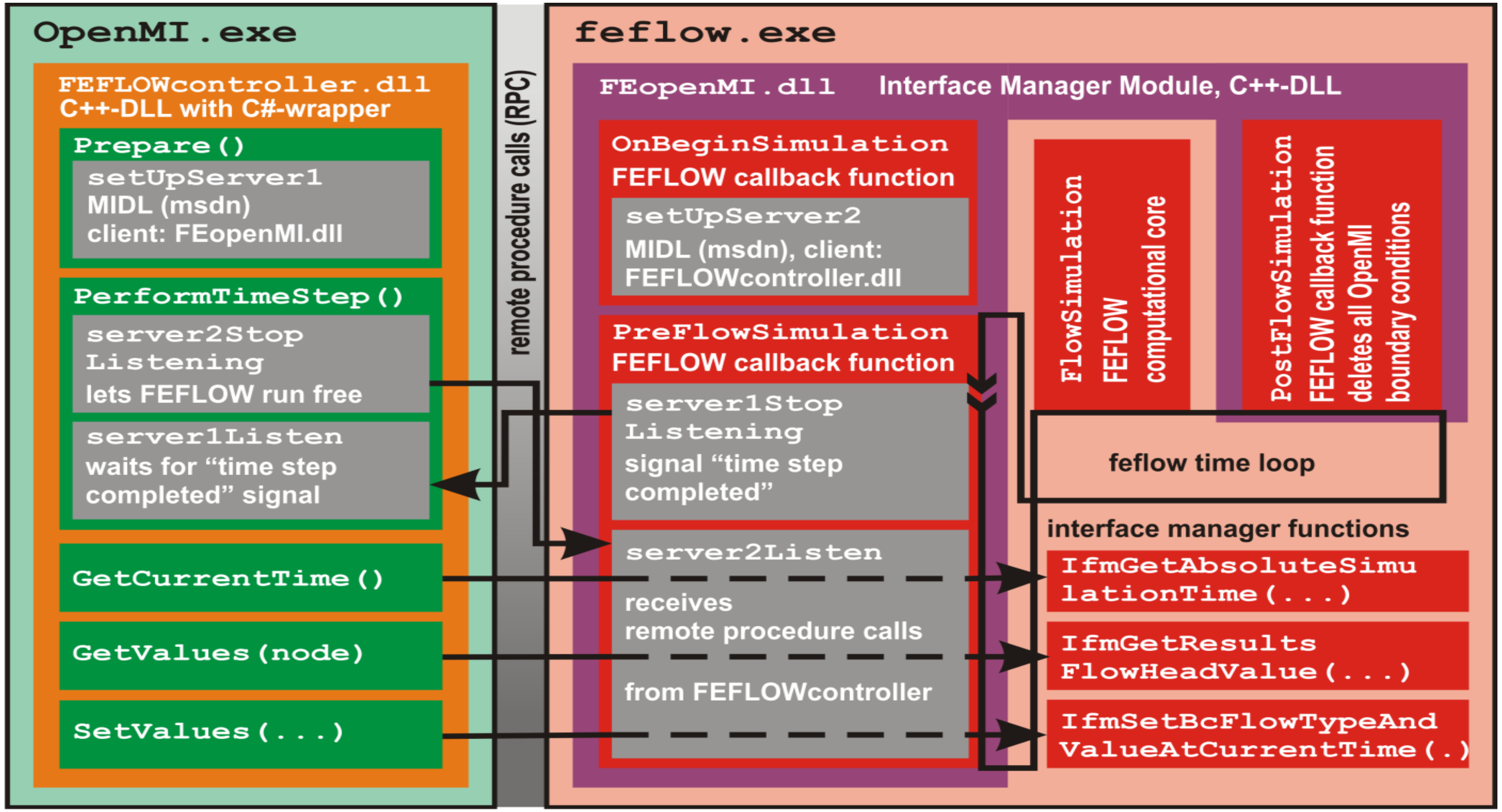
OpenMI compliance of FEFLOW



Feflow (DHI Wasy GmbH): control via the interface manager and remote procedure calls



Challenge:
Source code not available



Becker & Schüttrumpf, JHydroInf, 2011

Deltares

CIPRNet

Critical Infrastructure Preparedness and Resilience Research Network

www.ciprnet.eu

Verification and Validation (E0-D1-M6)

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Modelling, Simulation and Analysis of Critical Infrastructure Training School (Edition 0)

Deltares Headquarters – Delft (The Netherlands) – 3-4 February 2014

This lecture is about three things:

- You have to V&V
  - because there is risk involved
- You have to do V&V in a structured way
  - if you want to do it more effective and more efficient
- You have to choose the right V&V technique
  - in order to balance the risk with the effectiveness and efficiency

Part 1

- You have to V&V
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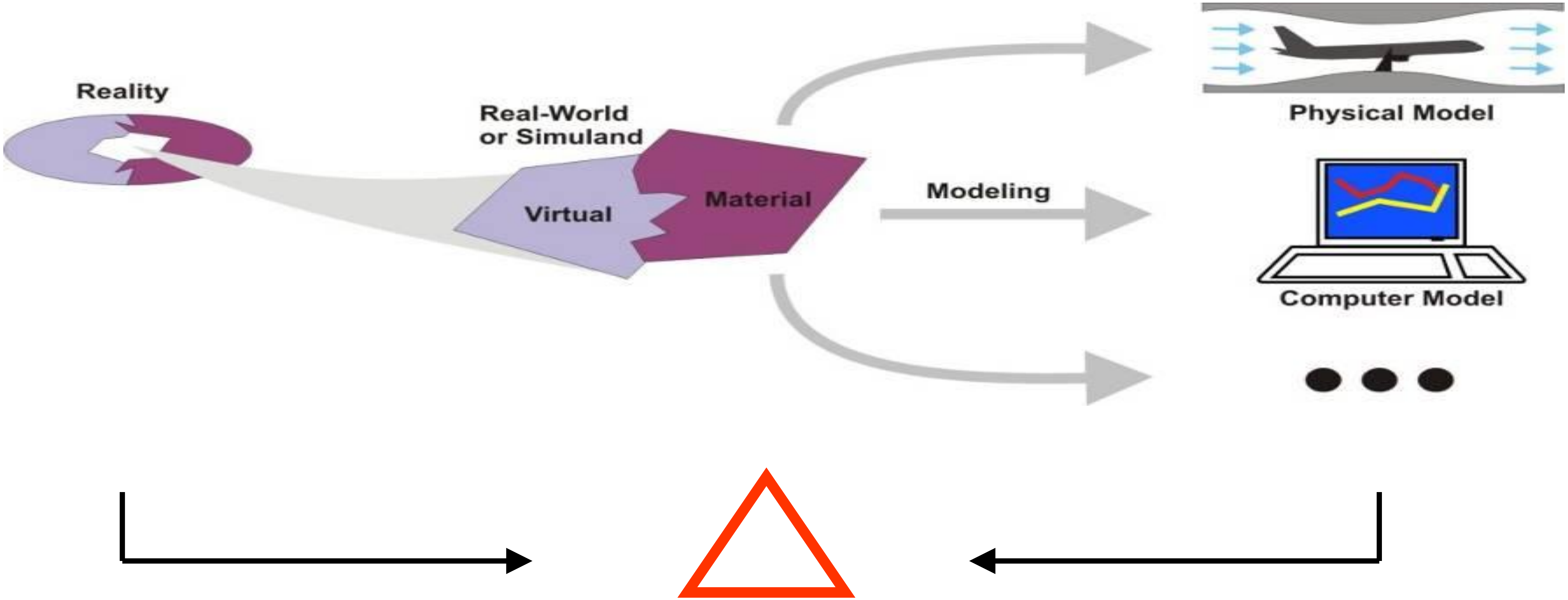
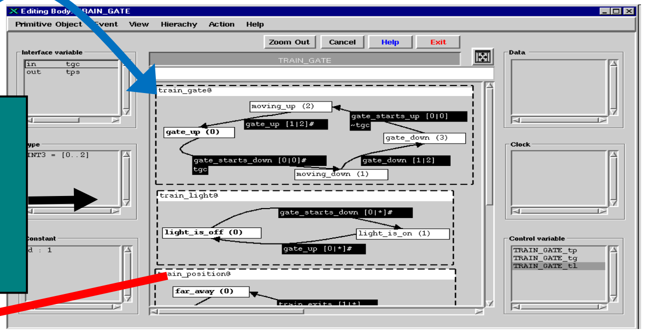
What is Modelling and Simulation (M&S)?



What is Verification and Validation (V&V)?

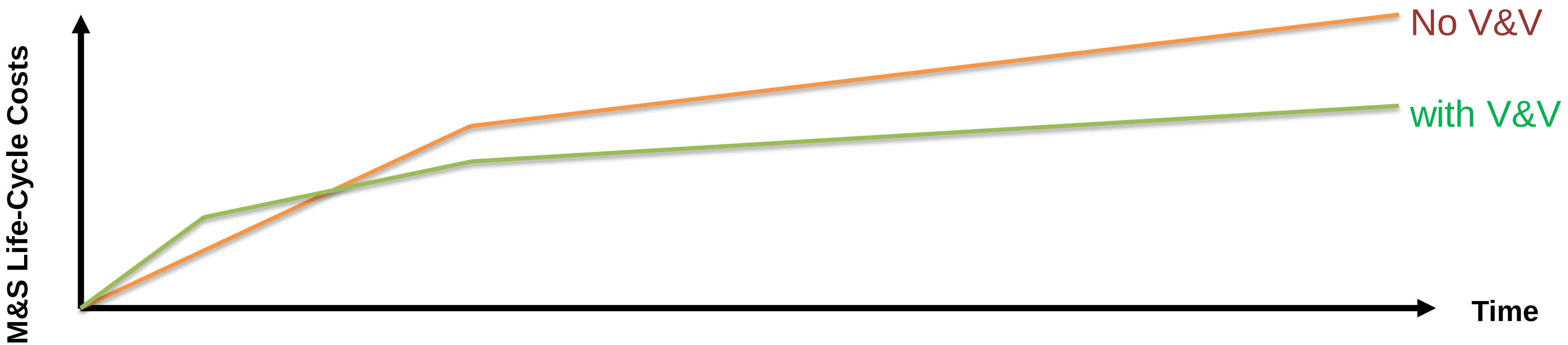
- Verification
  - Assesses if the M&S is build and used right
- Validation
  - Assesses if the right M&S is build or procured

Conceptual Model → Modelling → Implemen-tation



Provides Insight Into and Advise on the M&S System and it's Life-Cycle Quality, and the Associated Risks

Should you always do V&V?



Part 2

- You have to V&V
  - because there is risk involved
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Structured Approach to V&V

Simulation Interoperability Standards Organization
www.sisostds.org

Generic Methodology for Verification and Validation (GM-VV) to Support Acceptance of Models, Simulations and Data

GM-VV Vol. 1: Introduction and Overview

SISO-GUIDE-001.1-2012

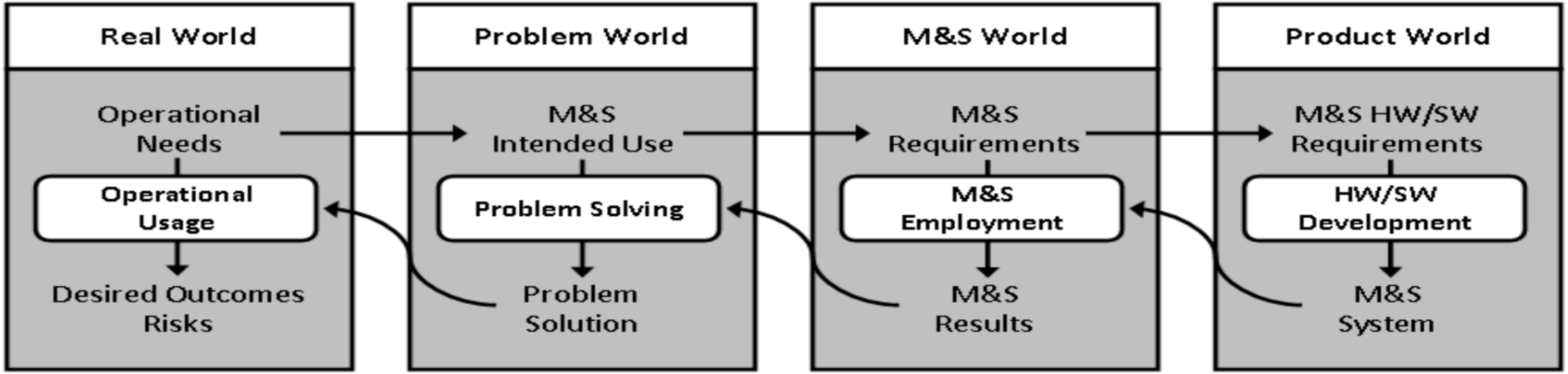
5 October 2012

Prepared by:
SISO Generic Methodology for Verification and Validation Product Development Group (GM-VV PDG)

Generic Methodology for V&V (GM-VV)

- Tailoring Framework
  - Adaption
  - Optimization
- Implementation Framework
  - Products, Processes, Roles
  - technical, project, enterprise
- Conceptual Framework
  - Basis of GM-VV
  - Connect to other V&V methods

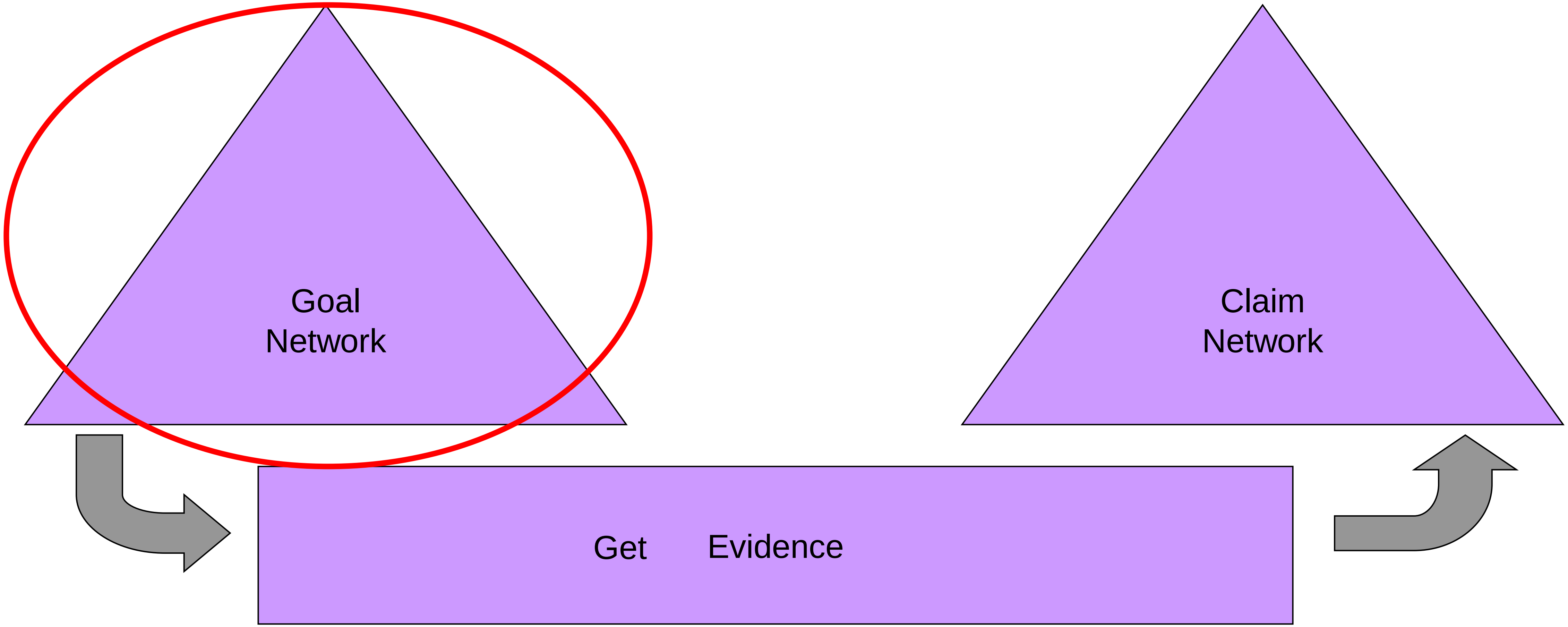
4-world model



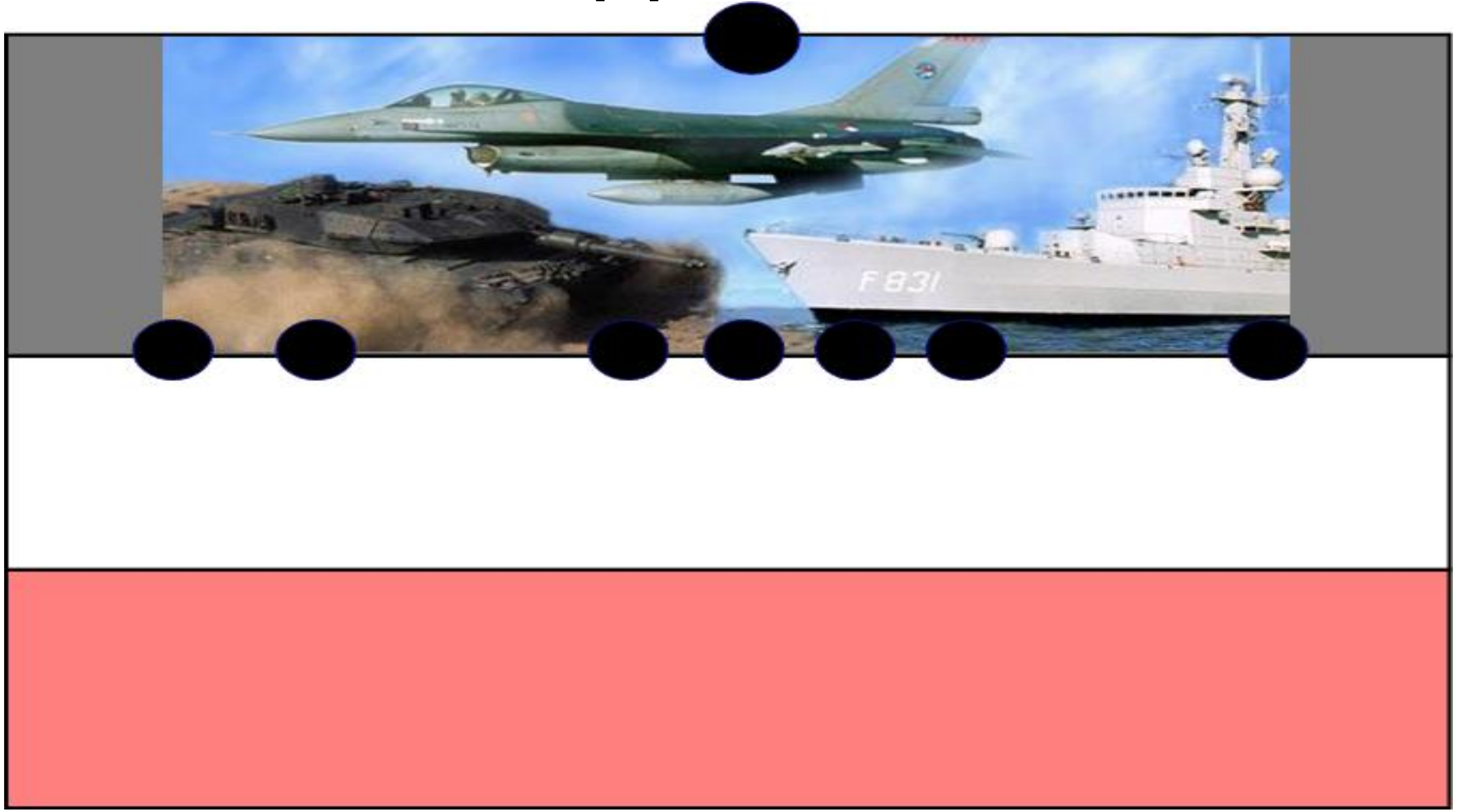
What needs to be V&V-ed for CIP?

- Simulators: power plants, banks, traffic generators, network, ...
  - Man-in-the-Loop simulators
- Exercise Management Facilities
  - Scenario development tools
  - Briefing/Debriefing tools
  - Trainers
- Analysis and Assessment Tools
  - Specialized analysis tooling
  - Loggers
  - 3D Viewers
  - Generic Didactic Modules (scoring, CAI)
- Network Infrastructure
  - Local
  - Wide Area
  - Security/Encryption
  - Different architectures used

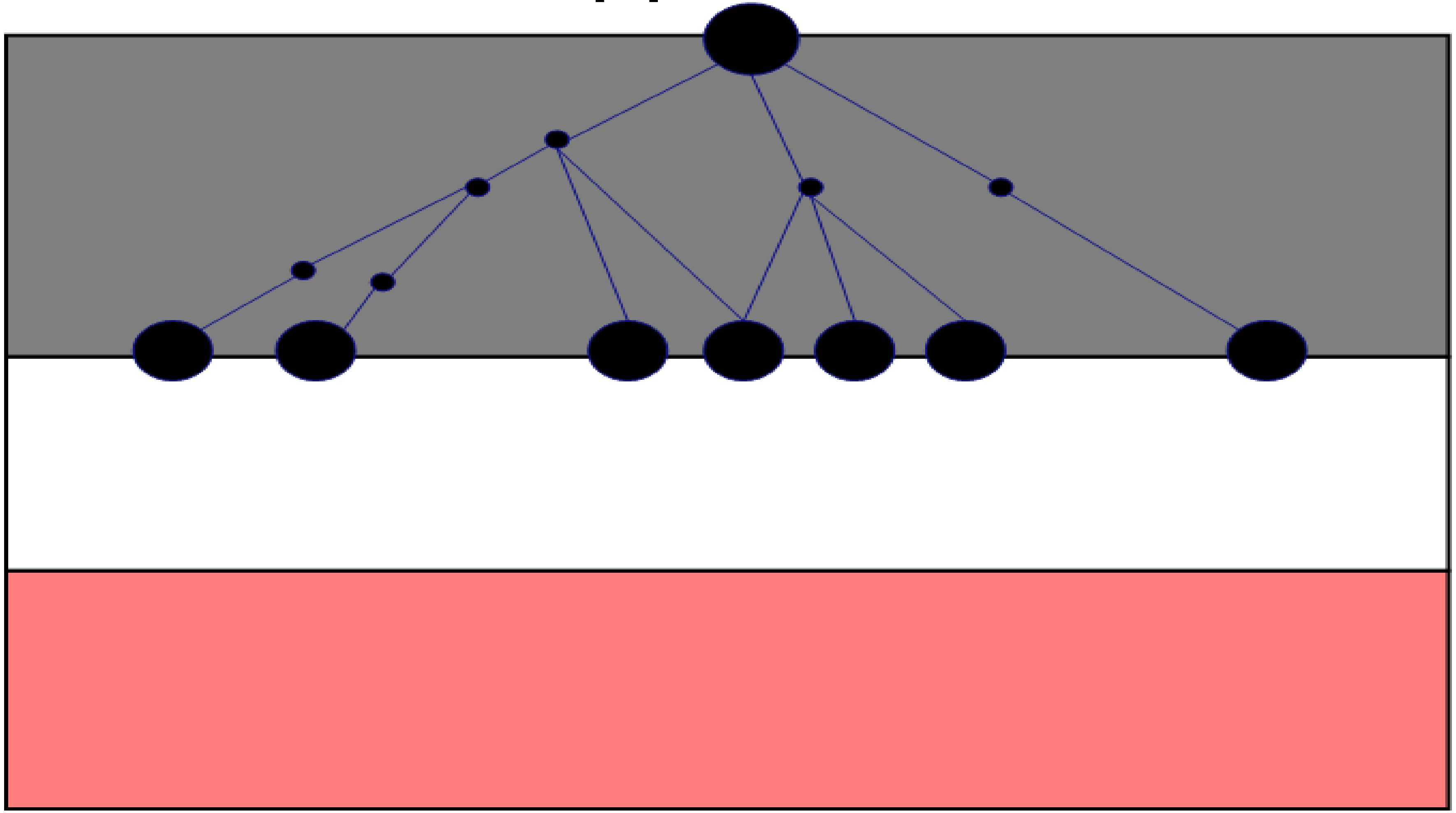
Argumentation Network



Approach

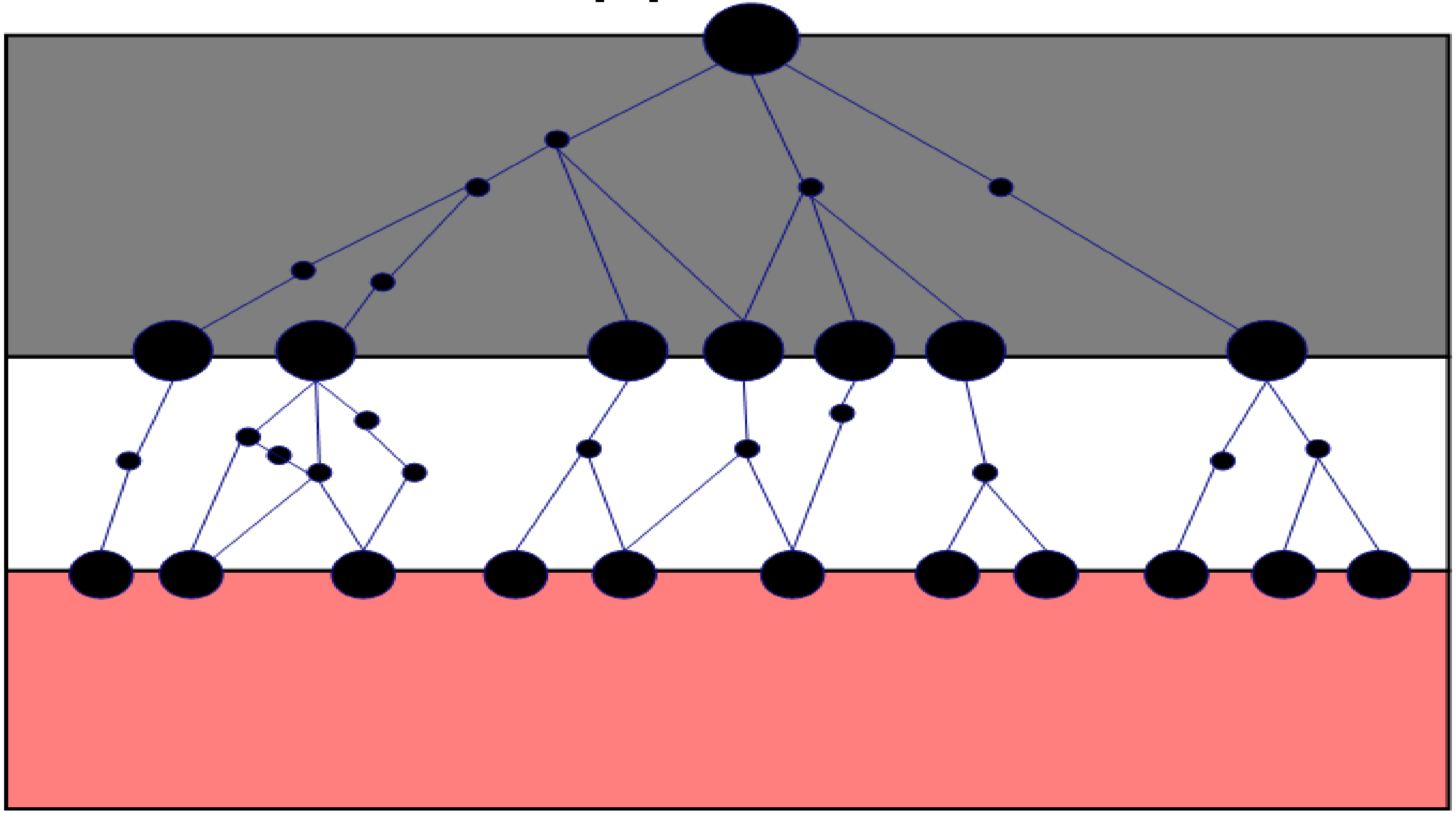


Approach

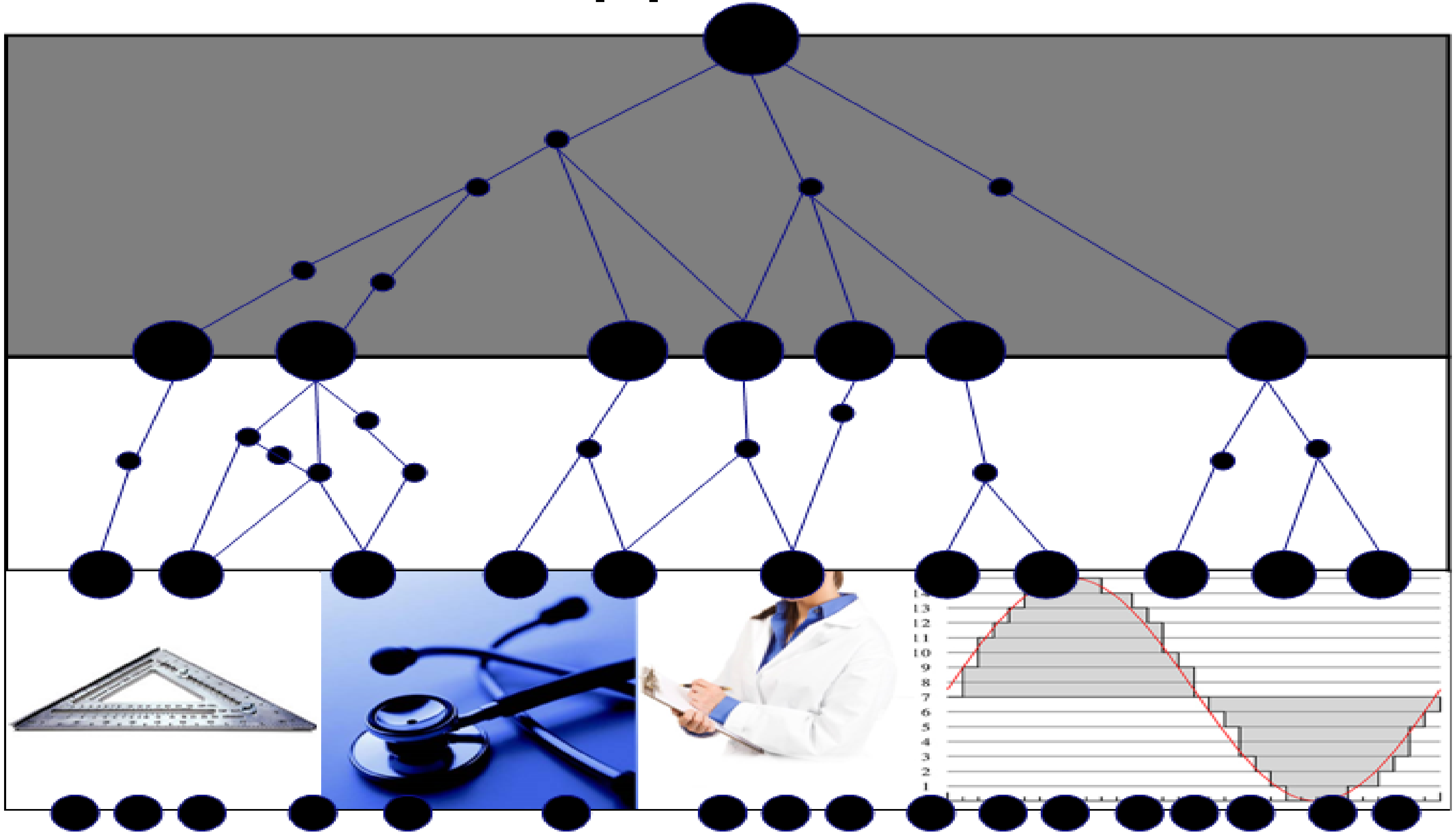


Approach

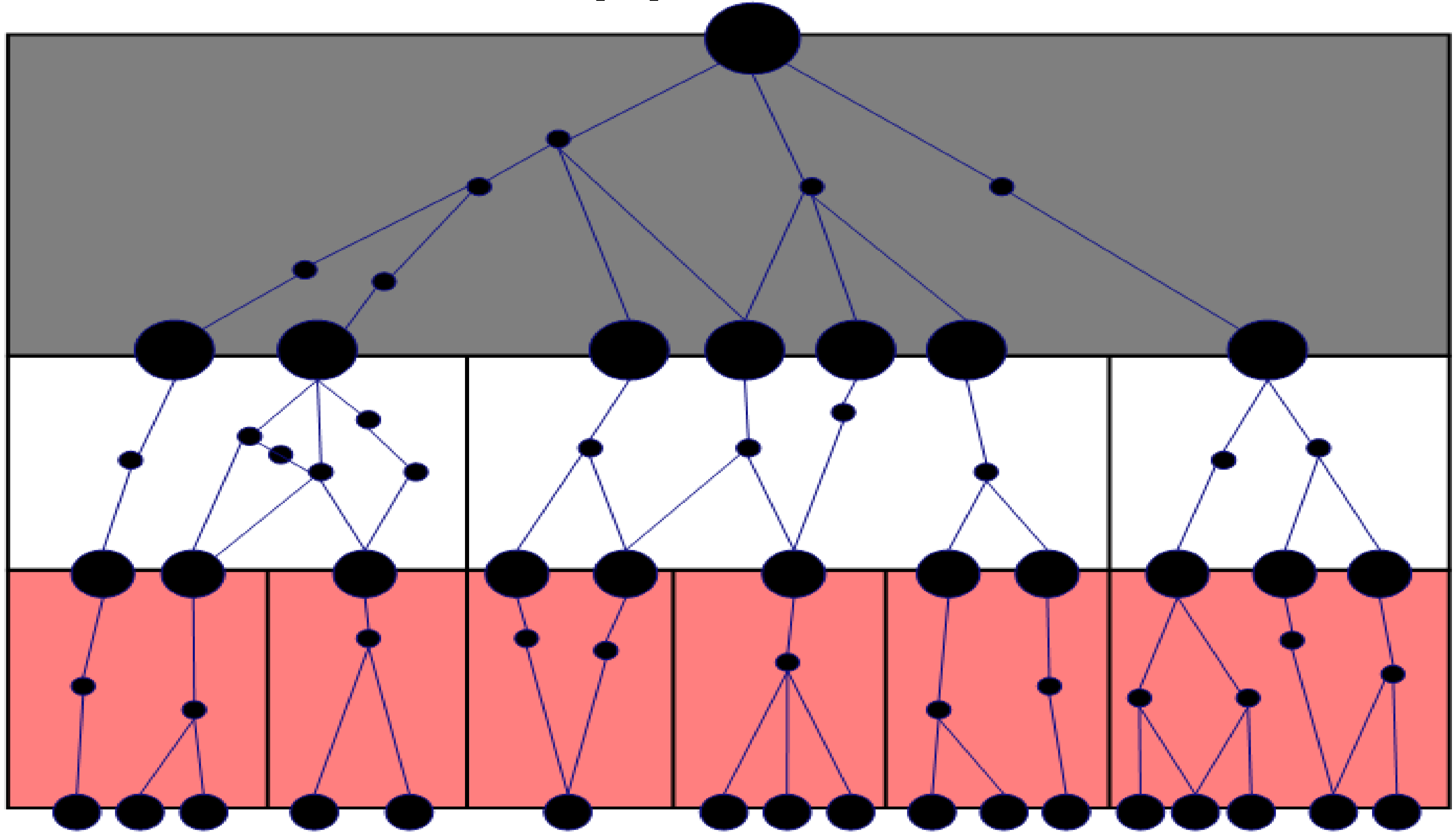
Approach

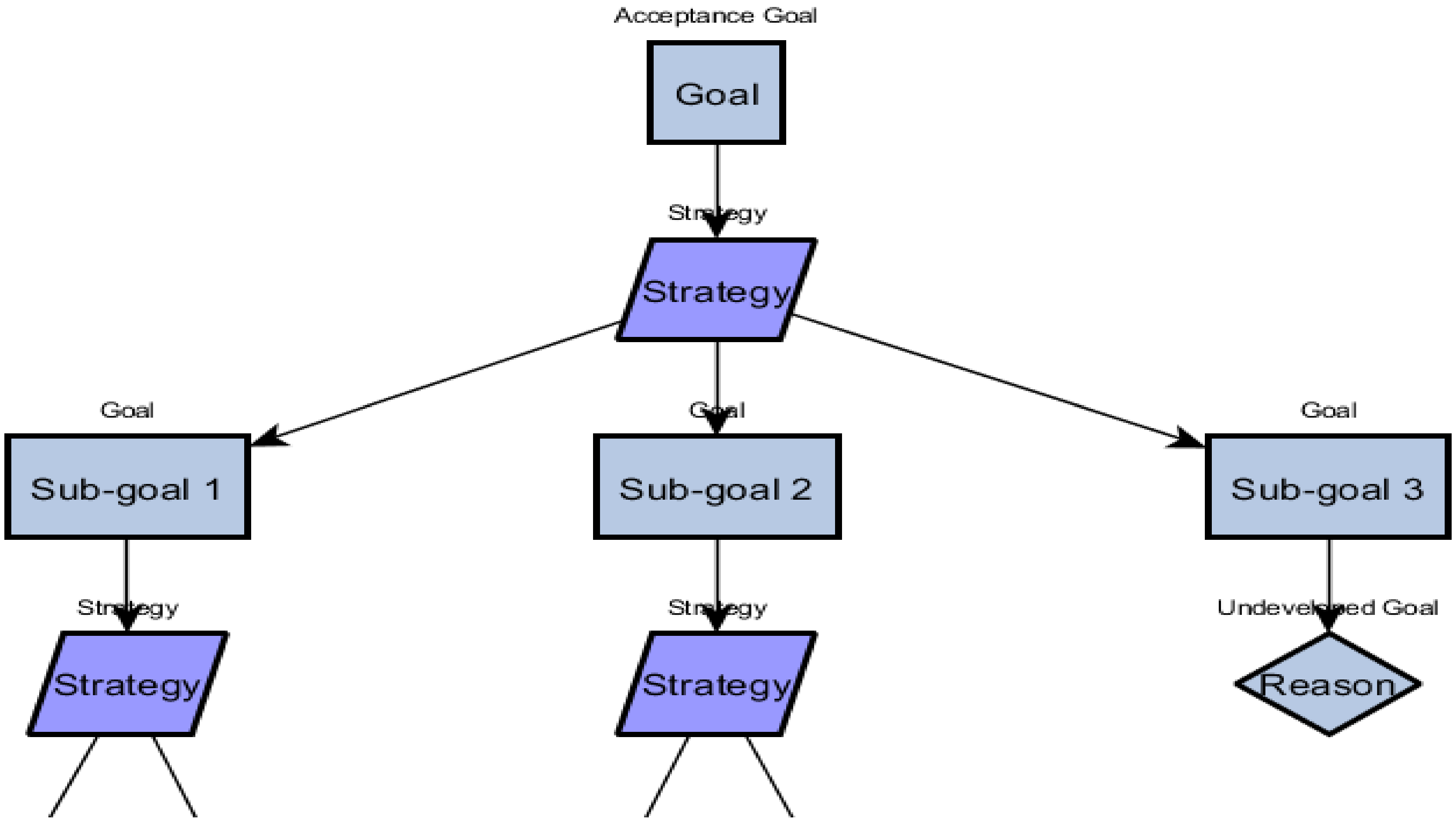


Approach

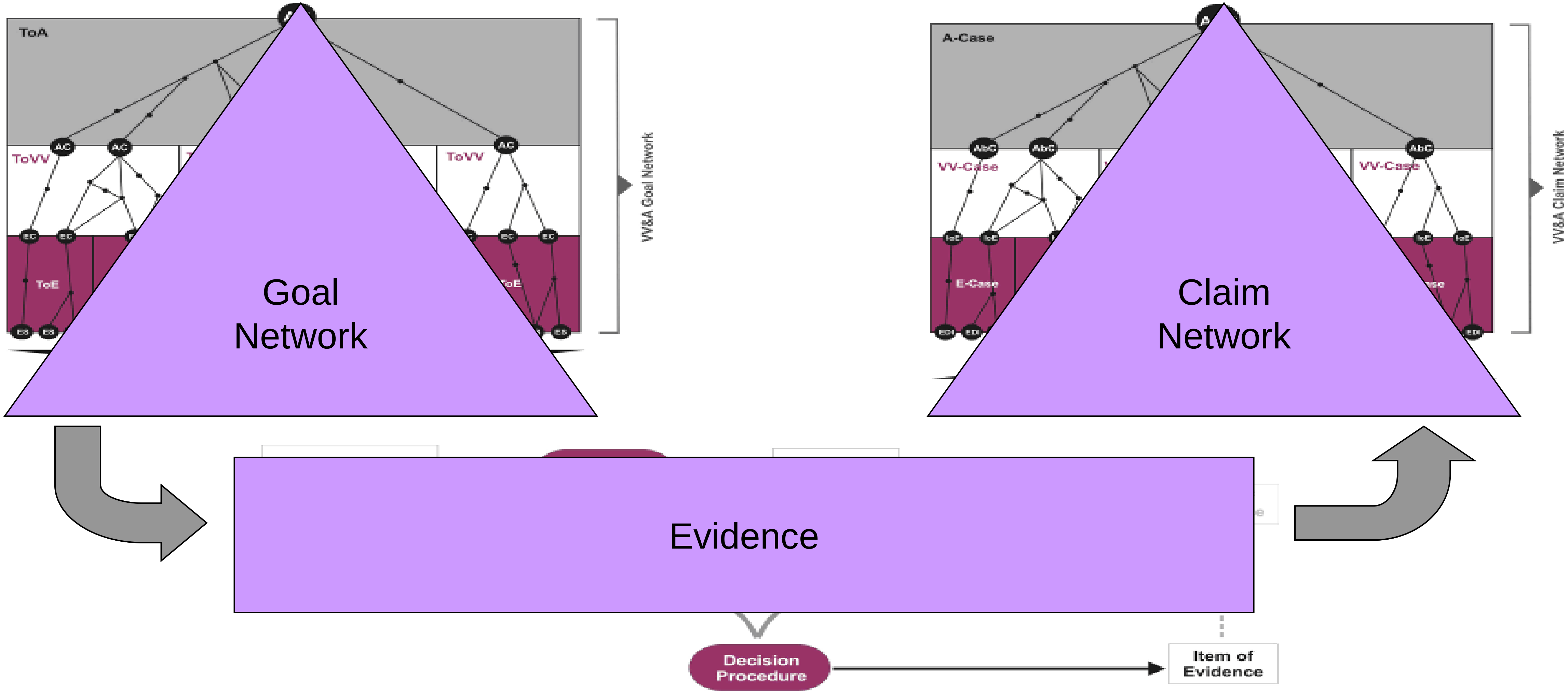


Approach



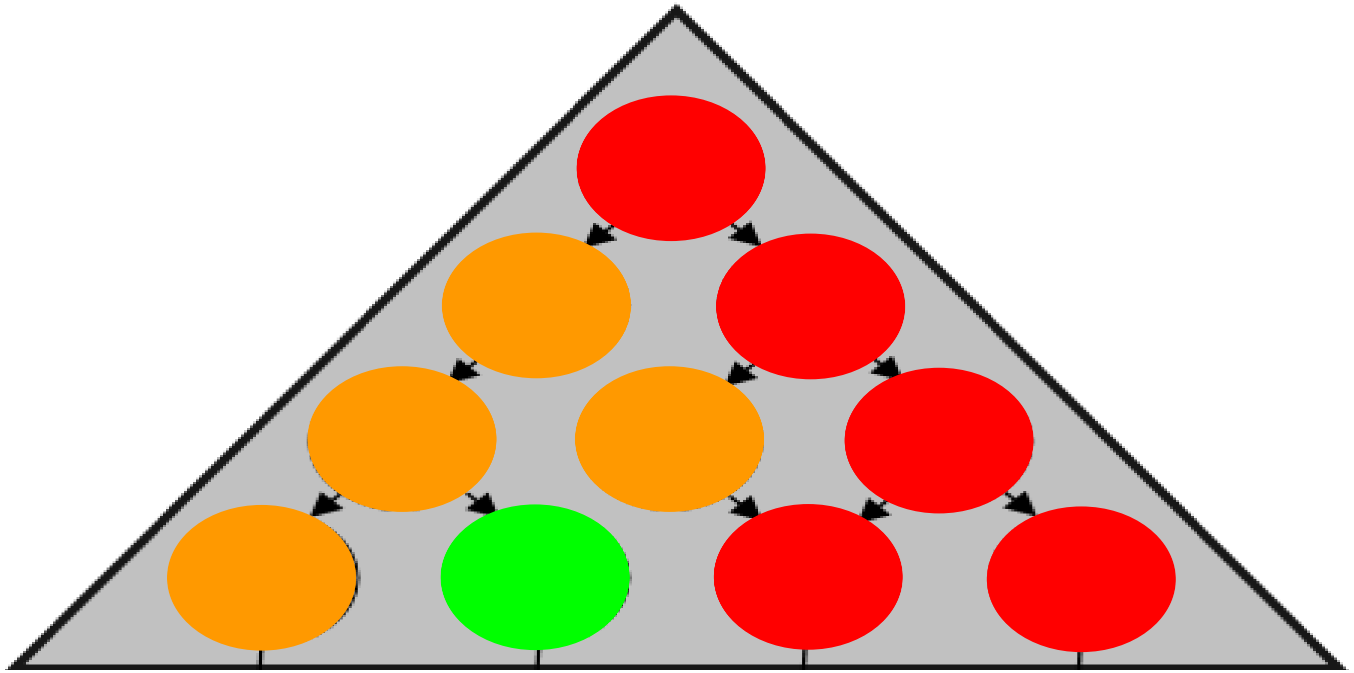

Acceptance Goal
Goal
Strategy
Strategy
Goal
Sub-goal 1
Goal
Sub-goal 2
Goal
Sub-goal 3
Strategy
Strategy
Strategy
Strategy
Undeveloped Goal
Reason

VV&A Goal-Claim Network

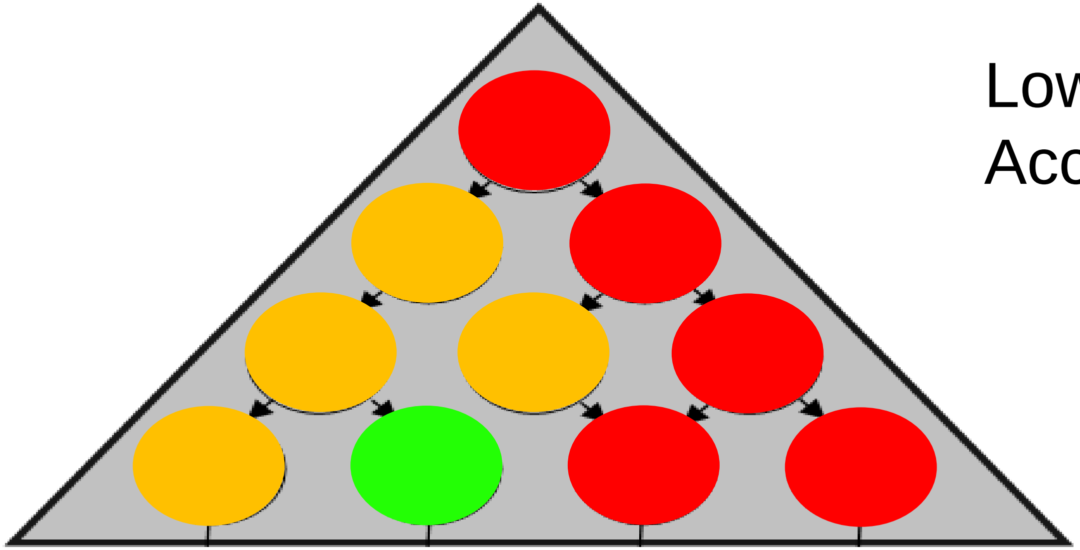


Risk decomposition

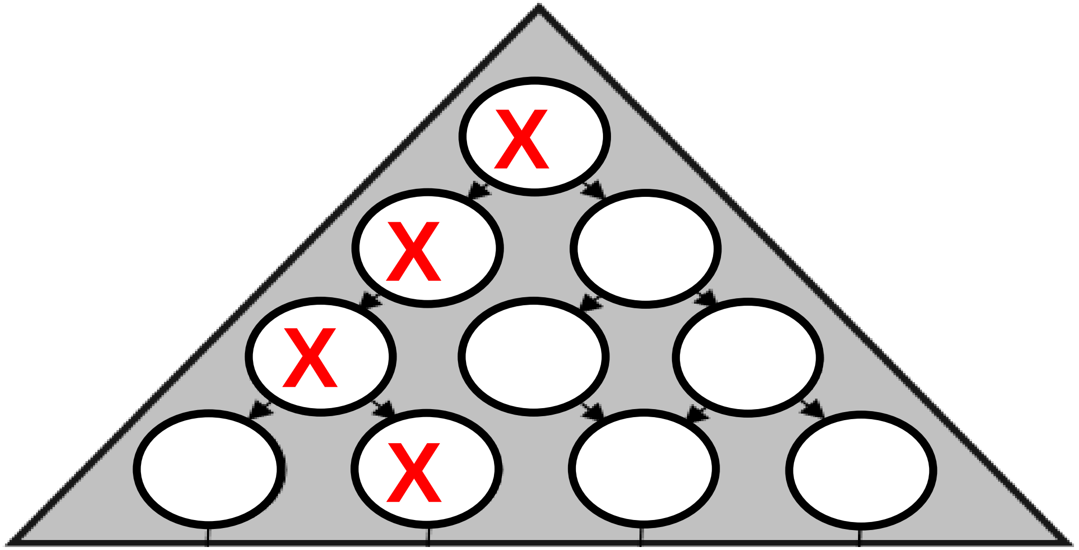
- Priorities
- Required certainty
- Specification of tests
  - resource distribution



Help! Not all criteria have been met!



Low risk →
Accept?



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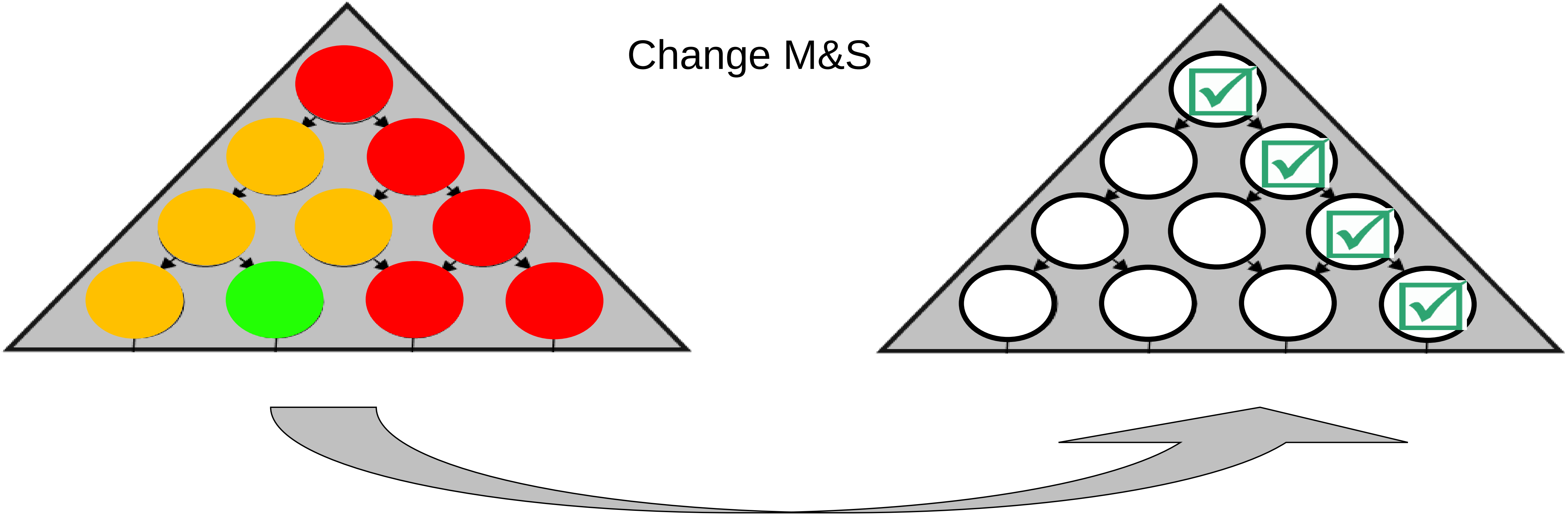

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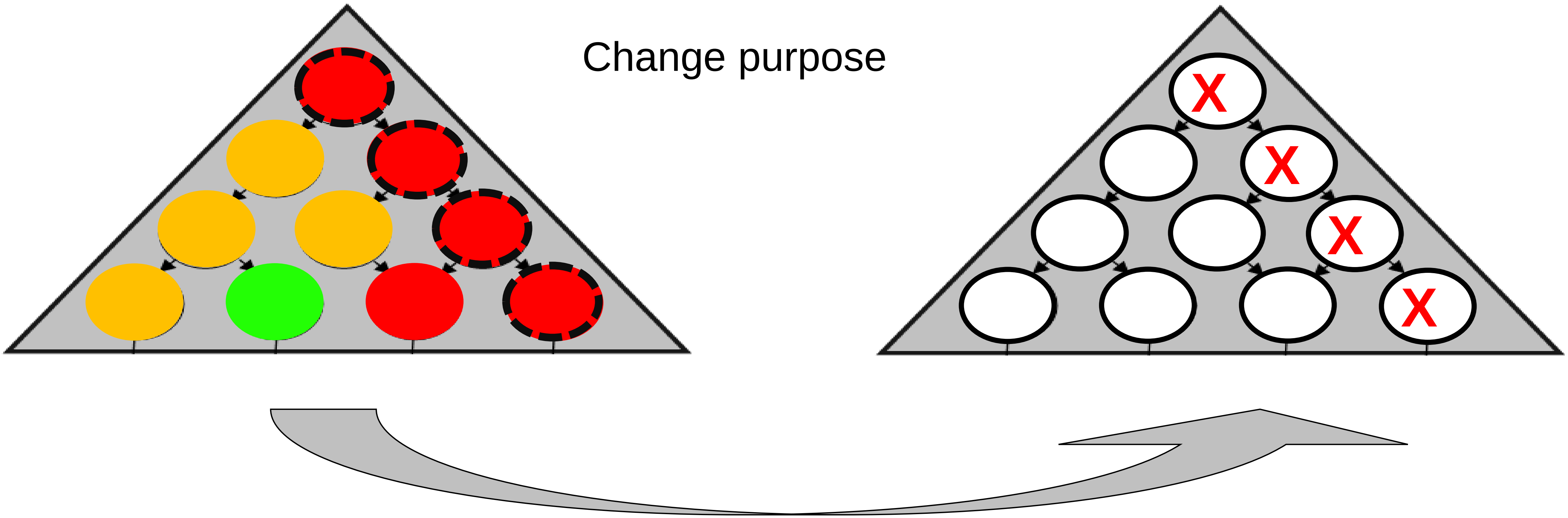
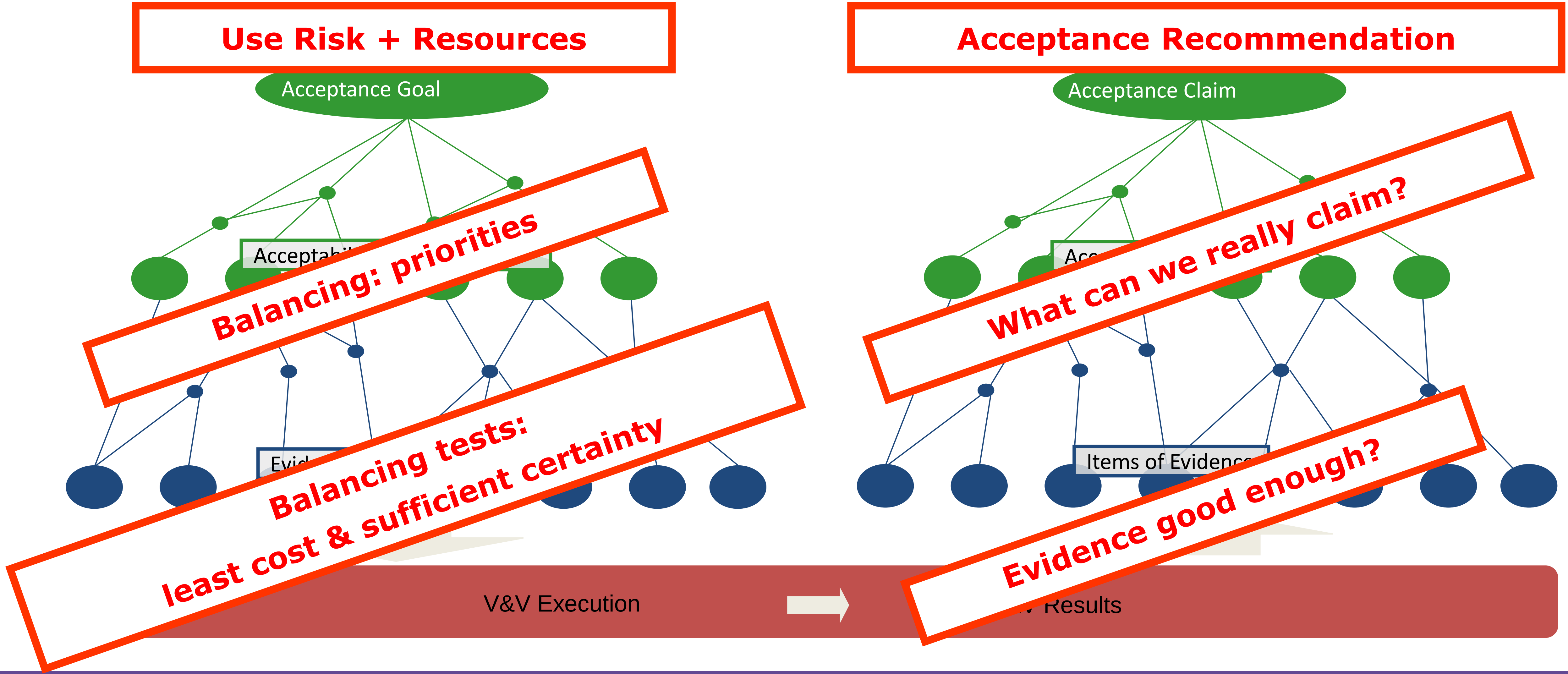


Project Level



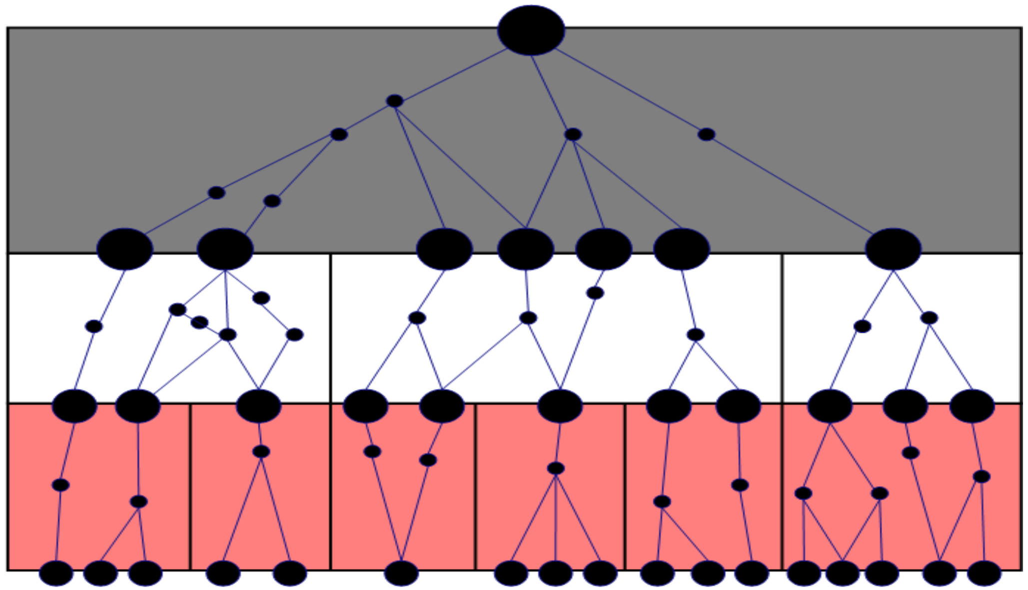
Enterprise Level

- Q-tility is an implementation of the GM-VV enterprise level
- Execute and/or manage projects, provide training
- V&V Expertise, tools, re-use, ...

- Q-tility.nl

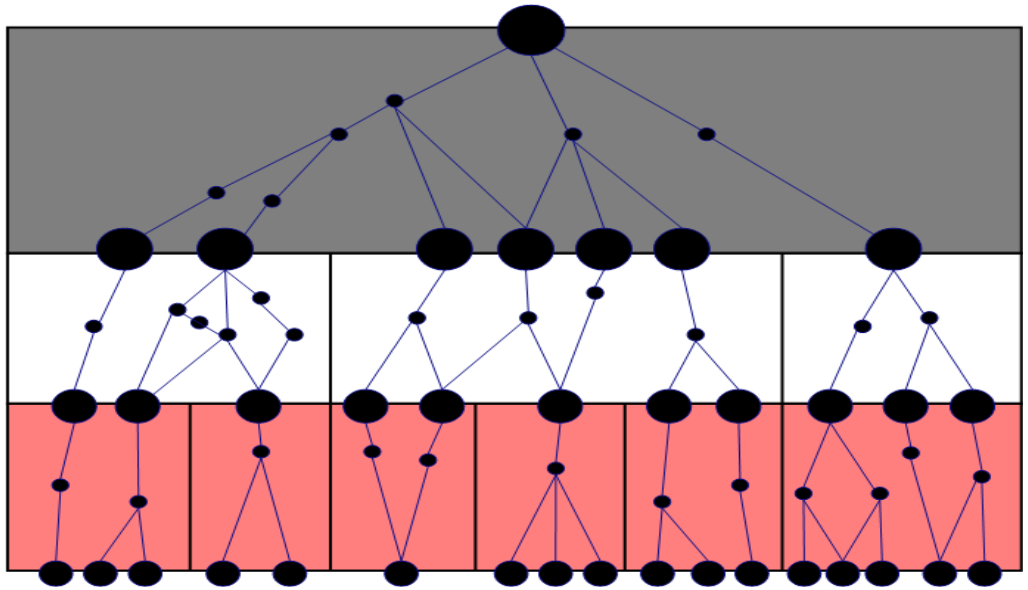
Advantages of the structured approach

- You start at the right point (effectiveness)
  - the risk of the user who applies the M&S results in the real world
- Re-usable domain knowledge (efficiency & effectiveness)
- Distribute the V&V work among all partners (efficiency)
  - V&V your own simulator (or you can assign it to another partner!)



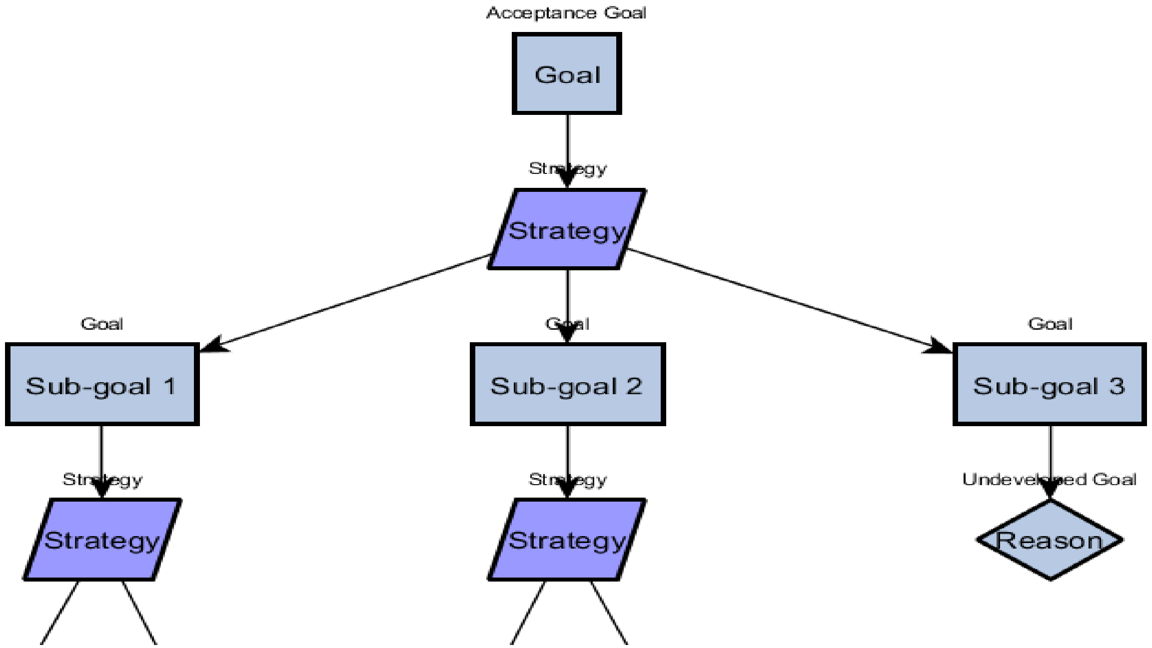
Advantages of the structured approach

- You can already do one branch of the AN while waiting (efficiency)
  - you can already identify problems and fix them
- If a new M&S System replaces a current one, you know immediately which tests have to be performed. (efficiency)



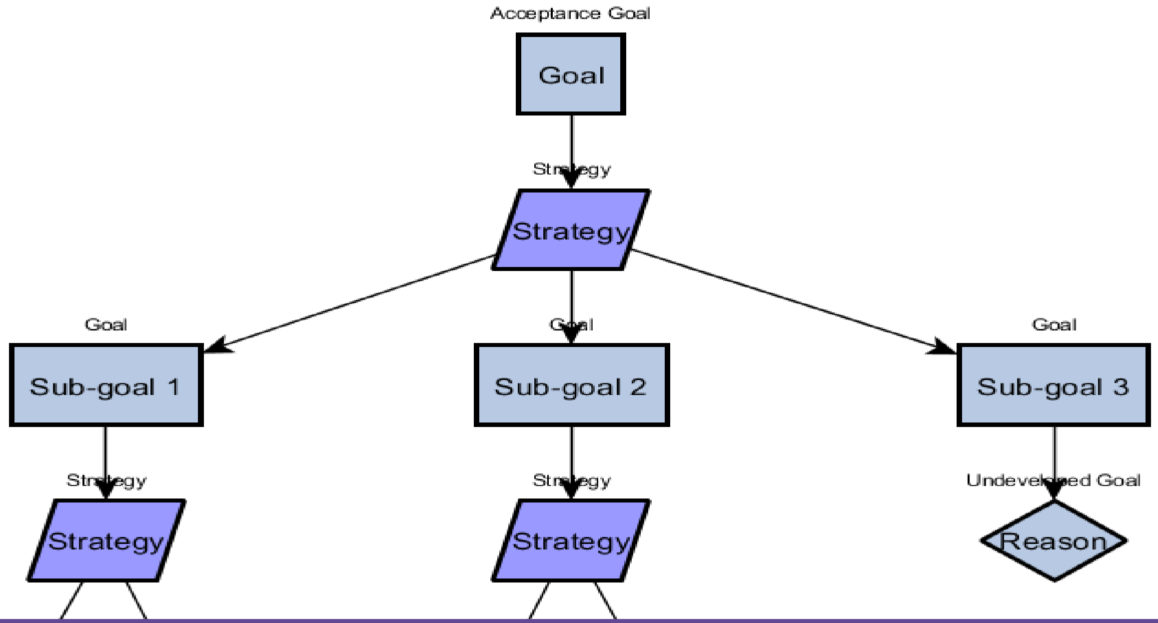
Advantages of the structured approach

- You have a good idea of how complete your V&V work is (effectiveness)
  - at every disaggregation you have to show if it is complete or not
- You can assign priorities based on the risk (efficiency)
  - disaggregate the risk over the sub-nodes



Advantages of the structured approach

- you can determine the required convincing force and assign resources such as budget, time, SMEs, etc. (efficiency)
- by standardizing the way the V&V work is documented, it is more easy to recall and re-use (efficiency)
  - re-use parts or the whole.
  - no big problem if a key-person leaves your organization



Advantages of the structured approach

- you can re-use the work over projects (efficiency)
  - if the M&S is re-used for a slightly different purpose, you can easily determine what additional tests have to be performed.
  - Add to what you already know -> more and more complete -> less chance you forget something (effectiveness)

Part 3

- You have to V&V
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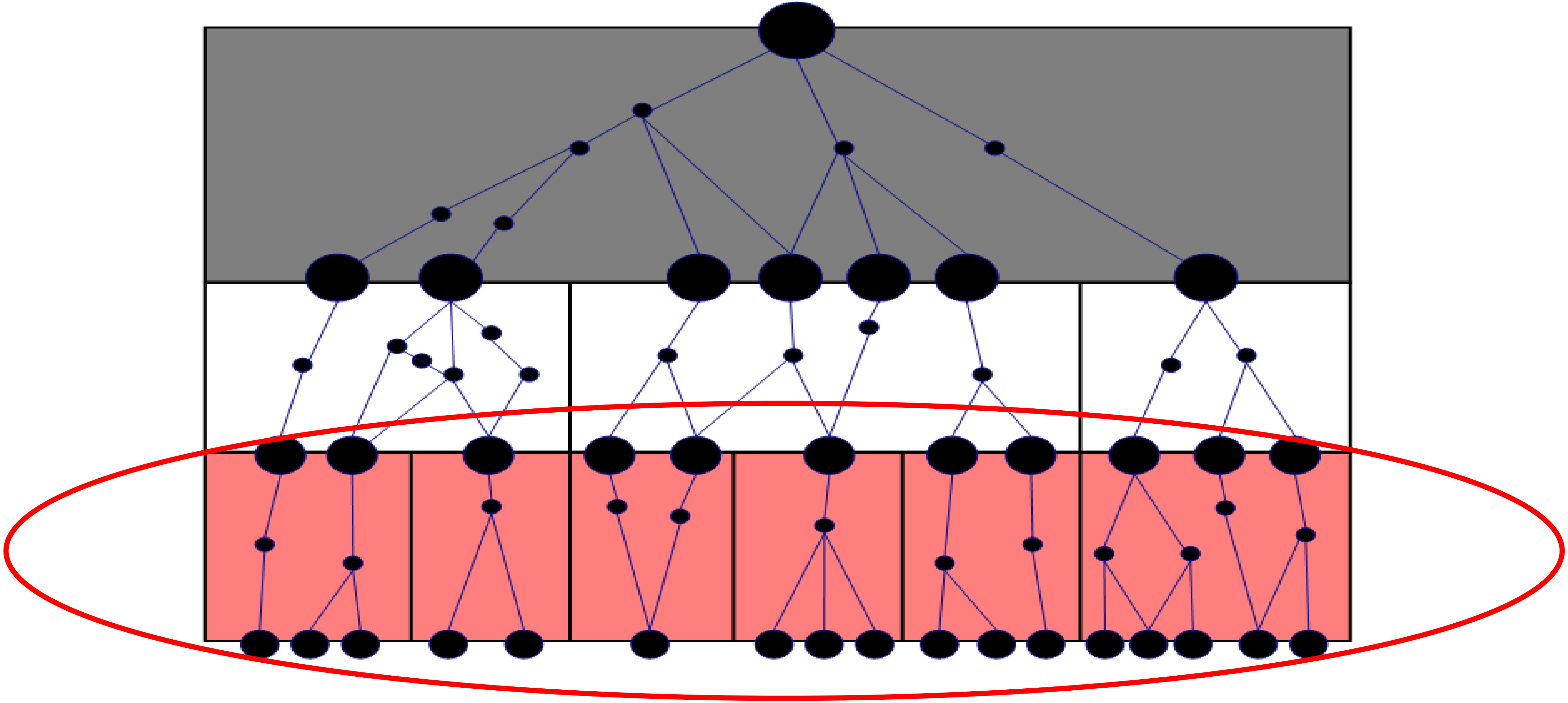


How to choose the right V&V technique

- Risk
  - The higher the risk, the more rigorous the technique
  - Expected residual uncertainty
- Available means
  - budget, time, knowledge, testing facilities, ...
- Referent data
  - knowledge of the real world
- M&S System availability
  - Access to development documents, M&S system internals
- ...

V&V Techniques

- Balci [1998]
- Sargent [2010]
- M. Petty [2013]

Informal	Formal	Static	Dynamic
• Audit • Desk checking • Documentation Checking • Face validation • Inspections • Reviews • Turing test • Walkthroughs	• Induction • Inductive Assertions • Inference • Logical Deduction • Lambda Calculus • Predicate Calculus • Predicate Transformation • Proof of Correctness	• Cause-Effect Graphing • Control Analysis • Calling Structure Analysis • Concurrent Process Analysis • Control Flow Analysis • State Transition Analysis • Data Analysis • Data Dependency Analysis • Data Flow Analysis • Fault/Failure Analysis • Interface Analysis • Model Interface Analysis • User Interface Analysis • Semantic Analysis • Structural Analysis • Symbolic Evaluation • Syntax Analysis • Traceability Assessment	• Acceptance Testing • Alpha Testing • Assertion Checking • Beta Testing • Bottom-Up Testing • Comparison Testing • Compliance Testing • Authorization Testing • Performance Testing • Security Testing • Standards Testing • Debugging • Execution Testing • Execution Monitoring • Execution Profiling • Execution Tracing • Fault/Failure Insertion Testing • Field Testing • Functional (Black-Box)Testing • Graphical Comparisons • Interface Testing • Data Interface Testing • Model Interface Testing • User Interface Testing • Object-Flow Testing • Partition Testing • Predictive Validation • Product Testing • Regression Testing • Sensitivity Analysis • Special Input Testing • Boundary Value Testing • Equivalence Partitioning Testing • Extreme Input Testing • Invalid Input Testing • Real-Time Input Testing • Self-Driven Input Testing • Stress Testing • Trace-Driven Input Testing • Statistical Techniques • Structural (White-Box) Testing • Branch Testing • Condition Testing • Data Flow Testing • Loop Testing • Path Testing • Statement Testing • Submodel/Module Testing • Symbolic Debugging

4 basic categories of tests

- Informal, Formal
- Static, Dynamic

- Informal
  - Usually executed and interpreted by humans.
  - Typically these require few resources
  - The convincing force depends on trust

- Techniques
  - Audit, Documentation Checking, Face validation, Inspections, Reviews, Turing test, Walkthroughs

4 basic categories of tests

- Formal
  - Based on mathematical proofs of correctness.
  - Application often limited due to large resource costs
  - The convincing forces of the V&V results are very strong.
- Techniques
  - Induction, Inductive Assertions, Inference, Logical Deduction, Lambda Calculus, Predicate Calculus, Predicate Transformation, Proof of Correctness

4 basic categories of tests

- Static
  - Can be applied early in the development process
  - Typically specialized tools are used
  - The required resources are normally limited.
  - Required access to documentation and half-products.
  - Convincing force is dependent on the rigor of the tests.

- Techniques
  - Cause-Effect Graphing, Control Flow Analysis, State Transition Analysis, Data Analysis, Fault/Failure Analysis, Interface Analysis, Semantic Analysis, Structural Analysis, Symbolic Evaluation, Syntax Analysis

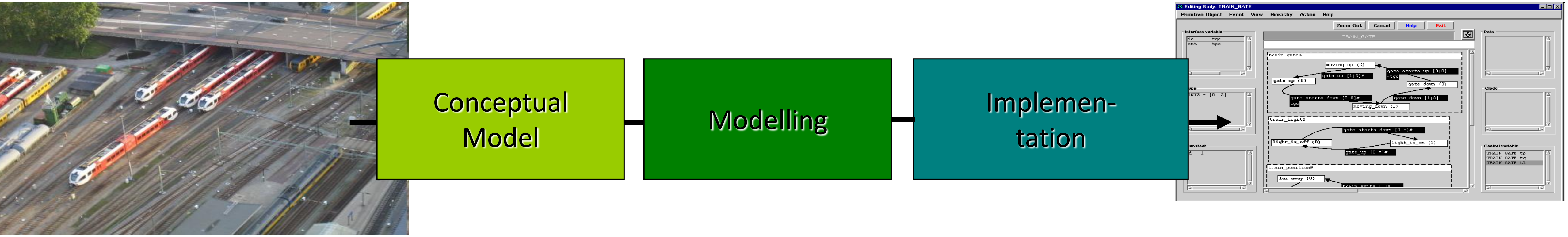
4 basic categories of tests

- Dynamic
  - Require execution of (part of) M&S System
  - The dynamic properties of the M&S System are studied
  - Typically specialized tools are used
  - The required resources are normally limited.
  - May require access to internals of the M&S System
  - Convincing force is dependent on the rigor of the test

- Techniques
  - Comparison Testing, Compliance Testing, Performance Testing, Security Testing, Standards Testing, Debugging, Execution Testing, Fault/Failure Insertion Testing

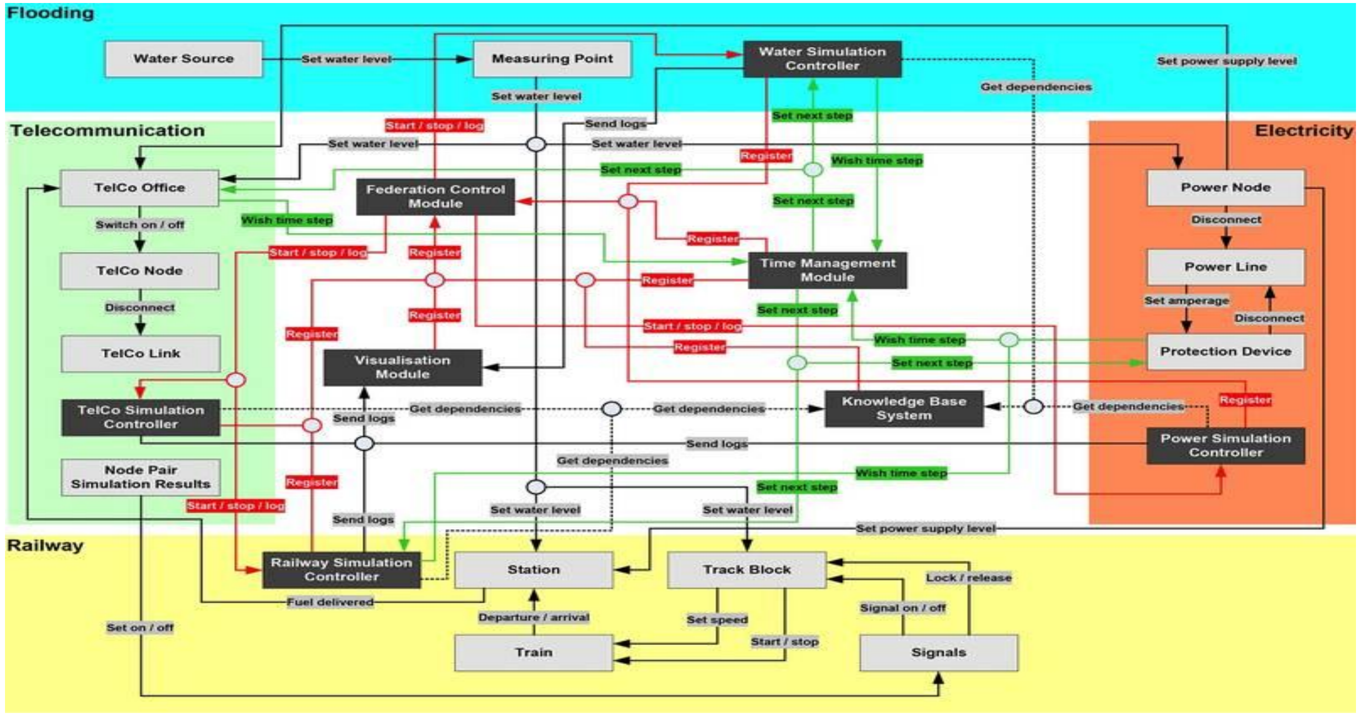
During development

- Static
  - models, design documents
- Dynamic when parts become available
  - (parts of) implementations
- Formal if you have sufficient resources
- Informal when you have sufficient SMEs



After development (but before use!)

- Dynamic
  - Components of the simulation, interoperability between components, emerging behaviour: cascading failures
- Informal
  - Face validation,
  - Walkthroughs



This lecture was about three things:

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References

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- SISO. GM-VV Vol. 2: implementation guide, SISO-GUIDE-001.2-2013, June 2013
- SISO. GM-VV Vol. 3: reference manual, SISO-REF-039-2013, December 2013
- Q-tility, q-tility.nl
- O. Balci, “Verification, Validation, and Testing”, in J. Banks (Editor), Handbook of Simulation: Principles, Advances, Applications, and Practice, John Wiley & Sons, New York NY, 1998, pp. 335-393
- Mikel D. Petty, “Model Verification and Validation Methods”, I/ITSEC tutorial 2013
- Robert G. Sargent, “VERIFICATION AND VALIDATION OF SIMULATION MODELS”, Proceedings of the 2010 Winter Simulation Conference, B. Johansson, S. Jain, J. Montoya-Torres, J. Hugan, and E. Yücesan, eds

Dependencies are part of the main set of threats to CI

The telephone fails as well ..

You are wrong!
That is the remote TV controller ..

CIPRNet

Critical Infrastructure Preparedness and Resilience Research Network

www.ciprnet.eu

Simulation of CI:
relevant applications

Marieke Klaver and Eric Luiijf

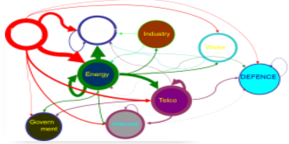
{marieke.klaver, eric.luiijf}@tno.nl

Modelling, Simulation and Analysis of Critical Infrastructure Training School (Edition 0)

Deltares Headquarters – Delft (The Netherlands) – 3-4 February 2014

Agenda

- Application of Modelling, Simulation & Analysis in CIP
  - different areas of application
  - added value for stakeholders
- Existing activities
  - USA: NISAC / HITRAC
  - Australia: CIPMA
  - CIPRNet consortium: I2SIM, DIESIS toolset, CISIA, more …
- Looking forward
- Questions/discussion



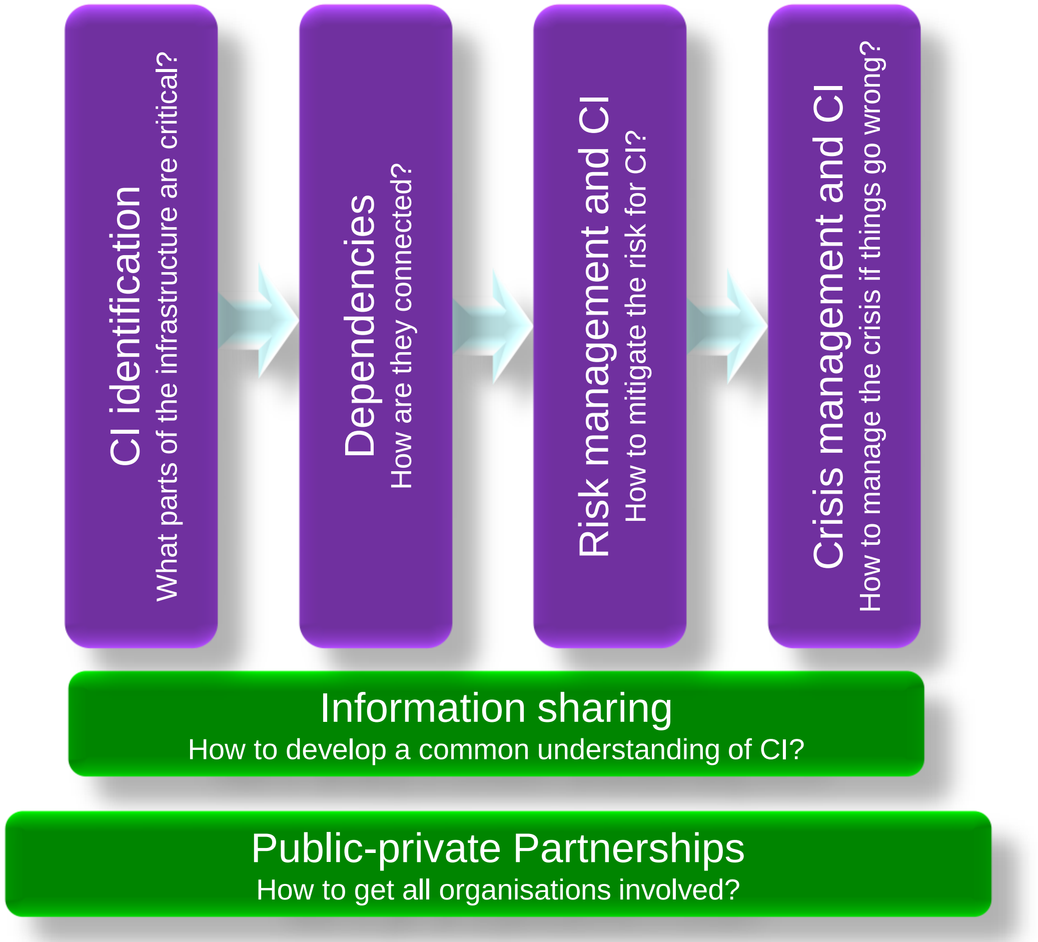
Objectives of this lesson

- Understand
  - the different areas of application of CIP Modelling, Simulation & Analysis (MS&A),
  - and the added value for stakeholders such as policy-makers, CI operators, emergency management (exercises, what-if, decision support)

- Understand the current activities in CIP MS&A and future directions

Main focus areas of Critical Infrastructure Protection (CIP)

- CIP in the EU and its Member States
  - EU since 2002
  - some of the main action lines of EPCIP may be supported by MS&A



Sheet may go to intro session; redesign graph readability

CIPR Net

TNO innovation for life

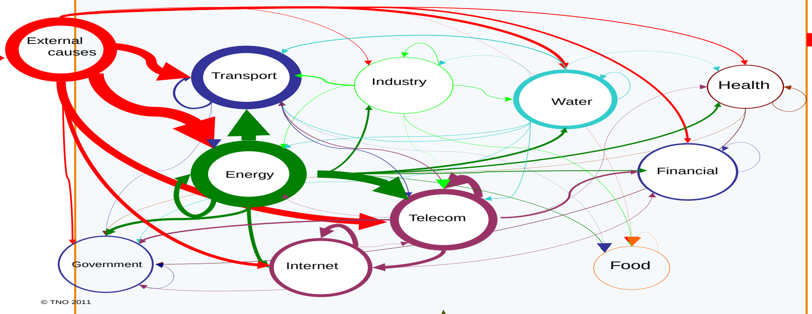
CI MS&A -- What is it all about?

Threat simulator(s)

e.g.
- extreme weather
- flood
- drought

- loss of sealines

Federation of CI simulations



Effects & consequence simulator(s)/model(s)
e.g.
- casualty
- affected area
- damages
- economic impact (long term)

visualisation & data exchange with existing emergency systems

STAKEHOLDERS

Sheet may go to intro session

CI simulation -- What is it all about?

CIPRNet

Threat simulator(s)

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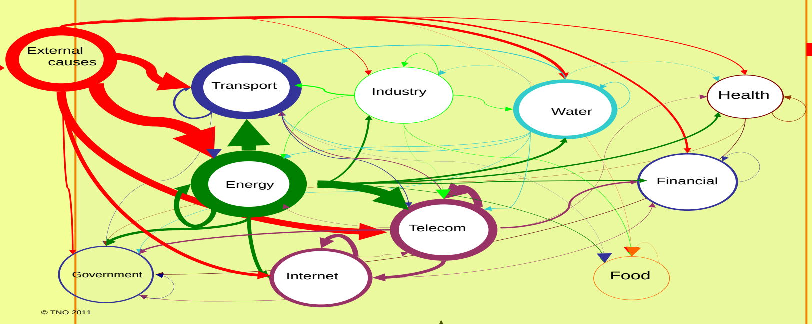
Federation of CI simulations



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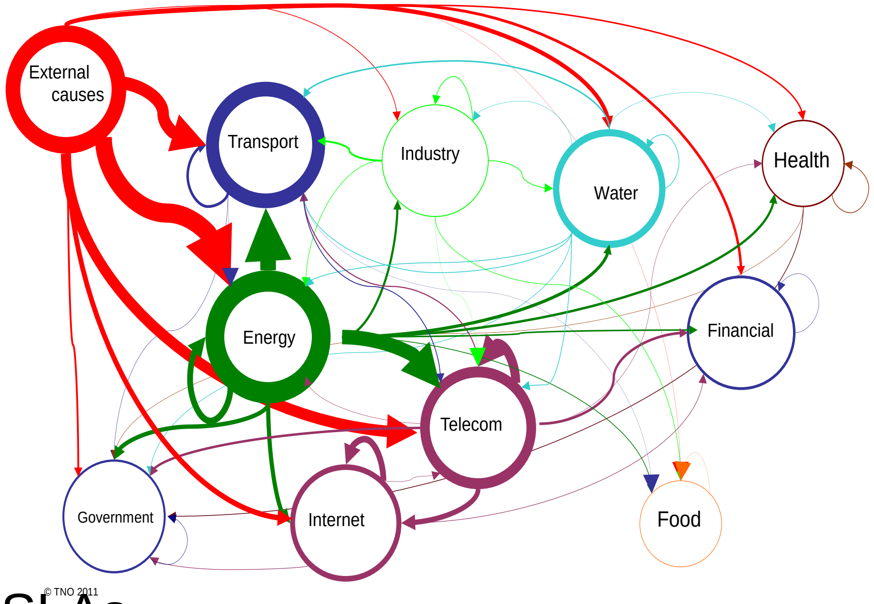
STAKEHOLDERS

Sheet may go to intro session

Application of MS&A in CIP – why?

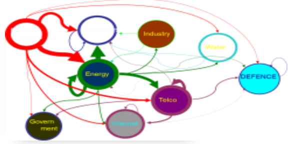


- To analyse complex infrastructure dependencies
  - different **modes of operation** of CI
    other sets and strengths of dependencies
  - cascading effects with various
    disruption & recovery characteristics; QoS - SLAs
  - **common mode failure**: simultaneous disruptions & combinations of CI cascades

- MS&A required for such analysis as
  - 1st order dependencies are simple; after x hours, y will happen
  - more complex effects are hard for humans to assess and present
    surprising outcomes other than the pre-programmed outcomes

Application of CIP MS&A (2)

- CIP MS&A may support **but has to prove its added value for stakeholders**
  - risk analysis and risk management
    (pro-action, prevention, preparation)
  - crisis management and response
    (prepare/exercises, response, recovery, aftercare)
  - CI resilience (CI design, what-if, exercises)
  - design of Next Generation Infrastructure



Risk analysis and CI

- Risk analysis (pro-action, prevention, preparation)
  - identifying risk scenarios and their impact on CI
  - all hazards, e.g. flooding, earthquakes, extreme weather, cyber attacks & failures, …

- CIP MS&A may help to assess the impact of different “what-if” scenarios and the effectiveness of countermeasures

Aggregation level

Machine, system

Company

Organisation, holding

National sector

National multi-sector

Multi-national / multi-sector

Main focus

Focus on impact on company

Focus on impact on society

finegrain .. coarse

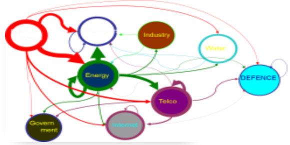
technical .. societal impact

Crisis management and response and CI

- Crisis management and response (prepare, response, recovery, aftercare)
  - identifying which CI may be effected
  - assess the impact of possible (sequences of) events
  - main stakeholders are crisis response organisations & CI operators

- MS&A may help to
  - assess effects of hazards on CI
  - assess effectiveness of countermeasures
  - perform a QUICK first order assessment
  - prepare decisions

  - identify lessons / better decisions by ‘replay’



Agenda

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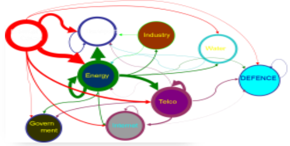


Activities: USA NISAC / HITRAC (1)

- US National Infrastructure Simulation and Analysis Center (NISAC)
  - Department of Homeland Security (DHS) as partner&sponsor
  - Sandia National Laboratories (SNL)
  - Los Alamos National Laboratory (LANL)

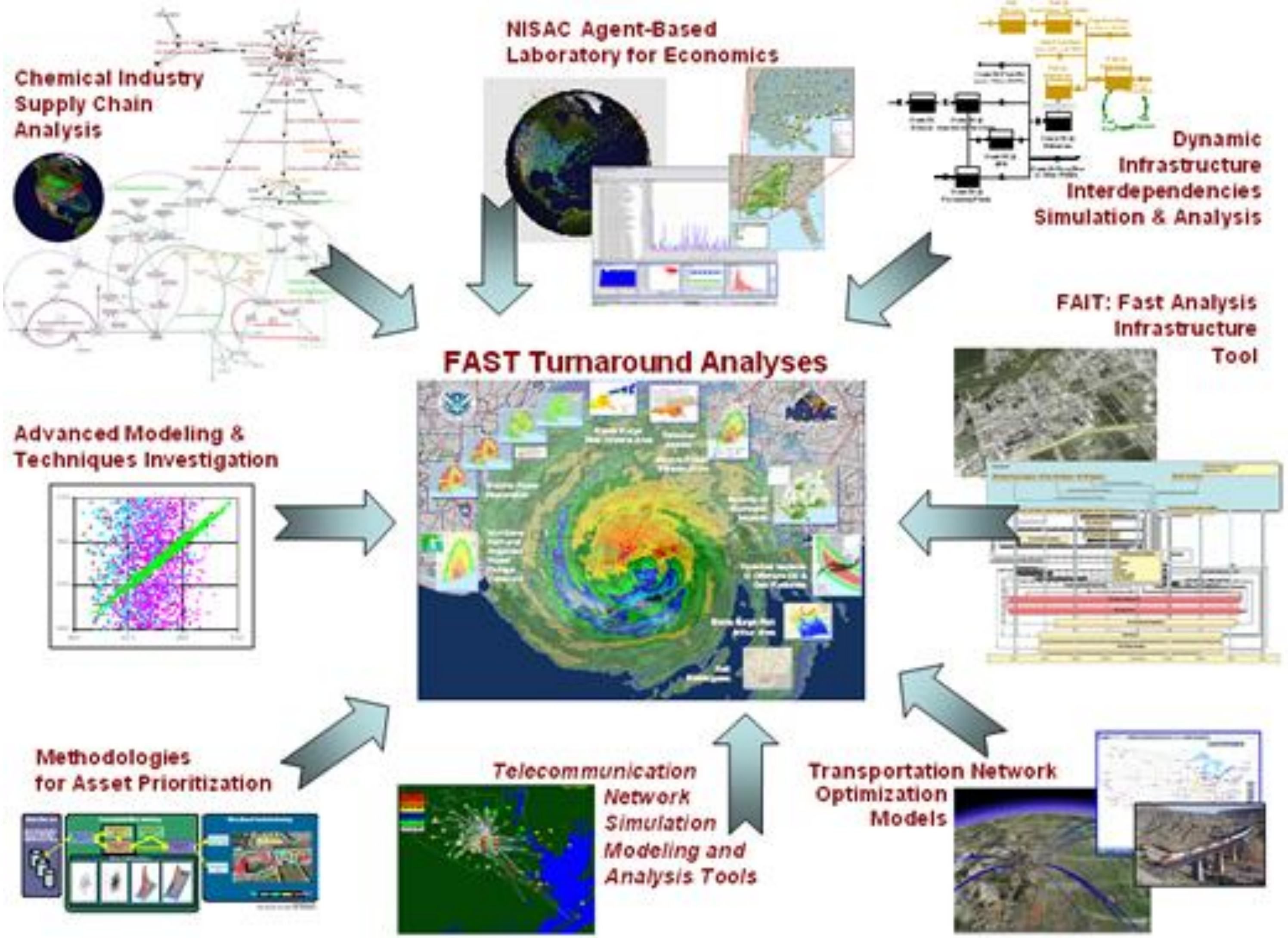
- Mandate and tasks
  - Congress mandated that NISAC serve as a "*source of national expertise to address critical infrastructure protection*" research and analysis
  - NISAC prepares and shares analyses of CI, including their dependencies, vulnerabilities, consequences, and other complexities

Activities: USA NISAC / HITRAC (2)

- NISAC has developed large-scale CI models and data sets to support decision-making **before and during** emergencies
  - assist in emergency management at various levels of authority (county, state, federal)
  - analyse the impact of possible scenarios
  - assess the effectiveness of possible mitigating measures
  - support of (ntl) crisis management in **hot phase** (HITRAC)

- Models supported HITRAC during major emergencies
  - Katrina and Rita hurricanes (2005)
  - Superstorm Sandy (2012)

Activities: Homeland Infrastructure Threat and Risk Analysis Center (HITRAC)



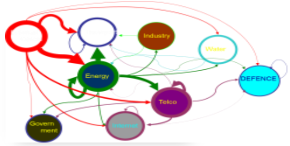
DHS
- Office for Infrastructure Protection
- Office of Intelligence and Analysis (OIA)

with NISAC

ALL HAZARDS

. prevention planning
. hot hazard analysis
. response planning
. base camp planning
. staging area

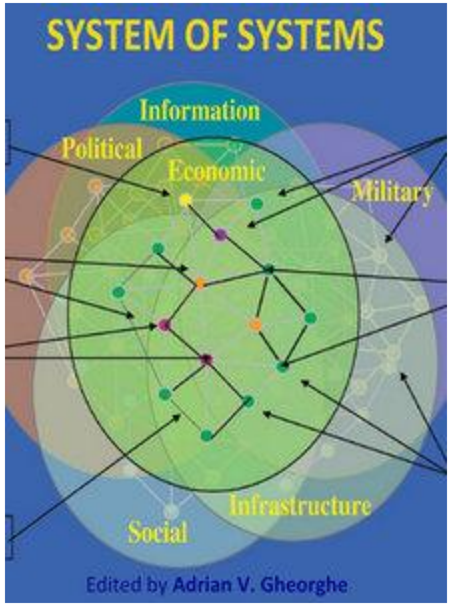
Source: DHS/HITRAC



Activities: USA Hampton Roads (Prof. Adrian Gheorghe, Old Dominion Univ.)

- Detailed modelling of transport, shipping, … (major container port; main naval port)
  - in support of (all hazard) emergencies, hurricane lane is one of them
  - planning evacuation routes
  - support crisis management

  - much is detailed operational & crisis management information (thus classified)



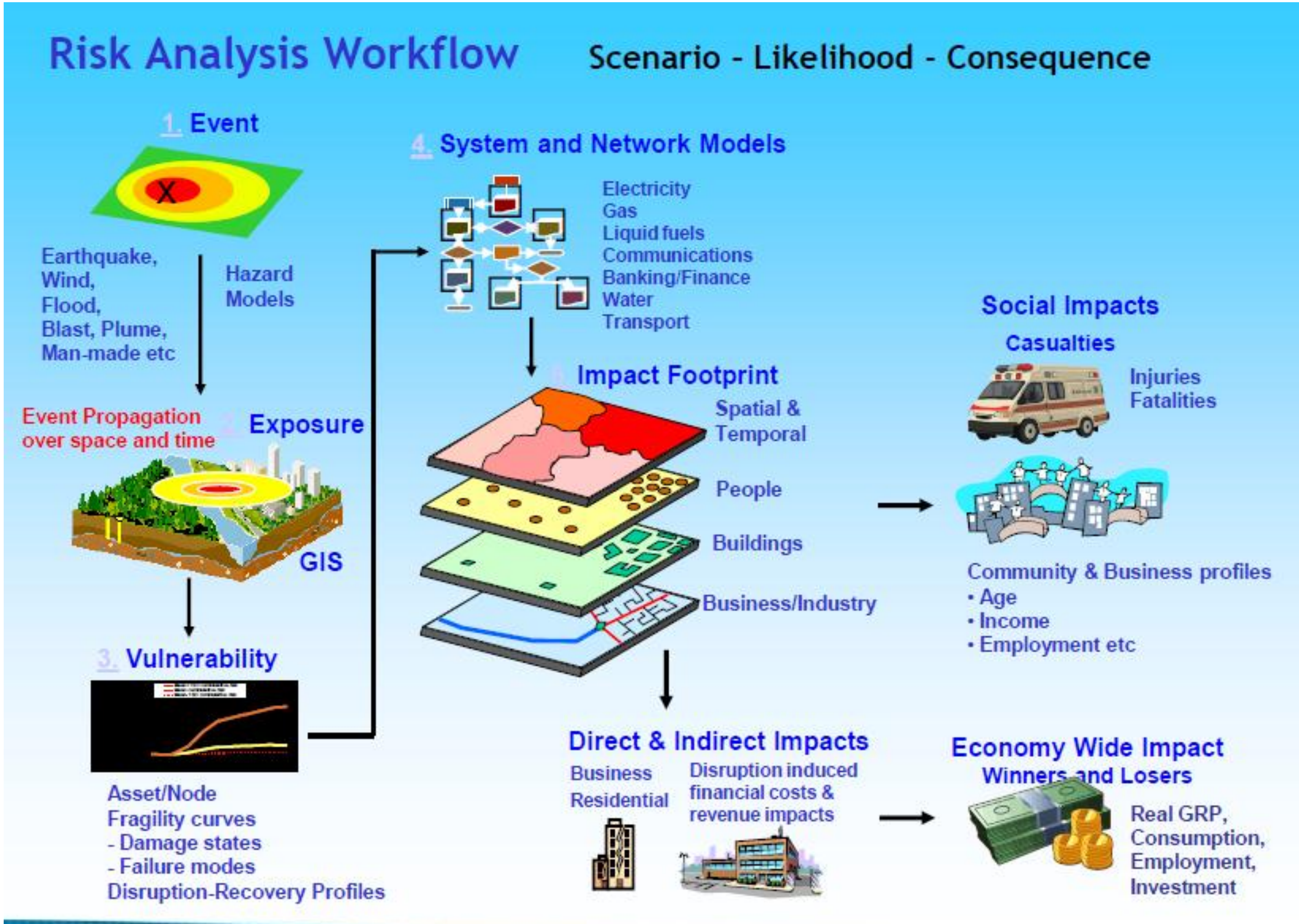
Activities: Australia CIPMA (1)

- AUS GOV Critical Infrastructure Program for Modelling and Analysis (CIPMA)
  - *governmental facilitation* of cross-sector analysis of the AUS CI sectors in a *joint public-private* approach *to increase CI sector resilience*
  - (single) sector by sector but stimulates inter-sector resilience studies

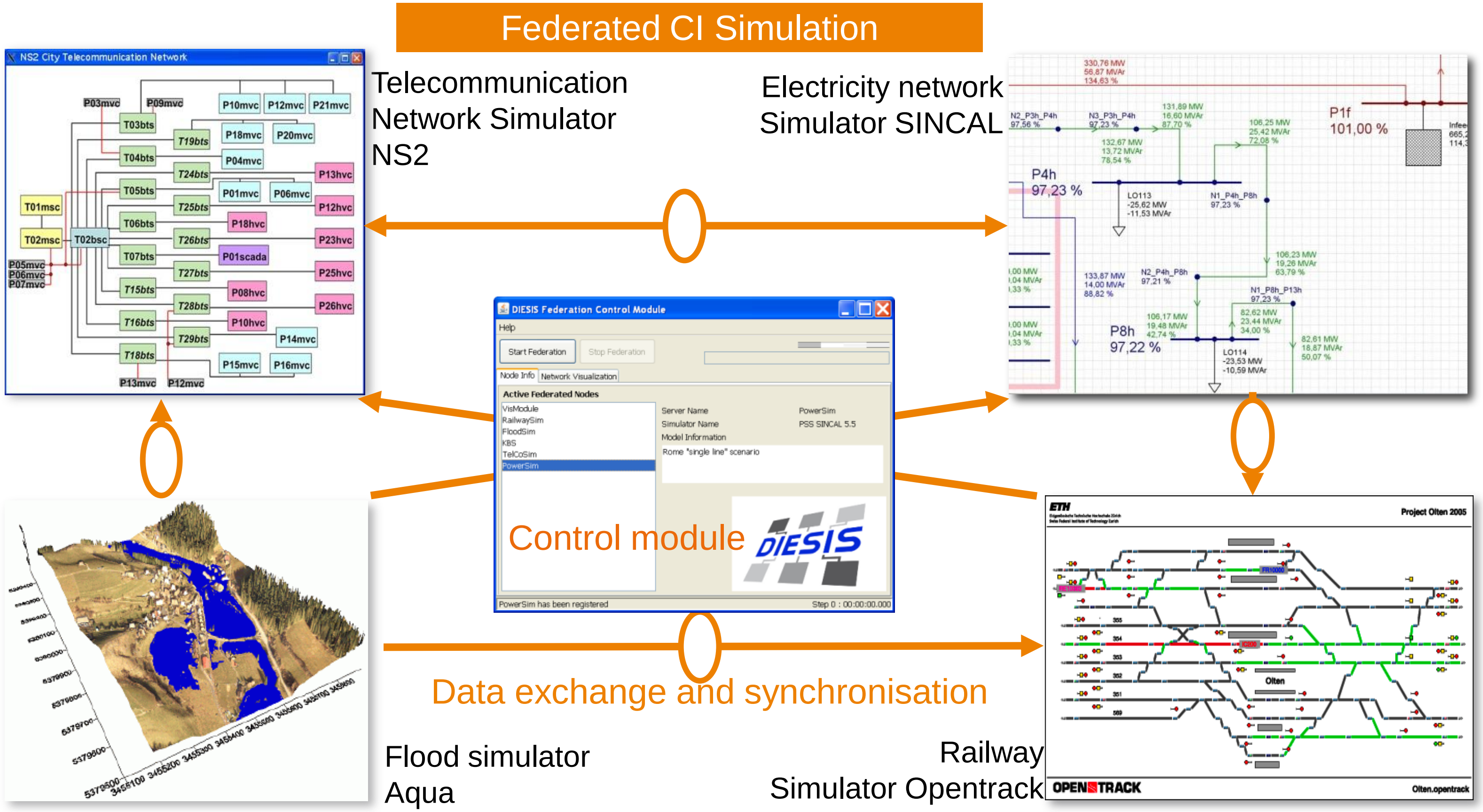
- Modelling capability is used to support CI sectors
  - strategic studies, fast turn-around analysis
  - *only* at request of a critical sector

AUS CIPMA

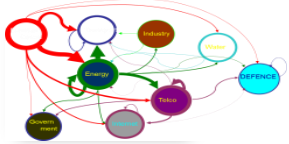
- CIPMA MS&A
  - reusability
  - consistency over time



Activities: EU CIPRNet consortium : DIESIS (1)

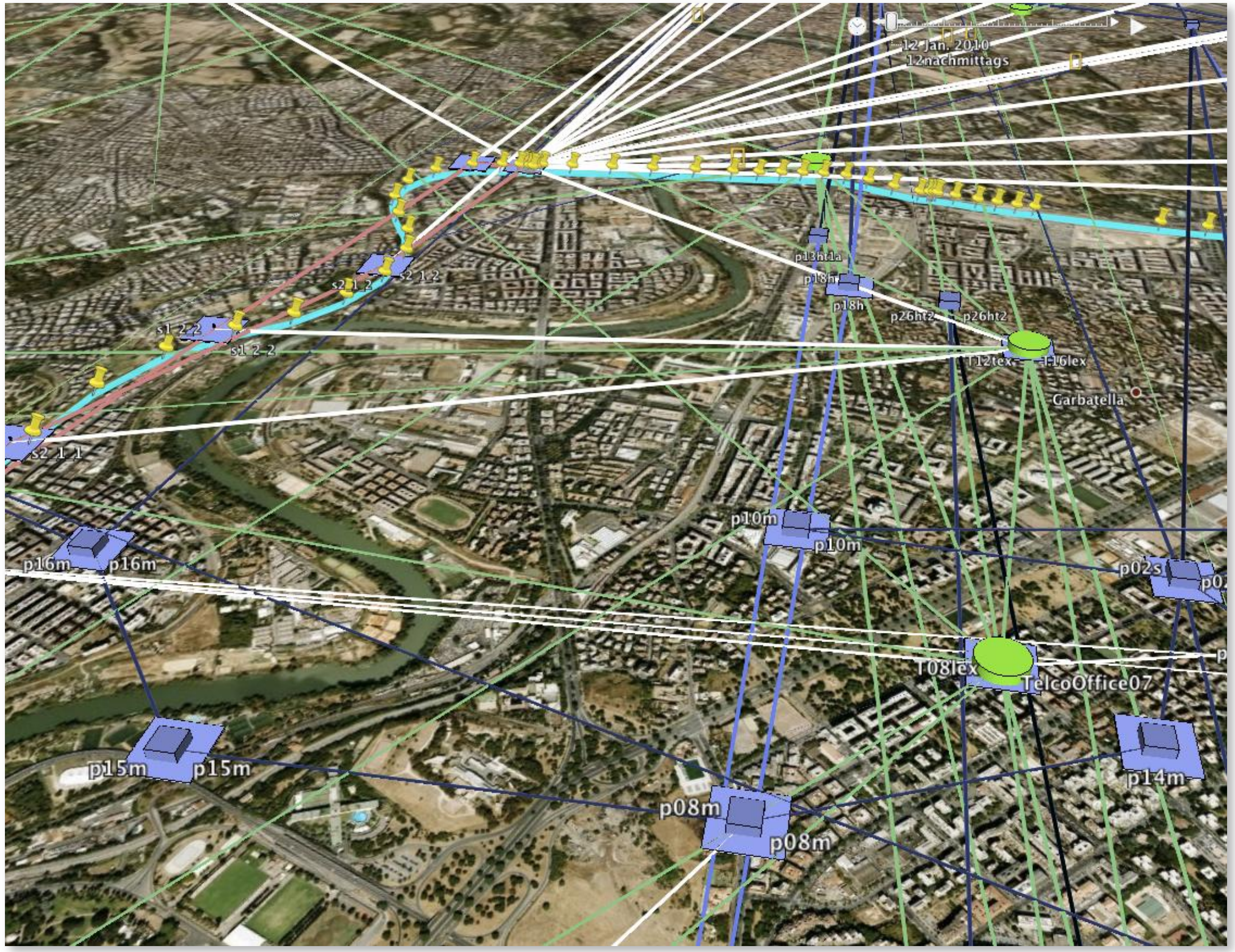


- details: see presentation by Andrij Usov

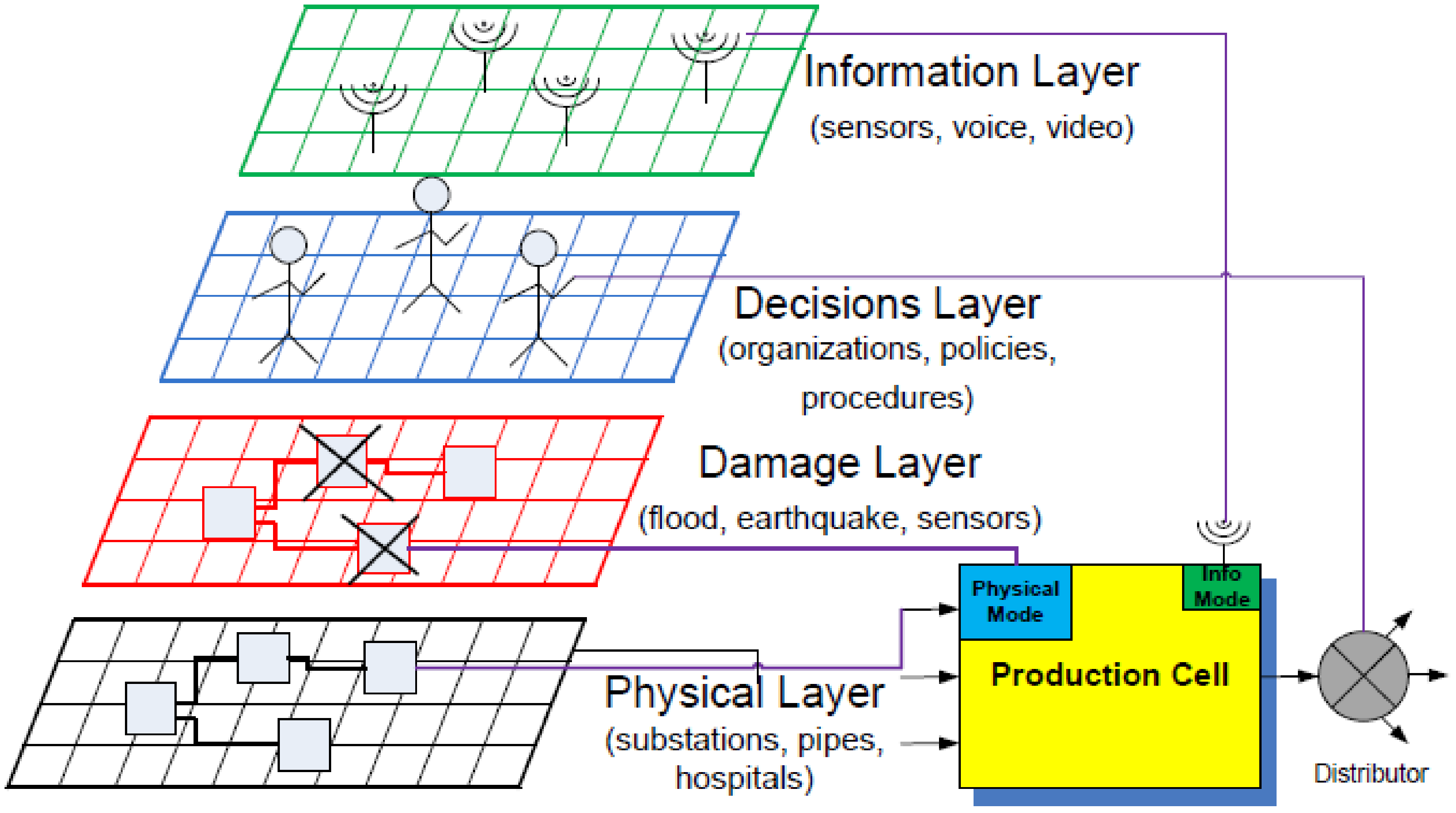


Activities: EU CIPRNet consortium : DIESIS (2)

- Example of analyses
  - visualisation of cascading effects
  - black lines indicate disrupted parts of the CI networks



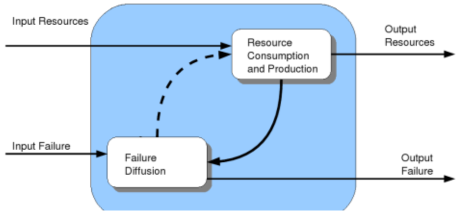
Activities: EU CIPRNet consortium : I2SIM

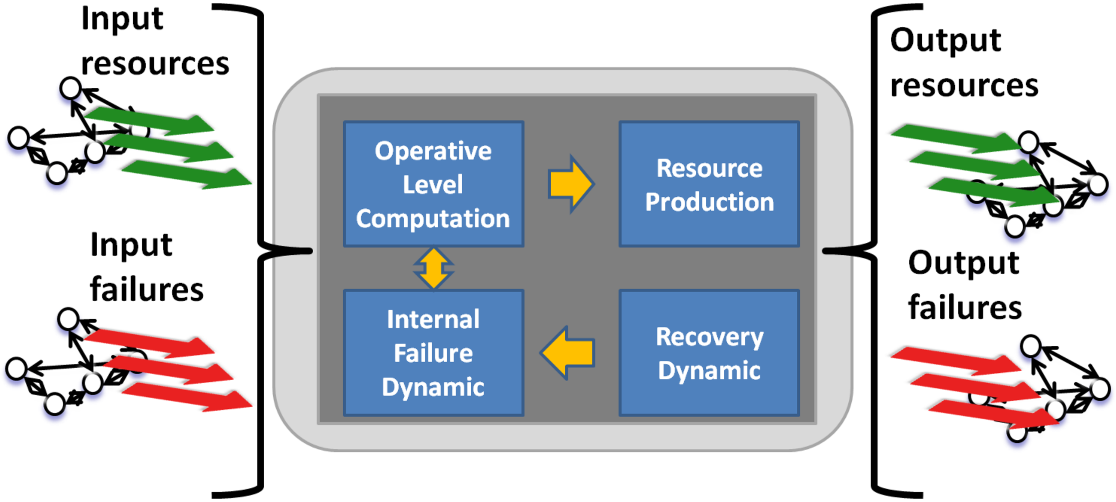


details: see presentation by Andrij Usov

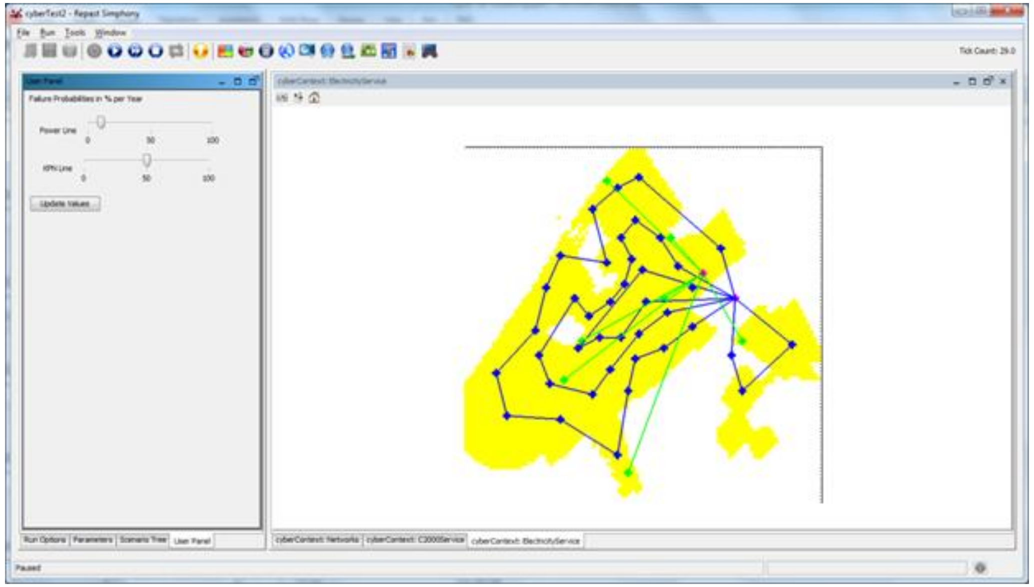
Activities: EU CIPRNet consortium : CISIA

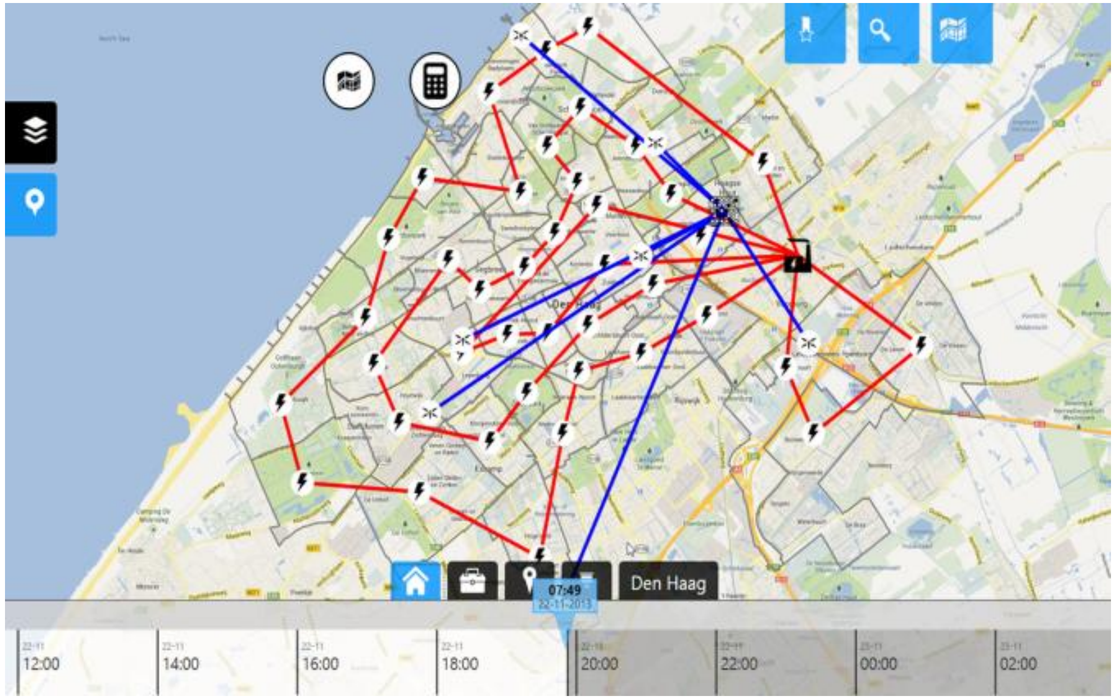
- Critical Infrastructure Simulation By interdependent Agents (CISIA) – *see Roberto Setola's lesson*





Activities: EU CIPRNet consortium - other toolsets

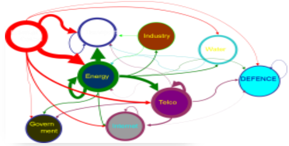




Successful MS&A requires more than building a model …

- DATA, DATA, DATA
  - collecting data requires a large effort
  - issues: how to collect CIP information
    how to protect this (often sensitive) information

- Acquiring sensitive CI operator data requires trust-building, but
  - some information is in the public domain
  - some models do not require fine grained data
  - governments may stimulate data availability



Successful MS&A requires more than building a model … (2)

- Public-private partnerships
  - collaboration between emergency management and CI operators is necessary
  - added value of (longer-term) MS&A (investment) shall be clear for stakeholders

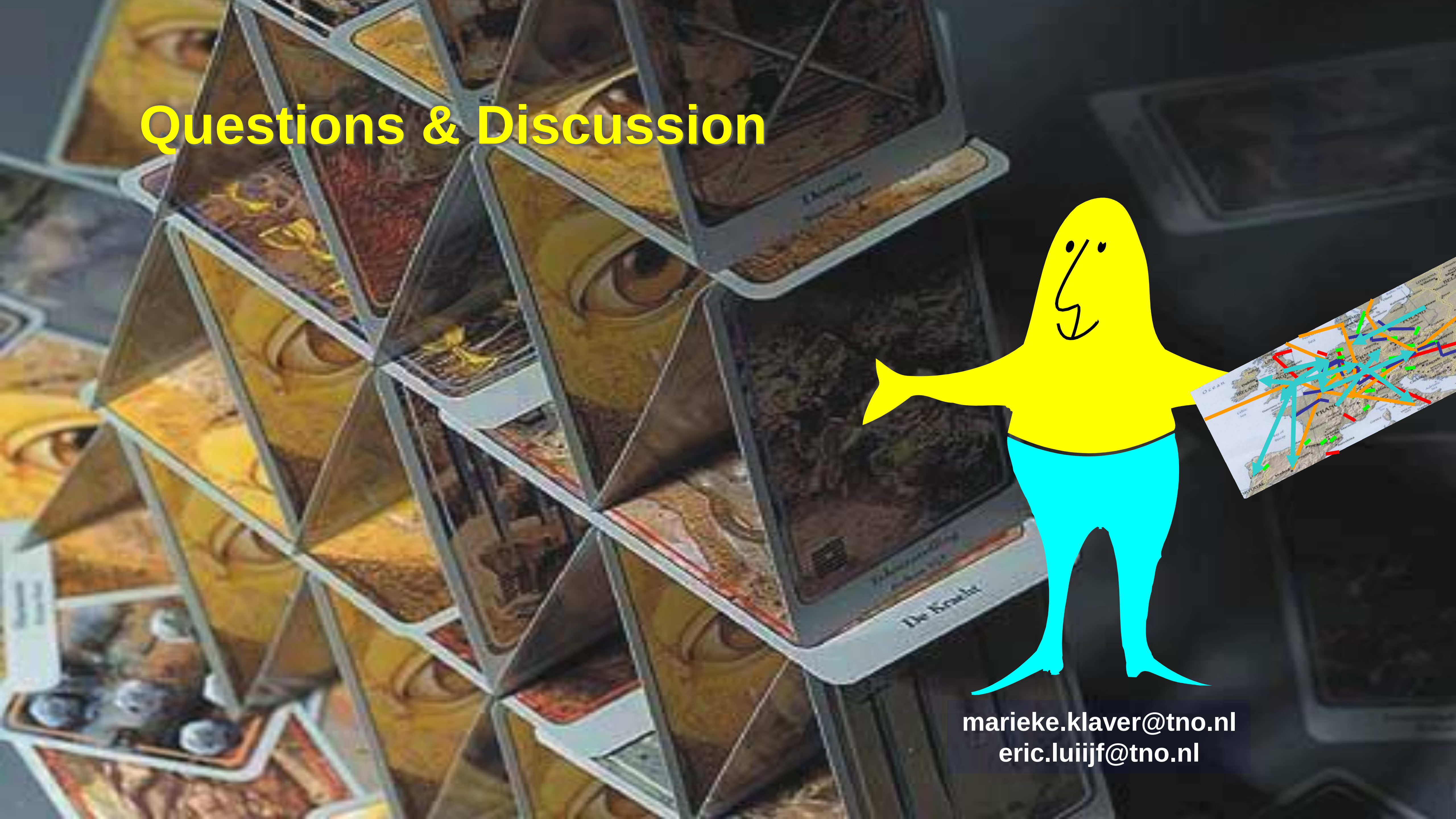
Looking forward

- CIPRNet is working towards a common MS&A toolset & (demo) data sets
  - based on good practices of e.g. NISAC

- CIP MS&A to assess the robust design of NGI, e.g. smart grids

- Coupling “cause” models and consequence/effects analysis models with CI models
  - economic impact (non-produce, damages)
  - how many people where in the impacted area? ➔ impact on evacuation, housing, psychological impact & behaviour of people, …
  - how many animals where in the impacted area? ➔ impact

➔ requires standard interfaces between components & GIS-based visualisation



Questions & Discussion

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Appendix C – List of Attendees

List of Participants

Zero - Edition, Deltares Headquarters, Delft (The Netherlands)

3-4 February 2014

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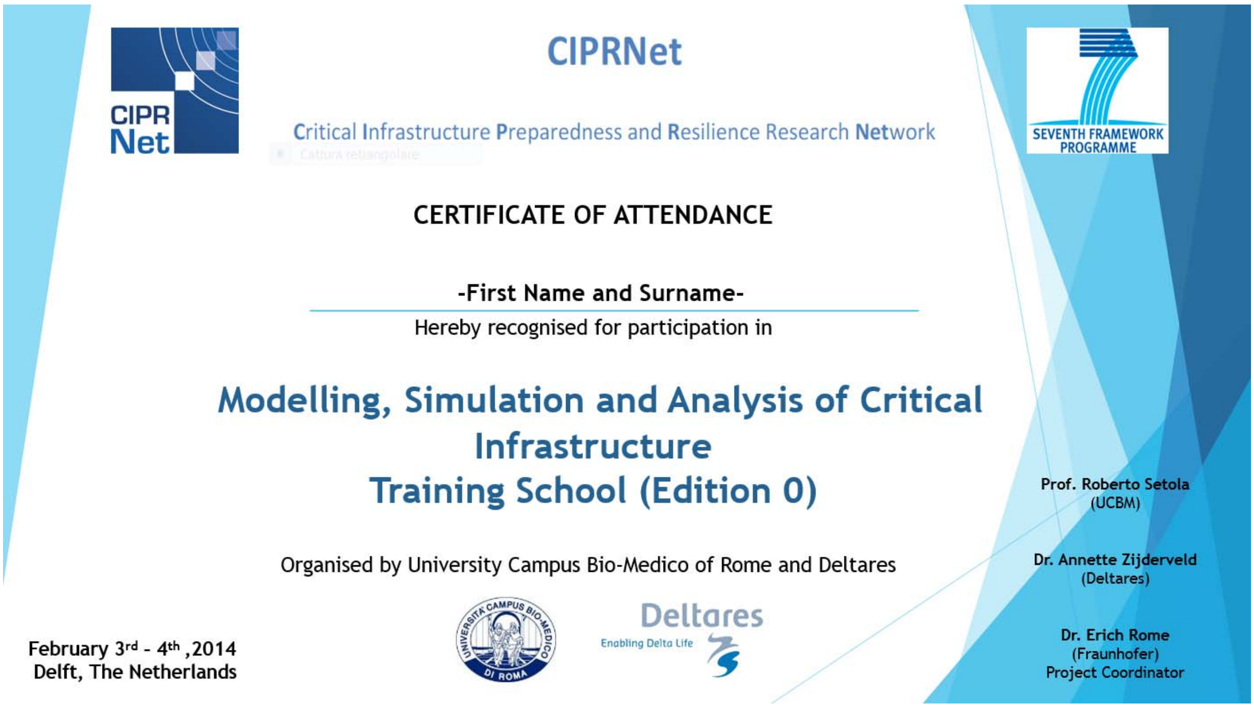
26	Zijderveld	Annette	Deltares	annette.zijderveld@deltares.nl

Appendix D – Certificate of Attendance



CIPRNet

Critical Infrastructure Preparedness and Resilience Research Network

SEVENTH FRAMEWORK PROGRAMME

CERTIFICATE OF ATTENDANCE

-First Name and Surname-

Hereby recognised for participation in

Modelling, Simulation and Analysis of Critical Infrastructure
Training School (Edition 0)

Organised by University Campus Bio-Medico of Rome and Deltares

February 3rd - 4th ,2014
Delft, The Netherlands

Deltares
Enabling Delta Life

Prof. Roberto Setola
(UCBM)

Dr. Annette Zijderveld
(Deltares)

Dr. Erich Rome
(Fraunhofer)
Project Coordinator

Appendix E – Customer satisfaction form feedback

General Aspects

Which were the most positive aspects of this training session?

- Very wide view on CI
- Overview of topics is very interesting. A large part of the CIP modelling palette is covered. Compliments on that!
- All presentations are relevant.
- Time keeping by chairs was well done
- I enjoyed the two days.
- It gave a lot of information and knowledge regarding the current state of critical infrastructure research.
- Gives the ability to interact with experts in the field.
- Provides directions regarding some of the software tools that can be furthered used.
- First time bringing most views together within the consortium.
- This training session provides a nice overview to what modelling options there are and could be useful to both researches and operators.
- Well-structured meeting, orderly discussion.

Which aspects should be improved in terms of topics, clearness, time scheduling?

- Synchronizing the several presentations in a format, so attendees keep track of where they are in the training.
- We need an overview presentation in the beginning of the course in order to link to the central theme!
- Each speaker should indicate the relevance of his/her lecture by summarizing the objectives of his/her presentation
- Each speaker should provide up to three take home messages
- A general feedback round would be required after the training
- The topic "operational decision support" should get more impact. The conventional way is a map (paper) with some flags on it, used in disaster management headquarters. However, what is now the state of the science?
- The information I received in advance was limited and late. I did not now the set up until few days before, and I did not really know what to expect. The questions related to 'information in advance' are hard to answer.
- Coherence between presentations should be improved.
- Refer to each other's presentations.
- Use the same example cases
- Use the same terminology
- By calling it a training/course, I expected to leave with some more tools/methods/approaches in my pocket that I could apply immediately. In the current training, some presentations are very generic. More applied approach would work to this.
- Better scheduling of the presentations and the order in which are given.
- Some of the content of the presentations need to be revised in order to be covered detailed during the certain lecture time.

- The hands on training example is quite weak which need to be better if possible in the next editions
- Not (yet) aimed at the intended stakeholders.
- Lacking overview, introduction, relationship between the topics, and logical order of the topics.
- Too much academic (Mohammed, Roberto) … way beyond the intended audience.
- There was a strong emphasis to how to integrate/federate different simulators and less emphasis on what simulators there are and which problems they cover. An operator would be first interested to a list of available tools and later on how to combine them in a unified tool. The practical training should be revised as there was lots of time lost on seeing the OpenMI tool but not any real practise in modelling. The attendant could be organised in groups and asked to perform an exercise of "federated" modelling even if a specific tool is not used. Forming a scenario where various CIs exchange outputs would help operators from various sectors comprehend potential dependencies and the need for projects like CIPRNet to assist them in simulating more complex scenarios.

Notes (please provide general comments and suggestions)

- We would like to propose the network exercise from day 2 during day 1 and we would prepare such an exercise in advance
- The scores on this evaluation form are dependent on the audience of the real course. For me personally: to really learn from it, the presentations do not go in enough depth.
- General remark for all speakers: listen carefully to the questions and try to understand them before starting to answer, maybe even cross check. Mismatching answers give unprofessional impression.
- There are many presentations especially on the first day, which leads to a lot of information to be processed. Consideration might be to schedule one OpenMI session less (there are four in the current schedule now) and place one presentation from the first to the second day. The Second day is 'lighter' also because of the practical session.
- Overall, I believe it was a good start, the general base is good and with all the comments and suggestions, the next editions will be further improved. Some of the lectures (see the comments in the next section) with the collaboration of the presenters need to be revised and better connected to avoid confusion and repetition on some of the topics. The hands on training should be better and can be done in parts, were the presenter first explains what need to be done in certain steps and then the trainees can complete the exercise with the help of the presenter and others (from the training team) that can move around making sure that all the steps are followed correctly and no one is left behind.
- When filling in the first question per lecture, one writes comments, which are asked later. Please rearrange questions in a more logical order or ask clearer questions.
- What is your overall opinion about this training edition? Not (yet) aimed at the intended stakeholders
- Is the time scheduling adequate? Too much send mode only.. no time for reflection, discussion …
- Did the training contents covered your expectation? Hands-on did not reflect the intended integration – interaction with CI. Was merely how to couple and run two "local" models (note: remark is from the view of intended stakeholder; not about

the nice quality of the demo/hands-on)

- The presentations should have a more unified format (Slide numbers, logo). The contents should be presented as a unit and not individual lectures by invited speakers. One way is to link them with the CIPRNet project whenever possible (this is a chance of dissemination for the project anyway) and the idea to have an introductory lecture and a course map. The lectures should offer additional reading material to the attendants. Some lectures have one sentence abstract and some paragraph. They should have a similar level of abstraction.