2nd ERNCIP Conference
"Dissemination, Exploitation and New Initiatives"
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European Commission
Charlemagne Building, JENK Room
Rue de la Loi 170, 1040 Brussels

European Commission
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POLITECNICO DI MILANO





Dynamic Functional Modelling of Vulnerability and Interdependency in Critical Infrastructures (DMCI)

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Politecnico di Milano, Italy

Agenda

- Modelling and simulation of interdependent CI systems
- DMCI modelling approach and capabilities
- DMCI modular implementation and SW tool
- DMCI application in the context of a Regional CIP-R programme
- Conclusions

Approaches to Modelling Interdependent Critical Infrastructure systems

Ouyang's state-of-the art review (2014)

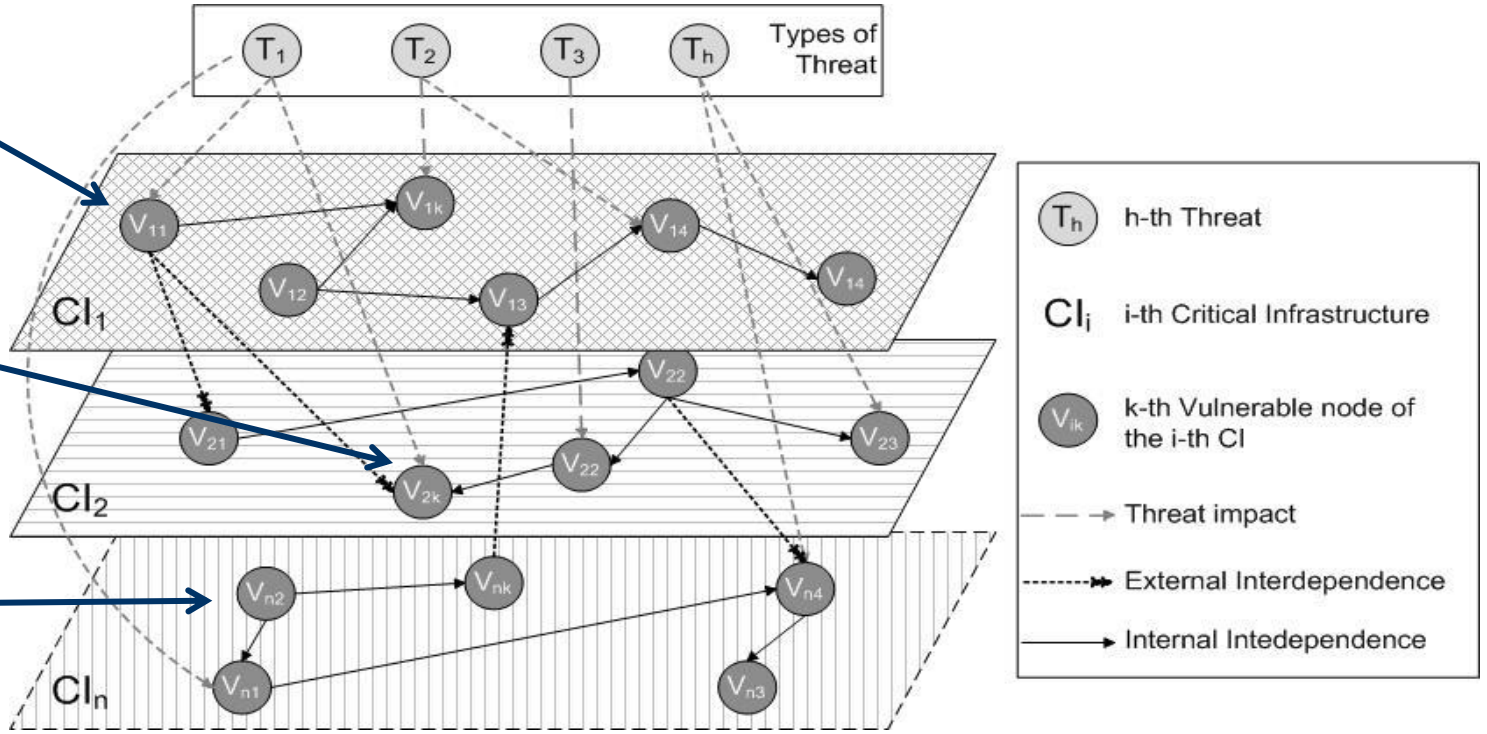
Approach type	Sub-approach	Quantity of input data	Accessibility of input data	Types of interdependencies	Computation cost	Maturity	Resilience
Empirical		M, L	M	P, C, G, L	S	M	1.3,2.3, 2.4, 3.3
Agent-based		L	S	P, C, G, L	L	L	1.1, 1.2, 1.4, 1.6, 2.1, 2.5, 3.1, 3.3
SD based		M, L	M	P, C, L	M	L	1.6, 2.5, 3.3
Economic theory based	Input output	M	L	P, C	S	L	1.3, 2.3, 2.4, 3.2
	Computable general equilibrium	L	M	P, C, G, L	M	M	1.3, 1.6, 2.3, 2.4, 2.5, 3.2,
Network based	Topology-based method	S, M	M	P, C, G, L	S, M	L	1.3, 2.2, 2.3, 3.2, 3.3
	Flow-based method	L	S	P, C, G,L	L	L	1.3, 1.5, 1.6, 2.2, 2.3, 2.4, 2.5, 2.6, 3.2, 3.3, 3.4
Others	HHM	L	S	P, C, L	S	S	1.6, 2.5, 3.3
	HLA based	L	L	P, C, G, L	L	S	1.1–1.6, 2.1–2.6, 3.1–3.4
	PN	M, L	M	P	M, L	M	1.3, 1.6, 2.3, 2.4, 2.5, 3.3, 3.4
	DCST	M, L	S	P, C, G, L	M	S	1.3, 1.6, 2.3, 2.4, 2.5, 2.6, 3.3, 3.4
	BN	M, L	S	P, C, G, L	M	S	1.3, 1.5, 1.6, 2.3–2.6, 3.3, 3.4

- **Flow-based methods**: nodes and edges representing the infrastructure topologies have the capacities to produce, load and deliver service (Network-based approach).
  - Large amount of data required and confidentiality issues
  - All types of interdependency: Physical, Cyber, Geo, Logical
  - Highest potential to model all the resilience capabilities: robustness, absorption, restoration

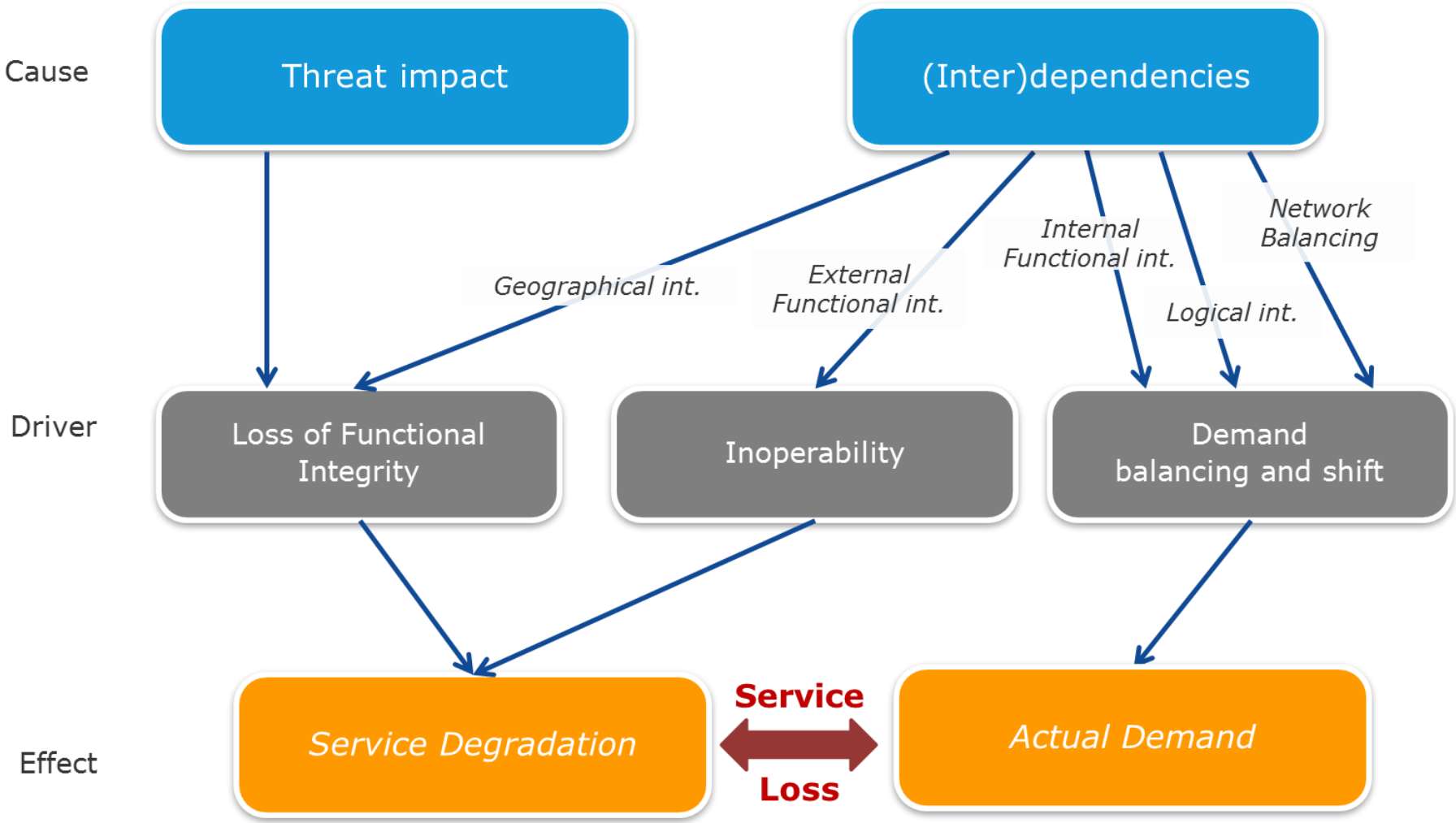
DMCI modelling approach
Key features

- **Propagation of inoperability and demand variations** throughout nodes within and between (inter)dependent CIs.
- Quantification of **functional (physical) and logical dependencies** based on service demand and service capacity parameters
- **Continuous simulation**





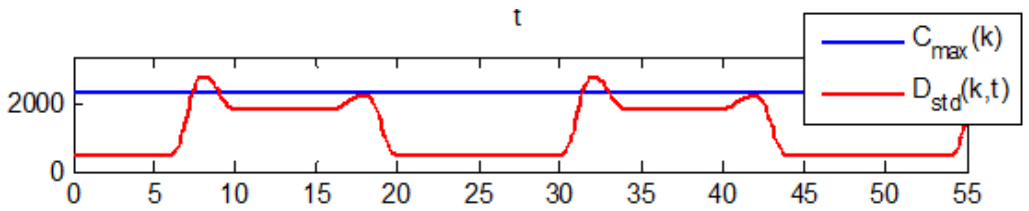
DMCI modelling approach
Assessment of Service disruption and loss



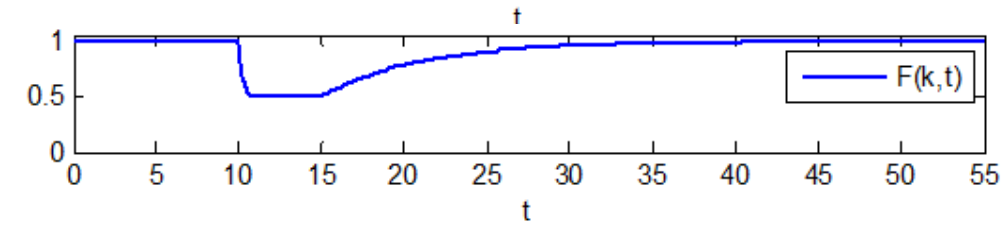
DMCI modelling approach
Determining the state of the node

Maximum Capacity

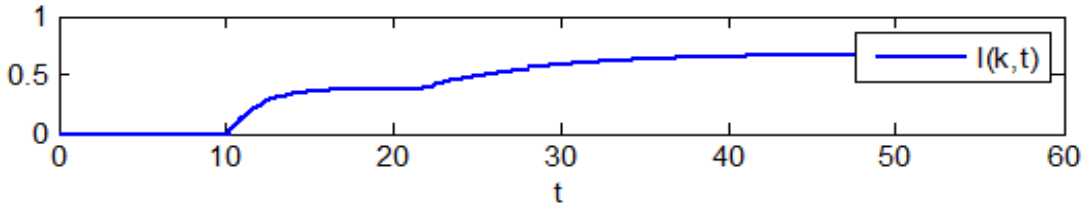
Nominal Demand



Functional Integrity

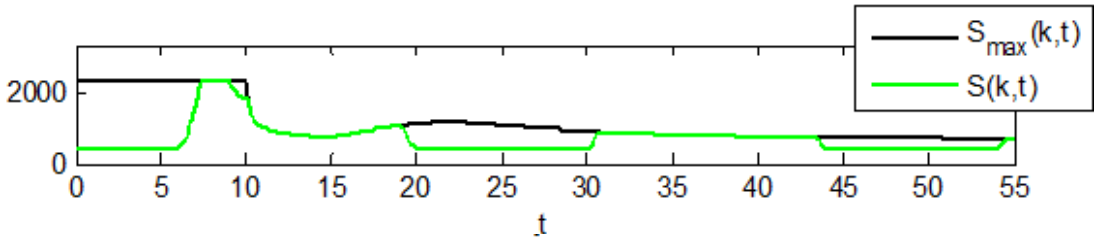


Inoperability

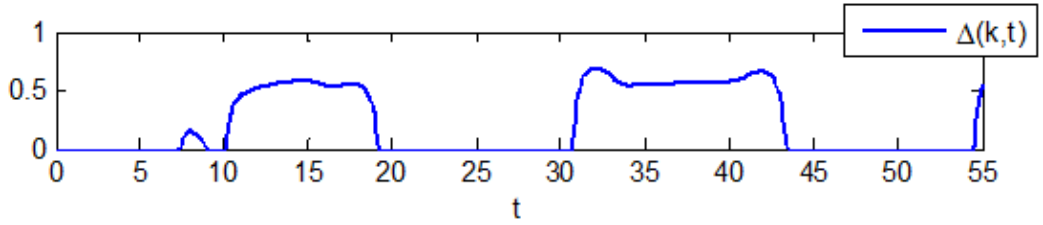


Maximum Service

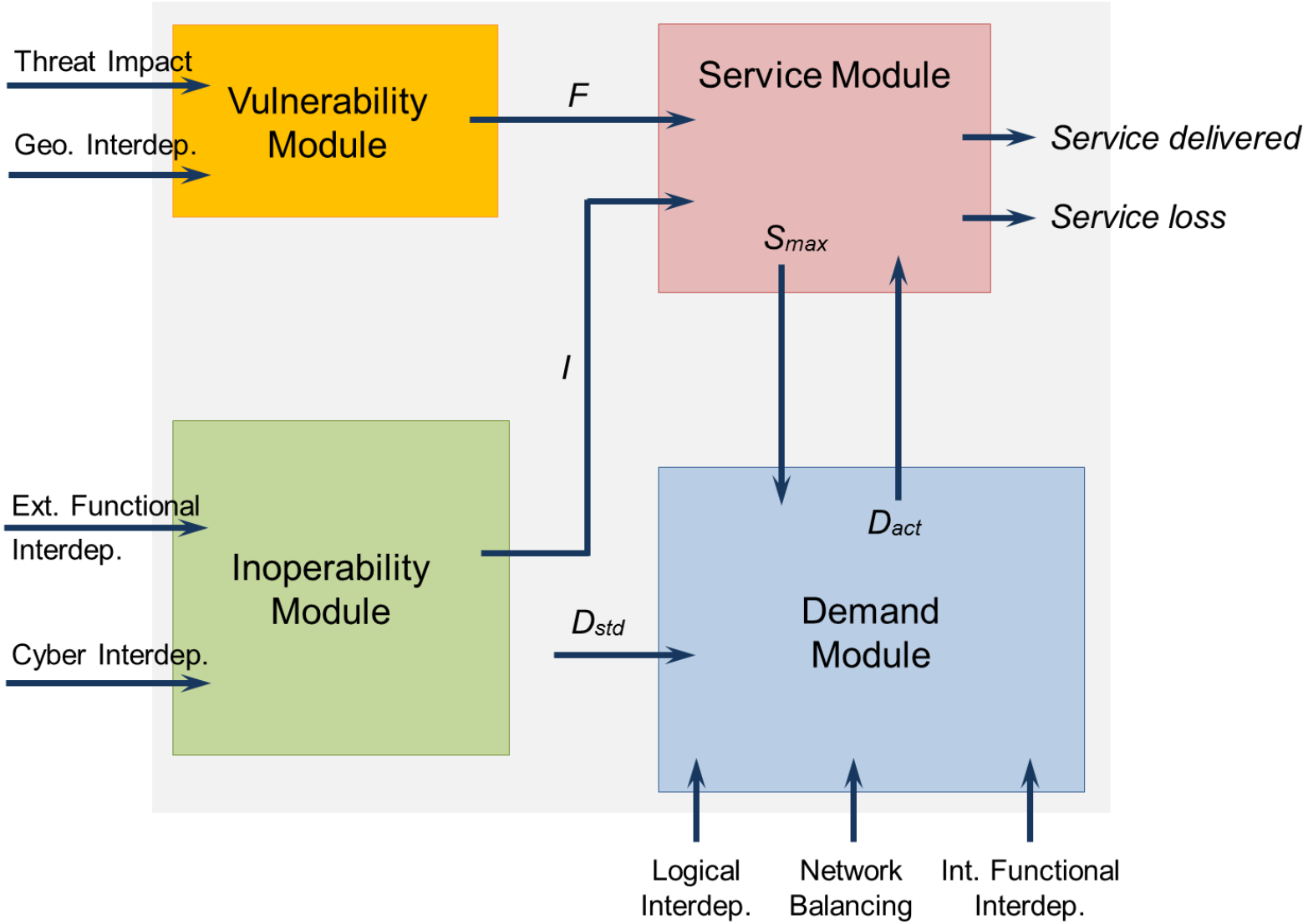
Delivered Service



Service loss



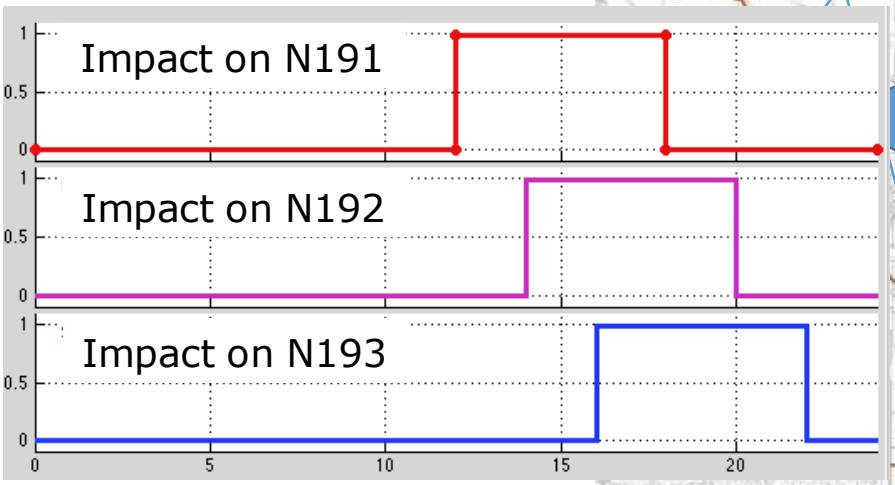
DMCI Modularization
Modular specification of the Vulnerable Node

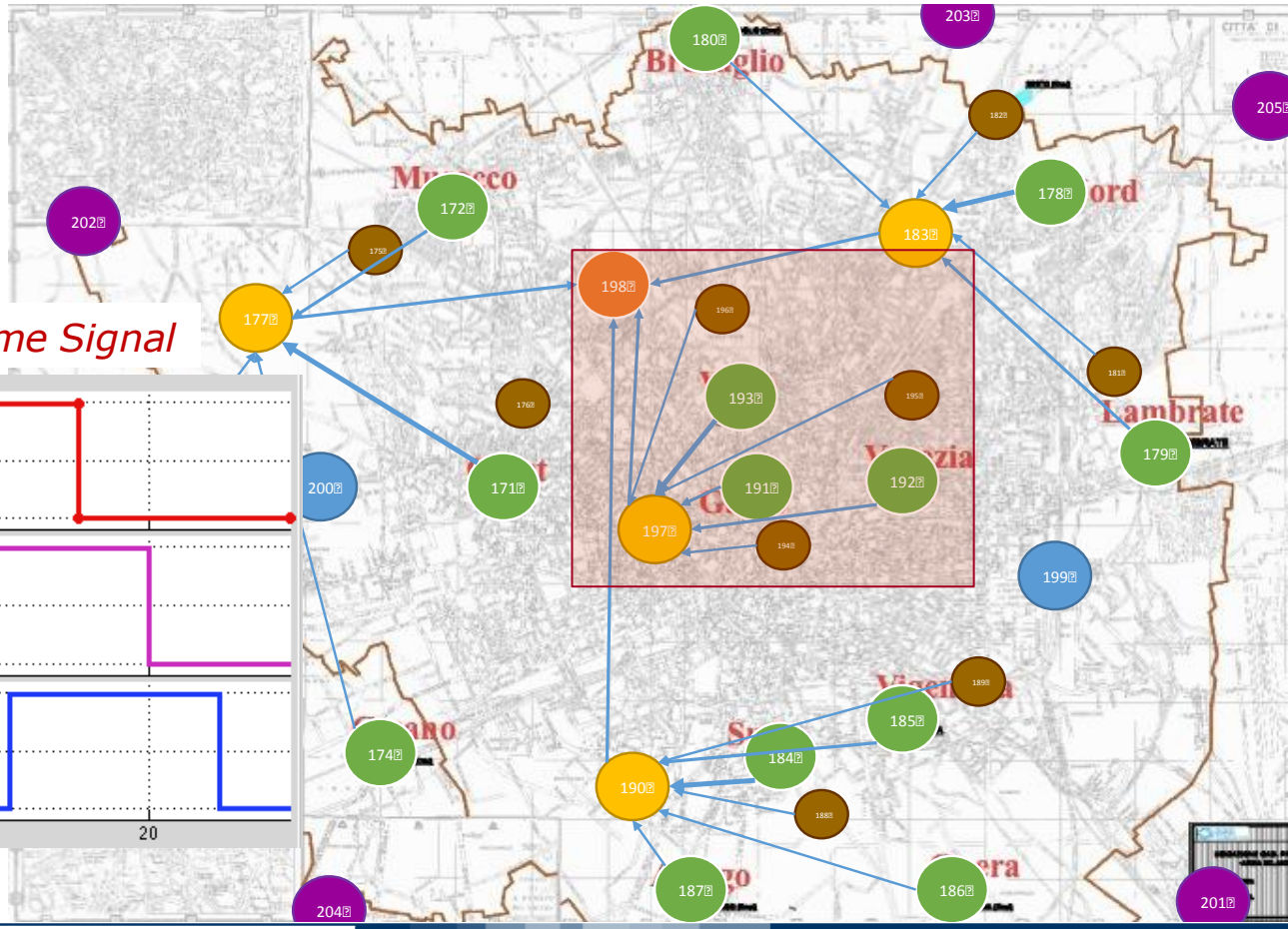


DMCI application to heterogeneous CI
Example – Electricity grid

- Milan metropolitan area
- Multiple failures at distribution grid level
- Available spare capacity in transformation cabins and by grid balancing

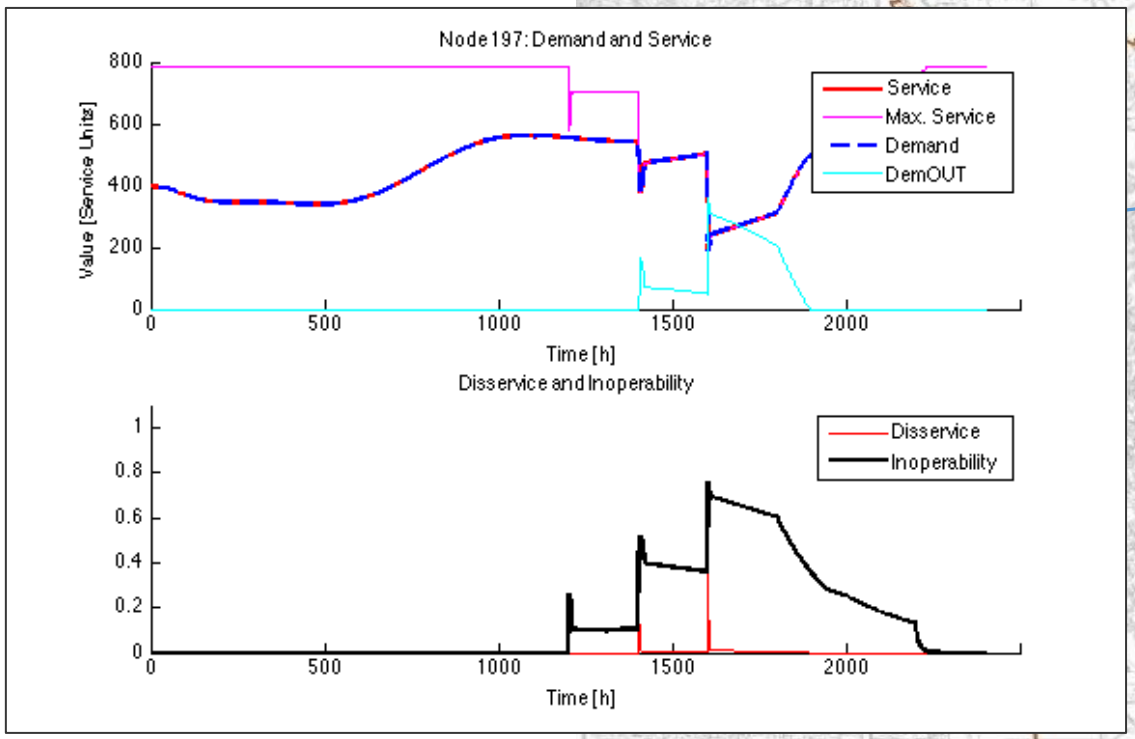
Multiple Step Threat Node's Time Signal

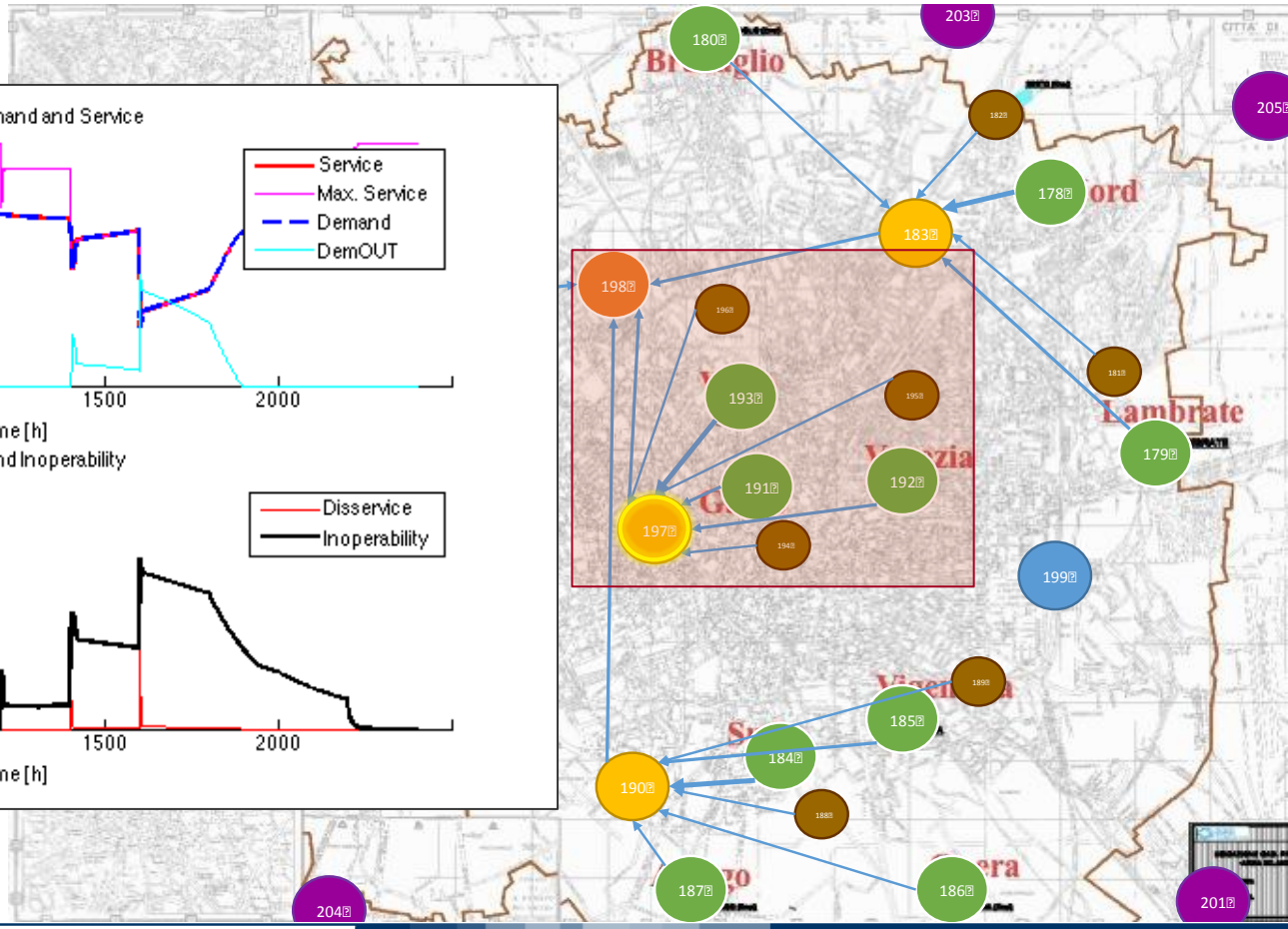




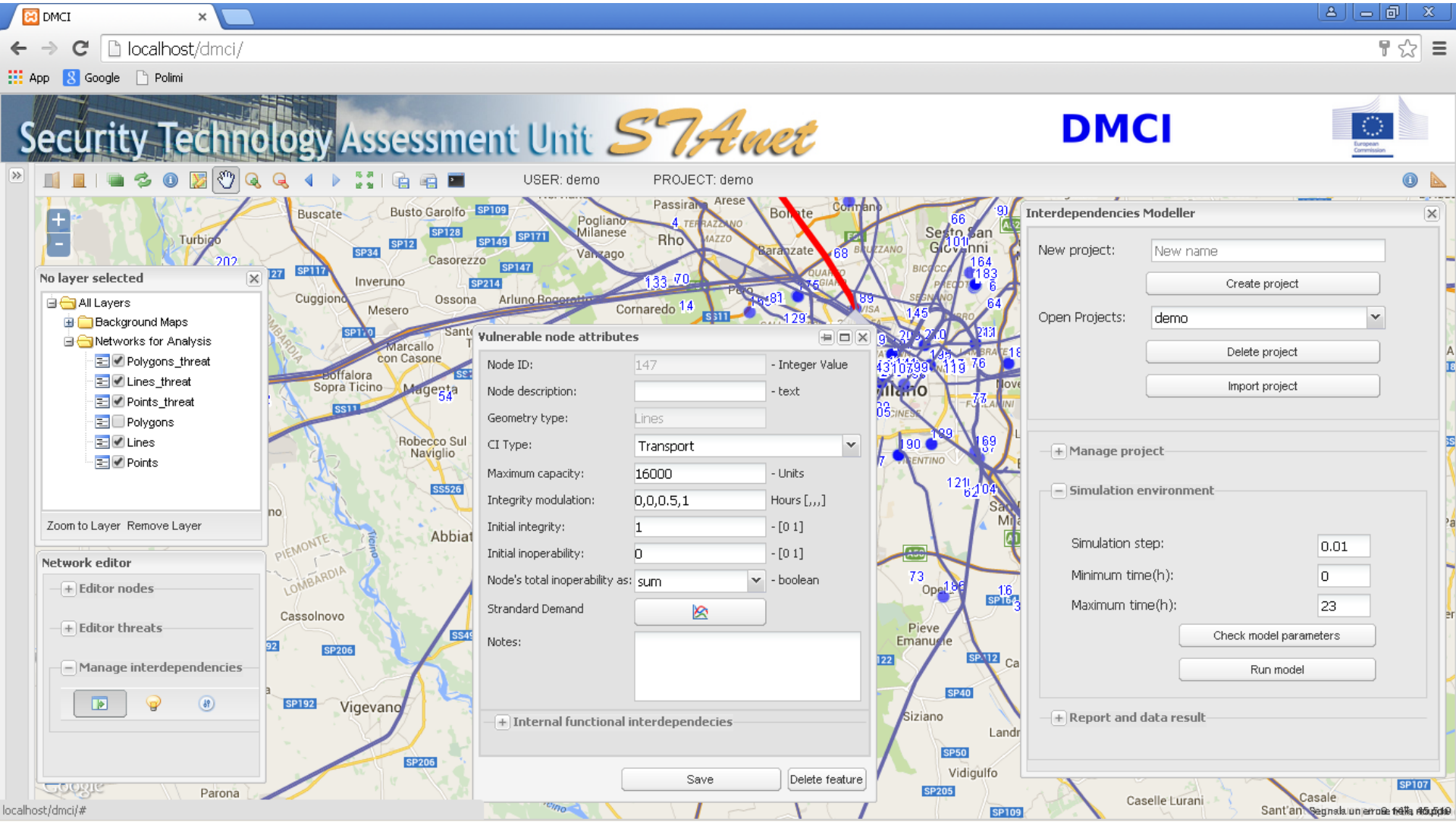
DMCI application to heterogeneous CI
Example – Electricity grid

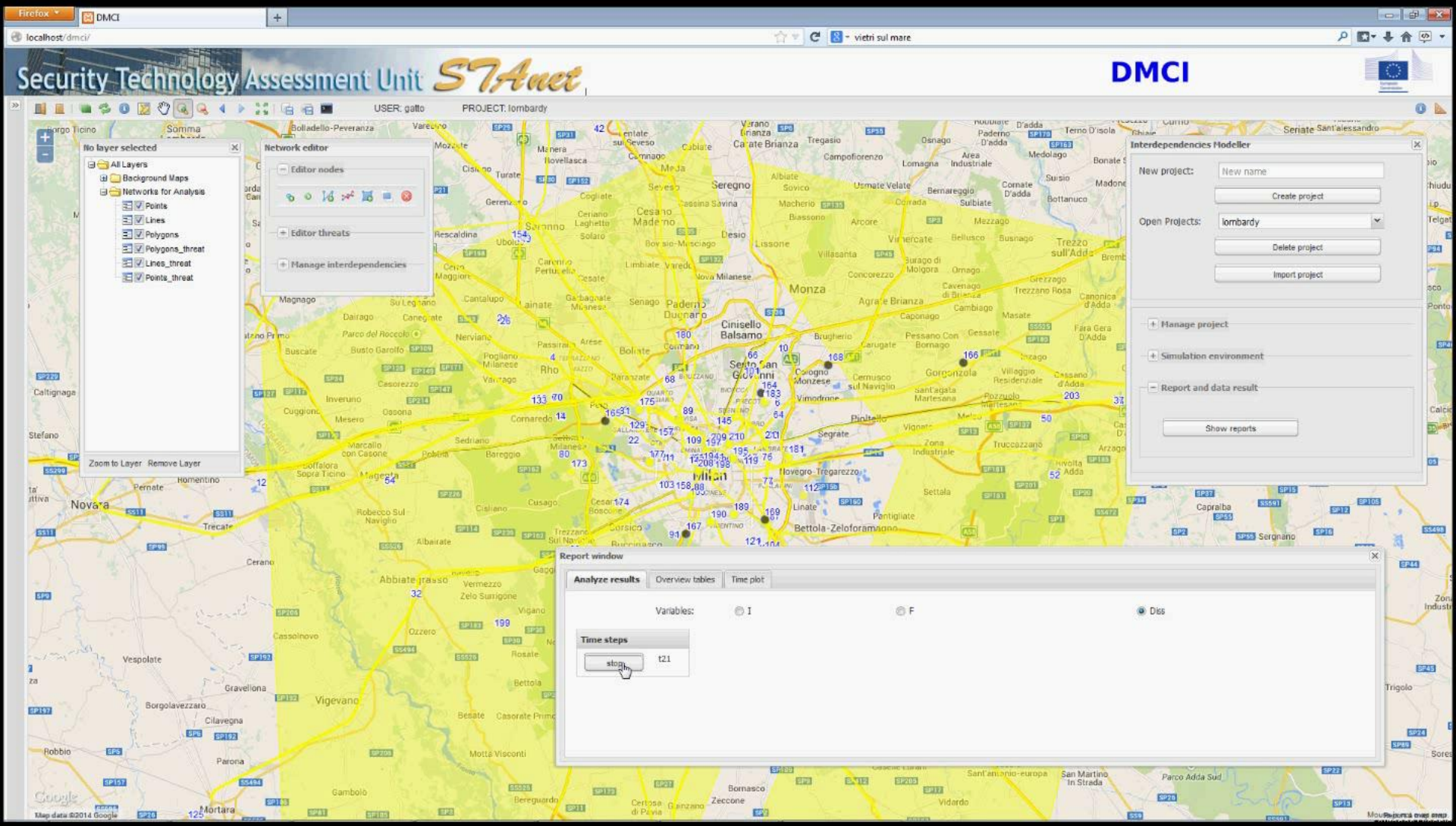
- Milan metropolitan area
- Multiple failures on the **Distribution Grid**
- Available spare capacity in transformation cabins and by grid balancing





DMCI Software tool
Integration in GR²ASP Platform

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Network editor
Editor nodes
Editor threats
Manage interdependencies
Interdependencies Modeller
New project:
New name
Create project
Open Projects:
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Google

Agenda

- Modelling and simulation of interdependent CI systems
- DMCI modelling approach and characteristics
- DMCI modular implementation and SW tool
- DMCI application in the context of a Regional CIP-R programme
  - System modelling and Data collection
  - Vital Node Analysis
  - Characterisation of CI system resilience
  - Collaborative response planning and assessment
- Conclusions

The PPP for CI Resilience in Lombardy Region (IT)

Integrated Programme for CI Protection and Resilience of (PReSIC)

Developing a collaborative environment and shared supporting tools as a regional resilience capability

- **Inventory of CIs nodes** and **interdependency analysis** (all-hazard approach)
- Identification of criteria and protocols for enhanced **information sharing and operational coordination**
  - Scenario-based
  - Interdependency-based
- Large **exercises**
  - Snowfall event (2012)
  - Blackout (2014)
- Support to EXPO2015 preparedness strategy
- Specification of requirements for a prototype **NEO platform** to support collaborative operations (MATRICS project)

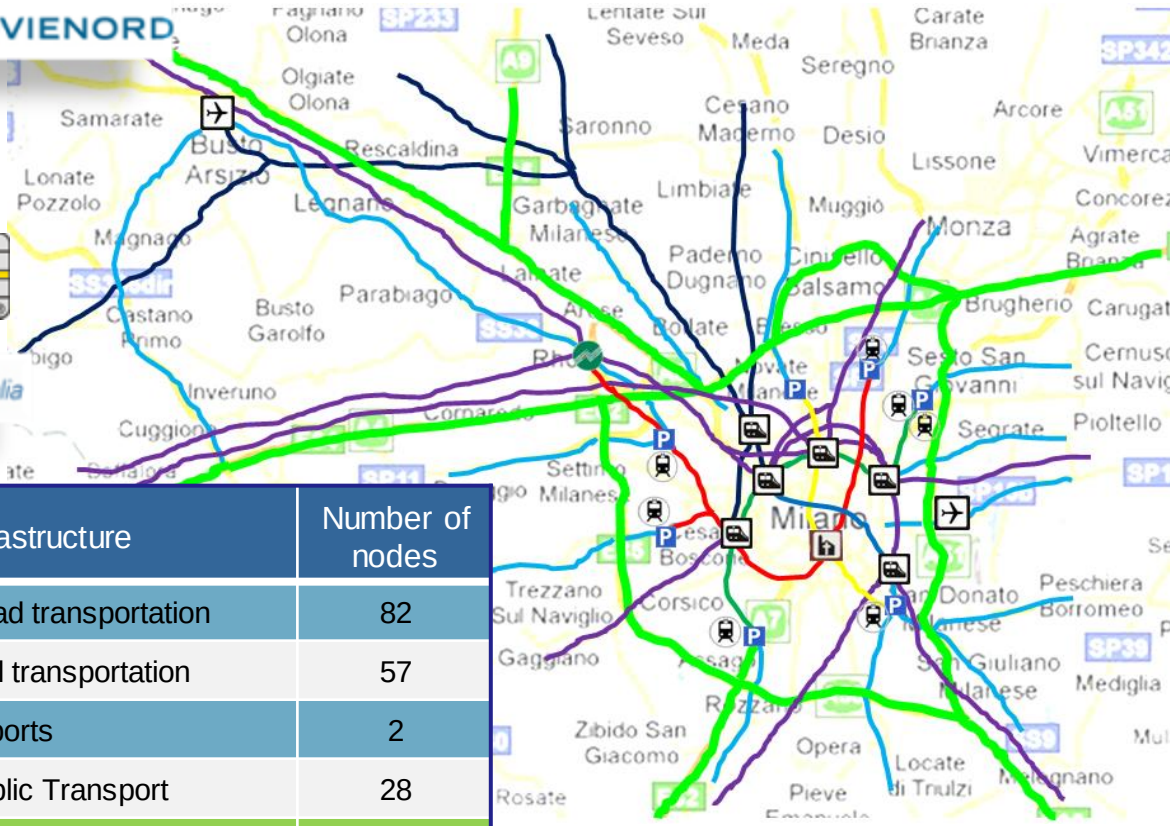
The PPP for CI Resilience in Lombardy Region (IT)

The PPP agreement involves **14** operators in the **Energy and Transportation** sectors and the Regional Civil Protection System

- Railways
- Metro lines
- Airports
- Highways
- National and regional road networks
- Power generation, transmission and distribution
- Gas

DMCI Application in PReSIC context
System modelling

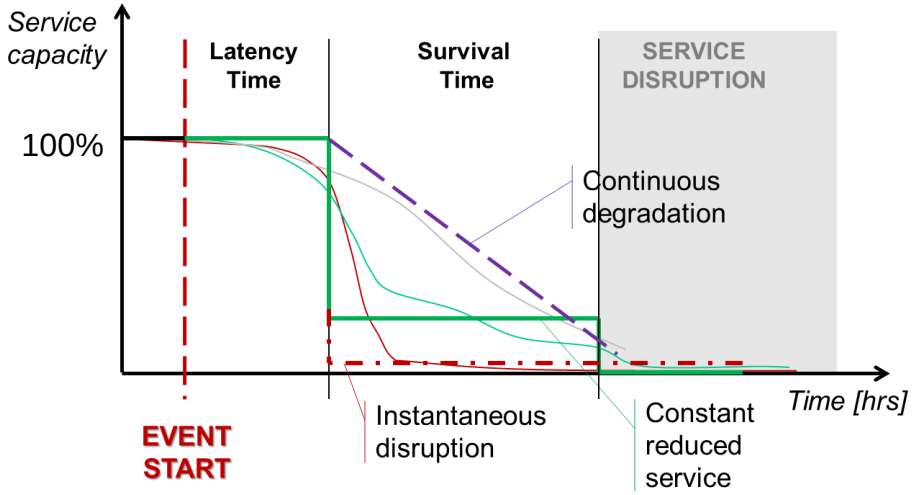
- Comprises 207 vulnerable nodes and CI from 5 different categories
- Characterisation of vulnerable nodes by means of:
  - PReSIC program and other data gathered from operators
  - Regional data from the Civil Protection system
  - Public data and theoretical models

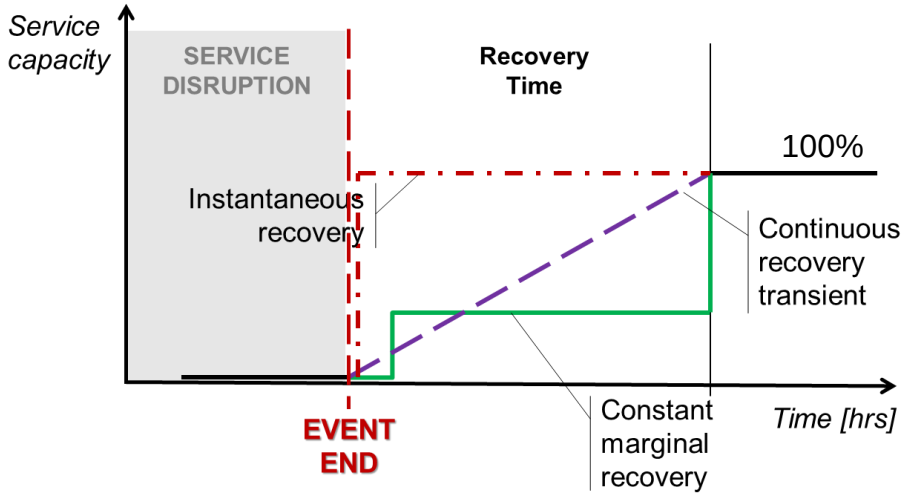


Infrastructure	Number of nodes
Road transportation	82
Rail transportation	57
Airports	2
Public Transport	28
Electric System	38

DMCI Application in PReSIC context
Data Collection – Vulnerable nodes

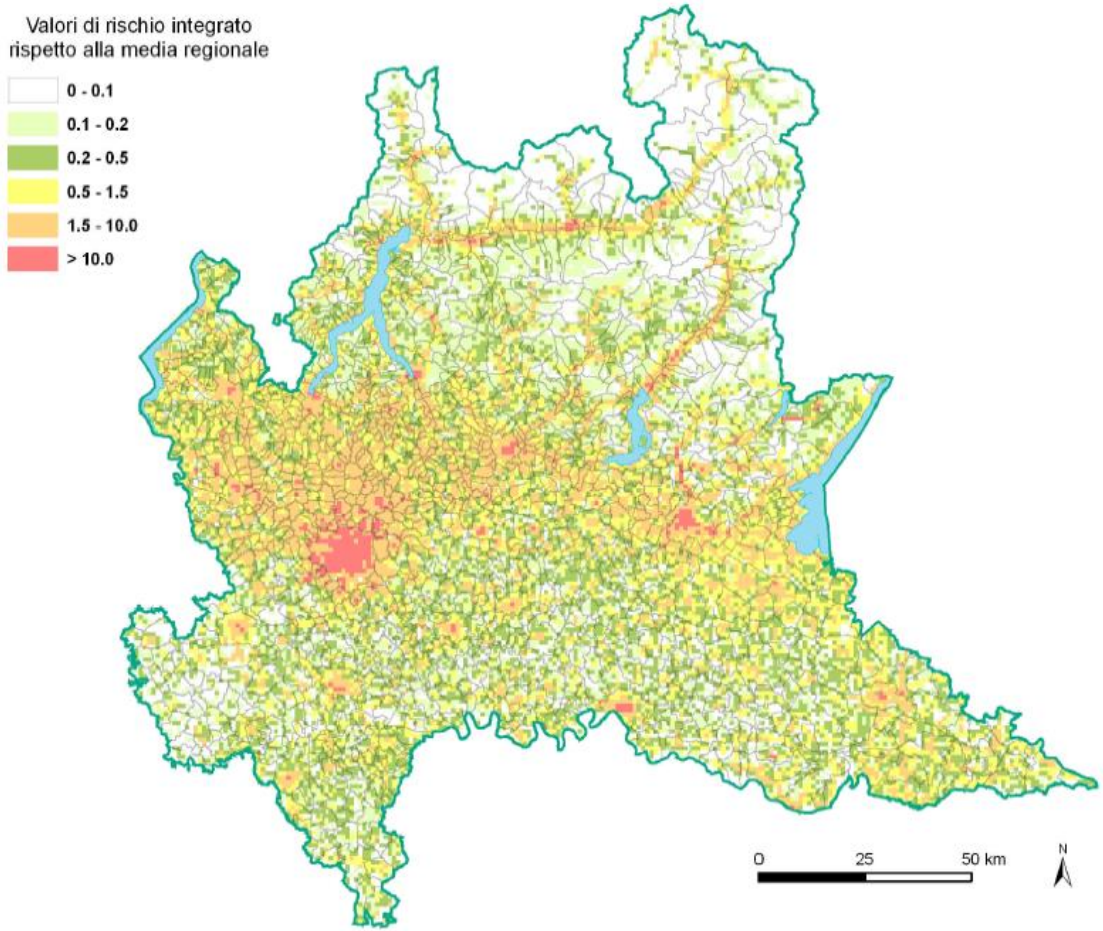
- **Resilience profile of vulnerable nodes**:
  - Specific Thematic Task Force for different scenarios
    - Heavy weather events
    - Electrical Blackouts
  - Template for data collection
  - Direct and indirect impact assessment
  - Identification and planning of mitigation and response strategies





DMCI Application in PReSIC context
Data Collection – Hazards and Threats

- **Inventory of external threats (natural and man-made):**
  PRIM - Integrated Regional Program for the mitigation of major risks (2007-2010)



RegioneLombardia
Protezione Civile, Prevenzione e Polizia Locale

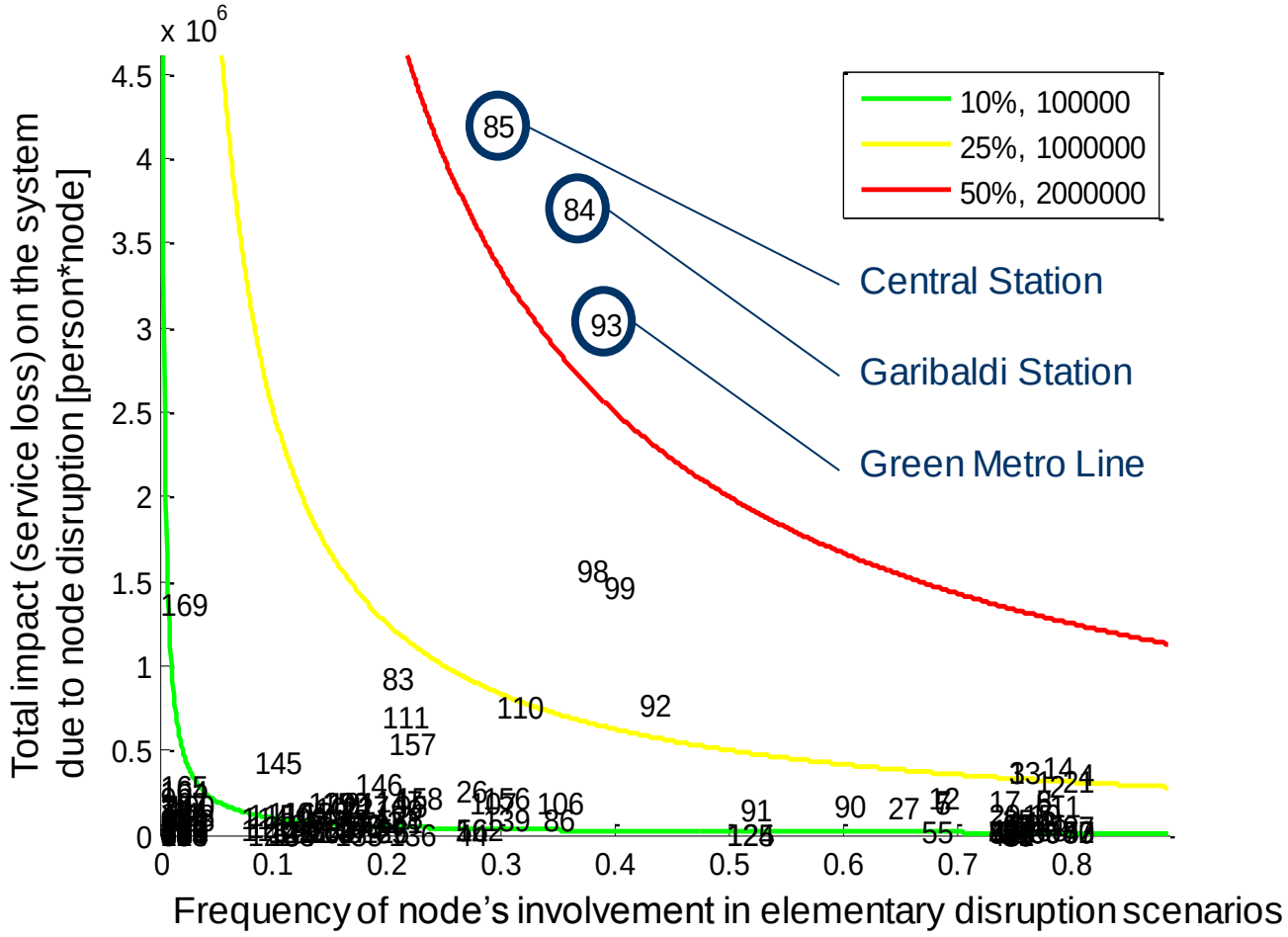
Programma Regionale Integrato di Mitigazione dei Rischi (P.R.I.M.) 2007-2010

9

Mappa di Rischio Integrato sul territorio lombardo

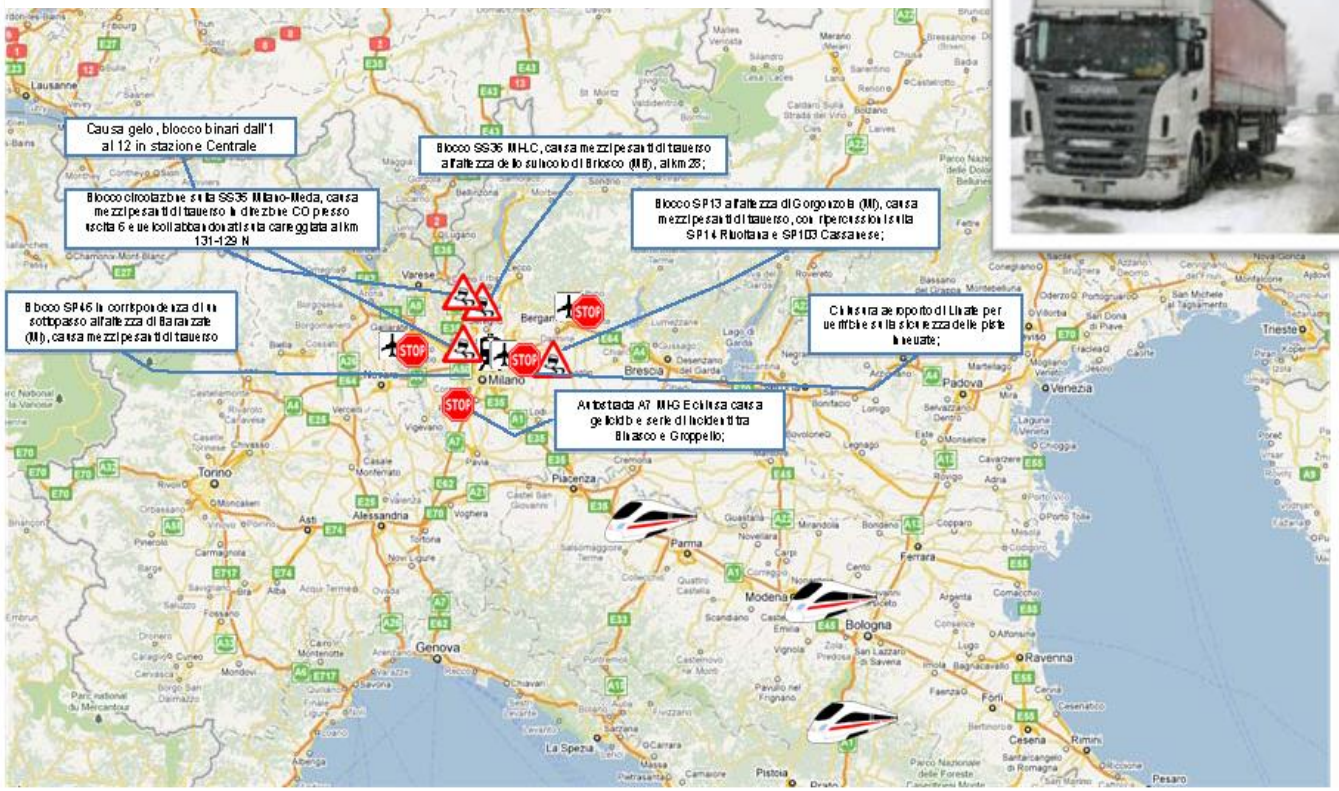
DMCI Application in PReSIC context
Vital Node Analysis

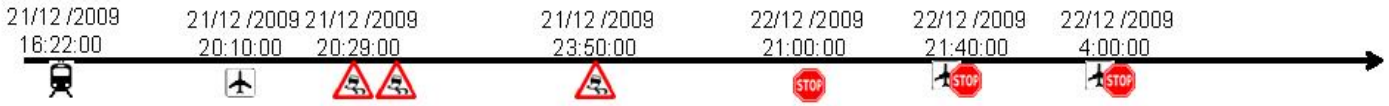
- **Elementary disruption scenarios**: each one triggered by a threat impacting on a single node at a time and blocking it for the entire simulation time-window (e.g. 36 hours)



DMCI Application in PReSIC context
Assessment of collaborative response strategies

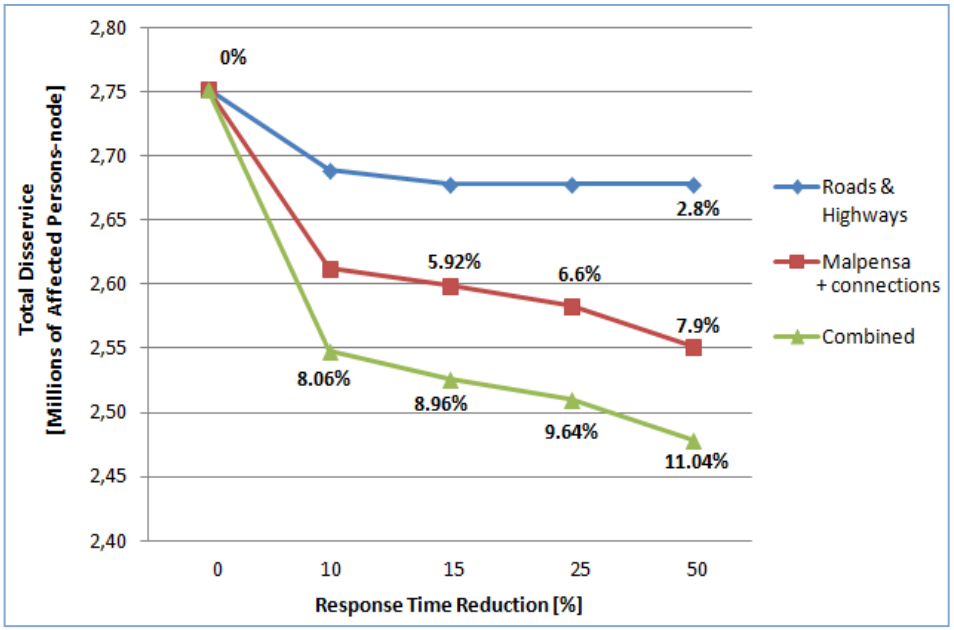
- Scenario: real large **snowfall event** (21-23 Dec 2009)
  - Data collection
  - Model calibration

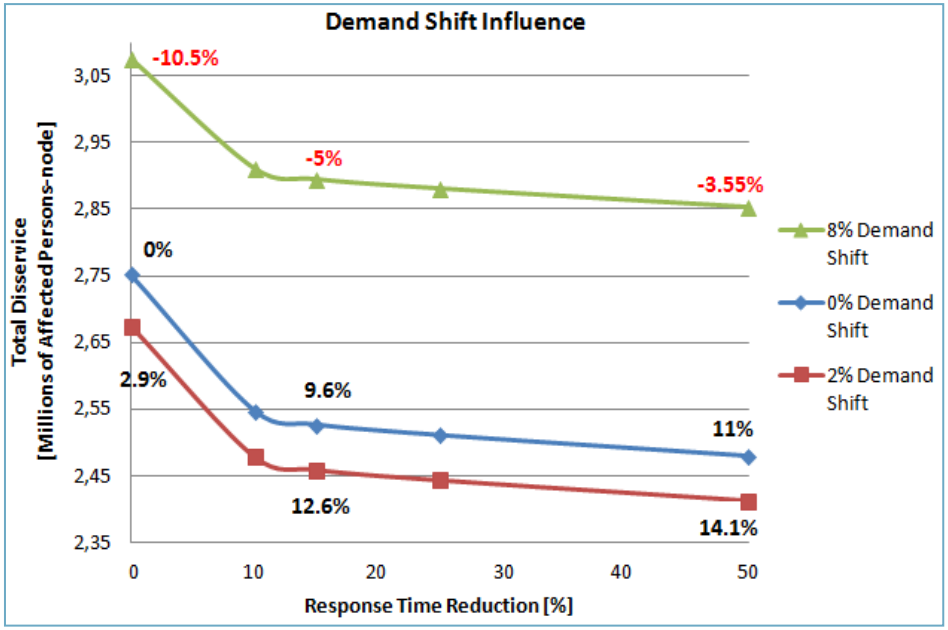




DMCI Application in PReSIC context
Assessment of collaborative response strategies

- Simulation Setting:
  - Target nodes: Beltways (#1, 3, 4); Highways (#13, 14); Malpensa Airport (#113); Railways (#156, 157)
- Reducing nodes' response time (from 10% up to 50%)
  - **Simultaneously in clusters of high agility nodes**
    → up to 11% impact reduction at system level, but with early saturation effect
  - **Exploiting replaceable services** (roads vs railways substitution)
    → Local reductions in disservice: 22% in roads and highways; 60% at Malpensa





Conclusions

- Flow-based approaches (Ouyang, 2014)
  - High potential for comprehensive resilience analysis
  - Data availability is an issue
- DMCI Functional modelling offers a good trade-off
  - Applicable to heterogeneous CI systems
  - Limited confidential data required (typical info sharing level within PPPs)
- DMCI tool features
  - Modular structure
  - Web GUI, GIS integration, import/export in MSExcel™ and Matlab®
- DMCI application portfolio
  - Vital Node Analysis
  - Resilience Characterisation
  - Collaborative response planning
  - Extension towards real time decision support

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Thank You!

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