Quantification of multi-mode risks and impacts

RAIN Workshop

Critical Infrastructure Safety in the Context of Climate Change

Delft

4th April 2016

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This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement no 608166. The contents of this presentation are the author's views. The European Union is not liable for any use that may be made of the information contained therein.

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Outline

- Introduction
- Risk Assessment Framework- Technical Framework
  - Hazard Assessment
  - Vulnerability Assessment
  - Consequence Analysis
  - Risk Evaluation
- Risk Assessment Framework- Illustrative Example
  - Alpine Region Flash Flooding in 2003

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Introduction

- **Problem**
  - Europe is the 3rd most affected region in the world based on average 10 year **disaster costs** of €10 Billion

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Introduction

- **Solution**
  - A systematic **R**isk **A**nalysis framework that explicitly considers **IN**frastructure networks in response to extreme weather events and develops an optimization tool for series of mitigation strategies

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Introduction

- Risk arises from uncertainty of information
  - 100% certainty of information = p_f=0.0 or 1.0
- Uncertainty and variability of (random variables):
    - material properties
    - dimensions
    - environment
    - loads (and load combinations)
    - etc.
- Accuracy of predictive models
  - computer models, hazard scenarios, consequence models
- Inherent variabilities
  - natural hazards, weather, individual exposure to hazard

probabilistic modelling

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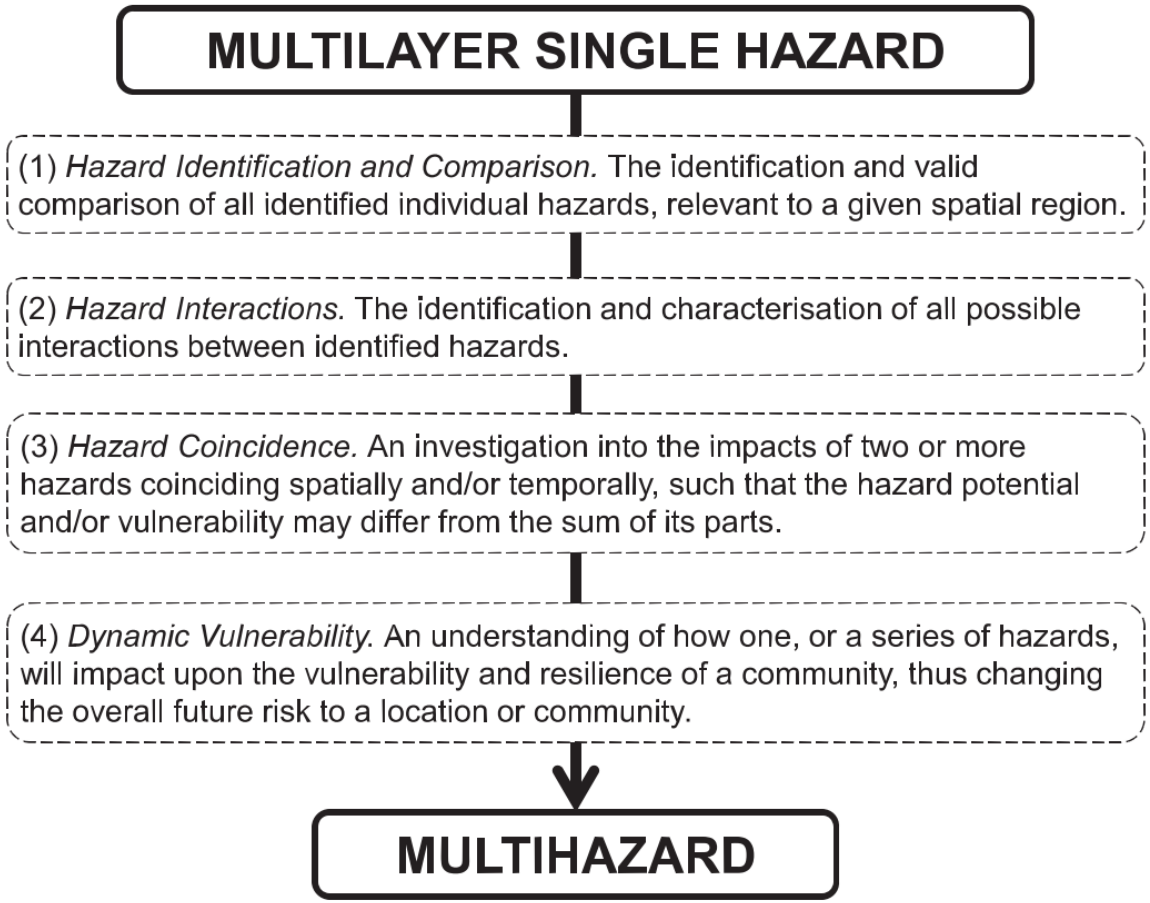

Figure 13. Multihazard framework. This figure represents the progression from a multilayer single hazard approach to a multihazard approach. This involves four key aspects, including (1) hazard identification and comparison, (2) hazard interactions, (3) hazard coincidence, and (4) dynamic vulnerability.

Gill and Malamud (2014) 'Reviewing and visualising the interactions of natural hazards', *Reviews of Geophysics,* 52 680-722

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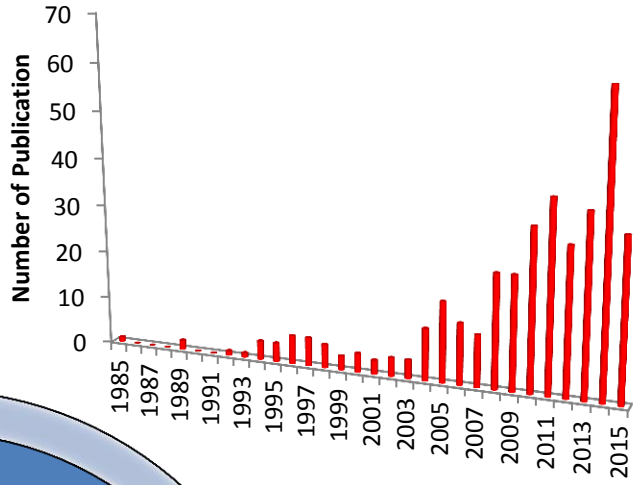
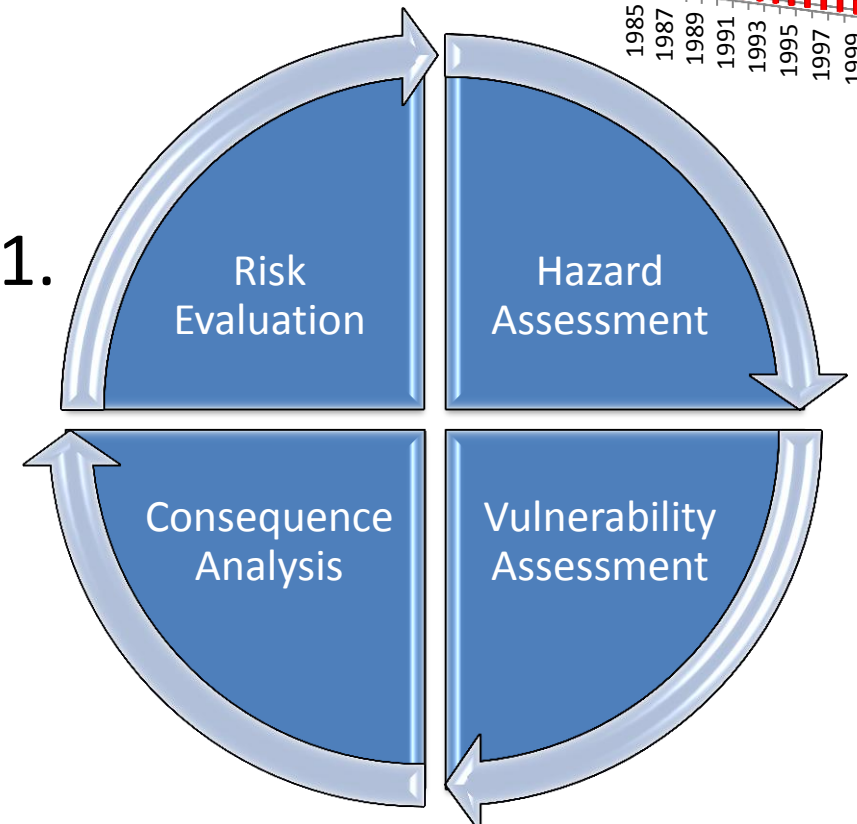
Introduction

- Available Risk Frameworks
  - MATRIX
  - UNDP
  - EC-TIGRA
  - ESPON 1.3.1.
  - Armonia
  - …





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Introduction

- **What is Different in RAIN?**
  - GIS-based Bayesian Probability Theory
    - Updating and optimising decisions and ranking Mitigation Strategies
  - Multi Hazard/Multi vulnerability using Markovian Networks
    - Cascading effects
  - (Inter)dependencies in Critical Infrastructure Network
    - System of system modelling
  - Graph Theory
    - Critical hotspots in network
  - Objective Ranking Tool
    - Similarity Judgement and Delphi Panel

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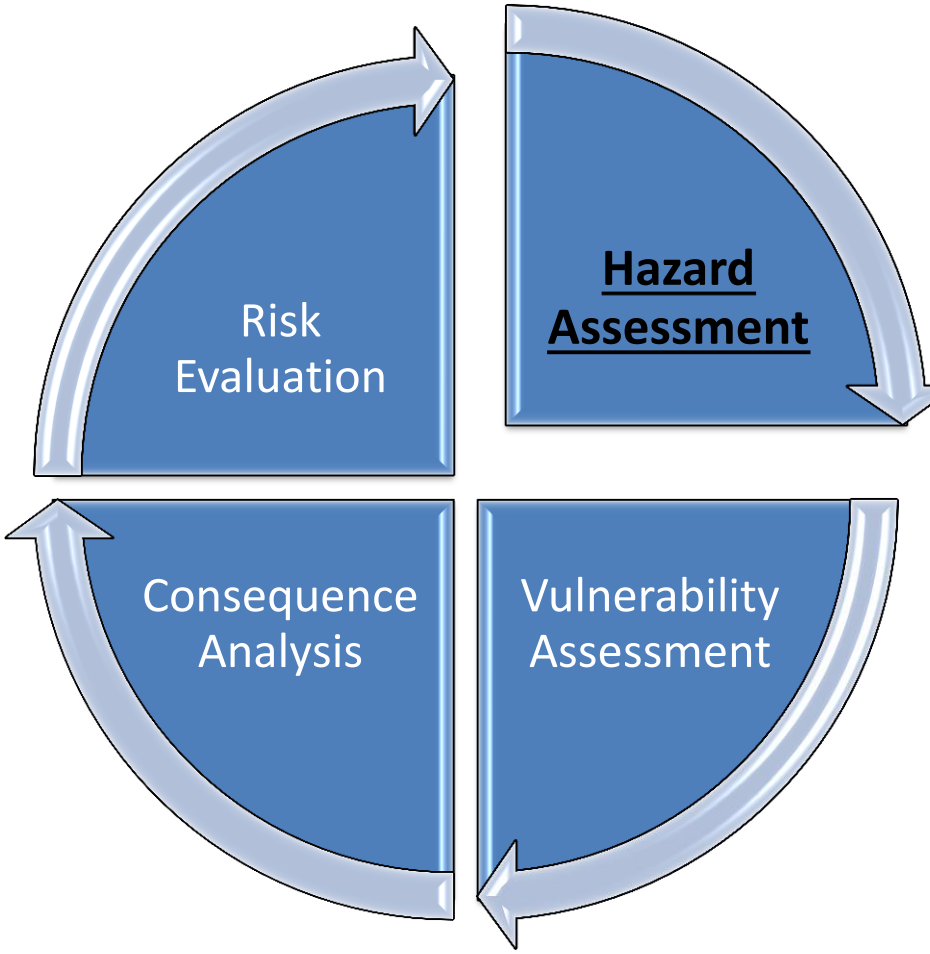
Risk Assessment Framework

- Identifying Extreme weather Events
- Thresholds of Extreme weather Events
- Probability of Extreme weather Event
- Projection of Climate change



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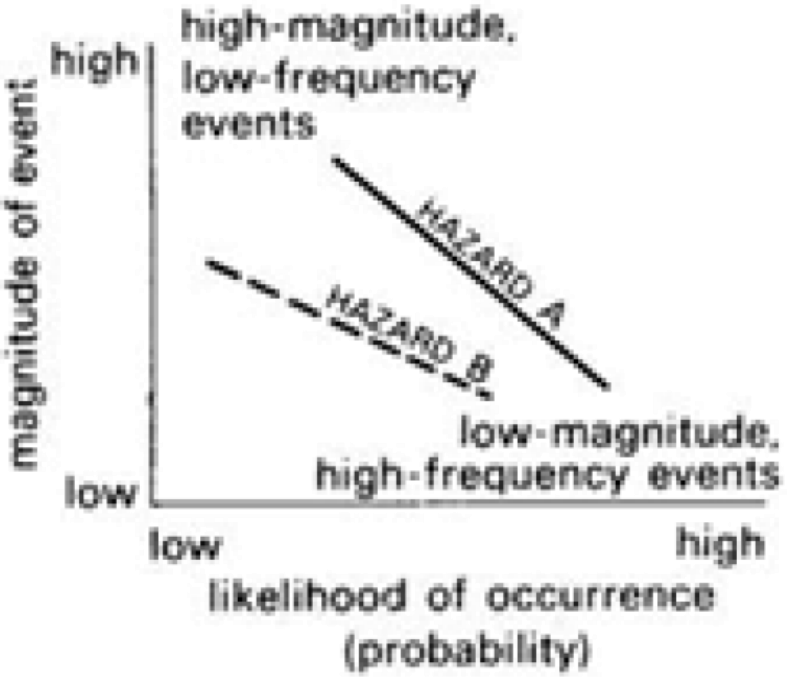
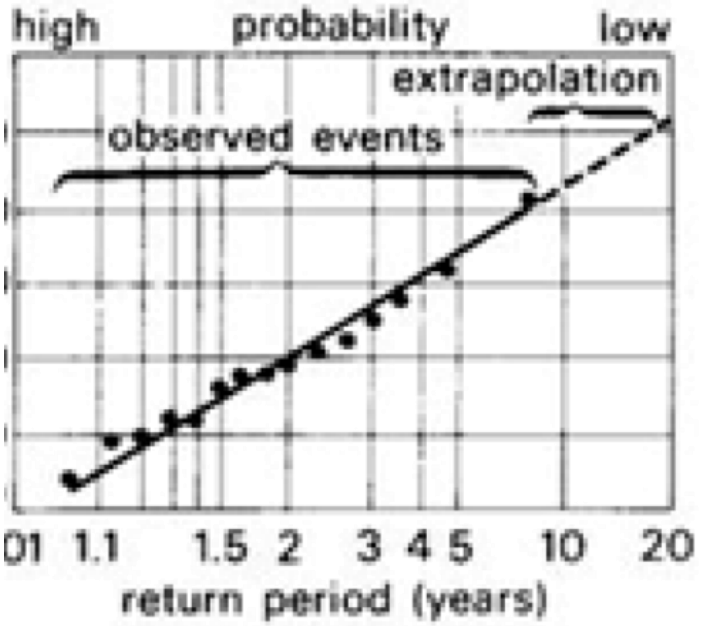
Hazard Assessment

Evaluation Probability of Extreme Weather Event





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Hazard Interaction

COLOUR CODE	NATURE OF SECONDARY HAZARD (FOLLOWING *ONE* OCCURRENCE OF PRIMARY HAZARD)
	Potential for a small number of hazard events (individual or a few occurrences)
	Potential for a large number of hazard events (multiple occurrences)

SYMBOL	EXPLANATION
	Hazard **Triggers** Secondary Hazard
	Hazard **Increases Probability** of Secondary Hazard
	Hazard Both **Triggers and Increases the Probability** of Secondary Hazard

Primary Hazard \ Secondary Hazard	Landslides	Snow Avalanche	Flood	Drought	Storm	Tornado	Hailstorm	Snow Storm	Lightening	Extreme Temperature (Heat)	Extreme Temperature (Cold)	Wildfires
Landslide	◢		◢									
Snow Avalanche	◢	◢	◢									
Flood	◢											
Drought												◢
Storm	◢	◢	◢			◢			◢			
Tornado									◢			
Hailstorm	◢	◢	◢						◢			
Snowstorm	◢	◢	◢									
lightening												◢
Extreme Temperature (Heat)	◢	◢	◢	◢	◢							◢
Extreme Temperature (Cold)				◢			◢	◢				
Wildfires	◢		◢							◢		◢

Gill and Malamud (2014) 'Reviewing and visualising the interactions of natural hazards', *Reviews of Geophysics,* 52 680-722

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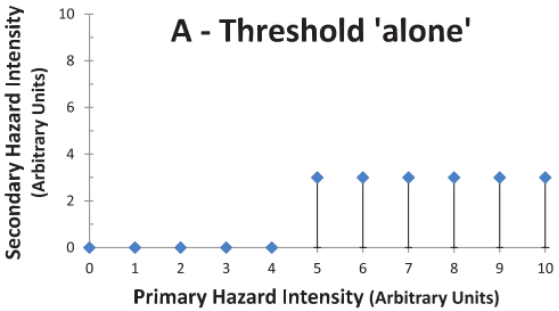
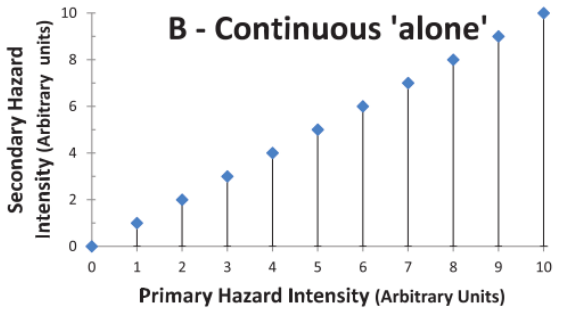
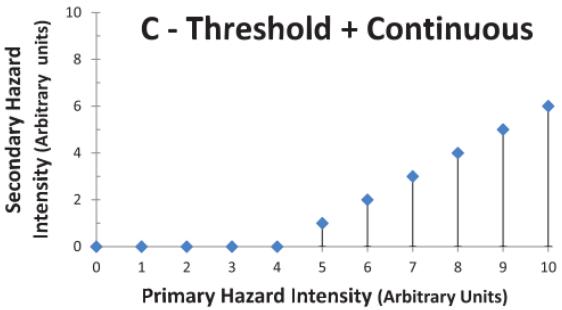
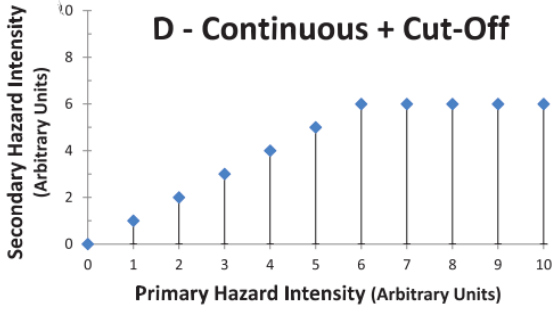
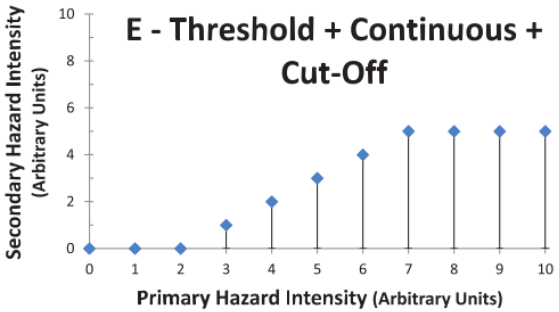
Hazard Interaction











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Forecasting Hazard Interaction

PRIMARY HAZARD	SECONDARY HAZARD	FORECASTING FACTORS			OVERALL RATING
		LOCATION	TIME	MAGNITUDE	
Landslide	Landslide	N – L – **M** – H	N – L – **M** – H	N – L – **M** – H	6/9
	Flood	N – L – **M** – H	N – L – **M** – H	N – L – **M** – H	6/9
Snow Avalanche	Landslide	N – L – **M** – H	N – L – **M** – H	N – **L** – M – H	5/9
	Snow Avalanche	N – L – **M** – H	N – L – **M** – H	N – **L** – M – H	5/9
	Flood	N – L – **M** – H	N – **L** – M – H	N – L – **M** – H	5/9
Flood	Landslide	N – L – **M** – H	N – L – **M** – H	N – **L** – M – H	5/9
Drought	Wildfire	N – **L** – M – H	N – **L** – M – H	N – **L** – M – H	3/9
Storms	Landslide	N – L – **M** – H	N – L – M – **H**	N – L – **M** – H	7/9
	Snow Avalanche	N – L – **M** – H	N – L – **M** – H	N – **L** – M – H	5/9
	Flood	N – L – M – **H**	N – L – **M** – H	N – L – **M** – H	7/9
	Tornado	N – **L** – M – H	N – **L** – M – H	N – **L** – M – H	3/9
	Lightning	N – **L** – M – H	N – L – **M** – H	N – **L** – M – H	4/9
Tornadoes	Lightning	N – **L** – M – H	N – L – **M** – H	N – **L** – M – H	4/9

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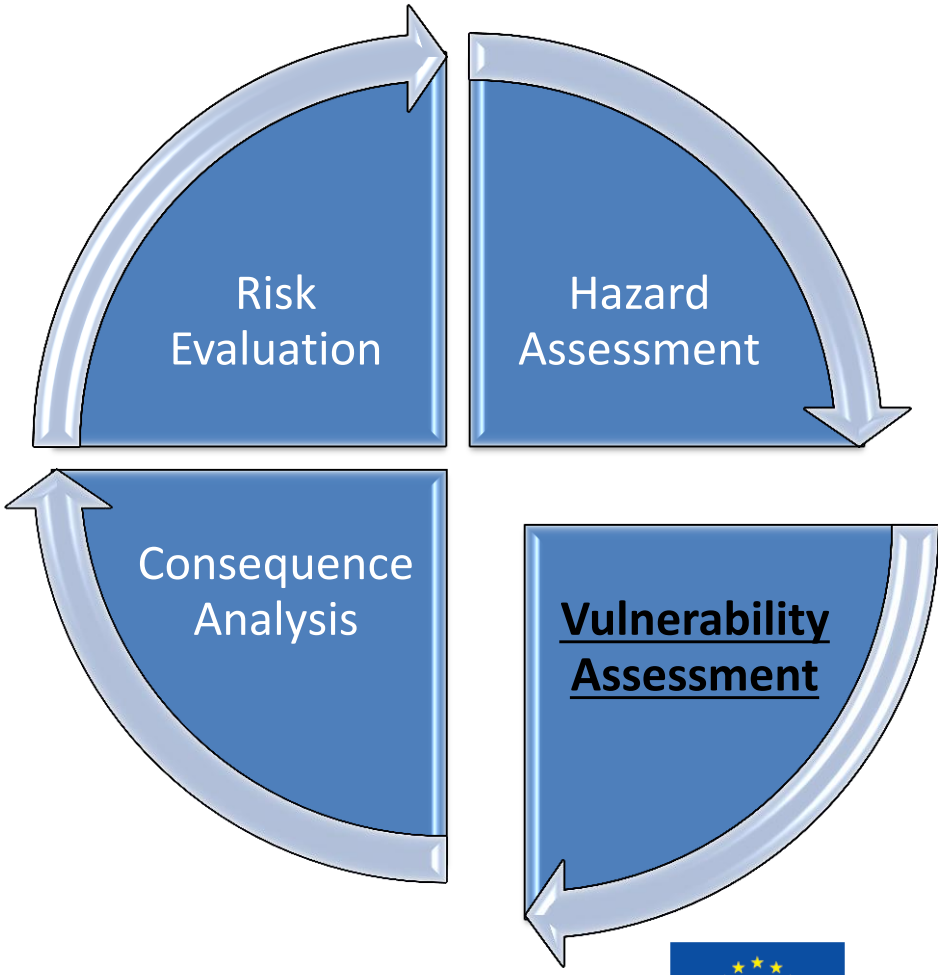
Risk Assessment Framework

- Identifying Critical infrastructure (CI)
- Indentifying (inter)dependencies
- Indentifying risks associated with CIs
- Vulnerability Analysis of CIs



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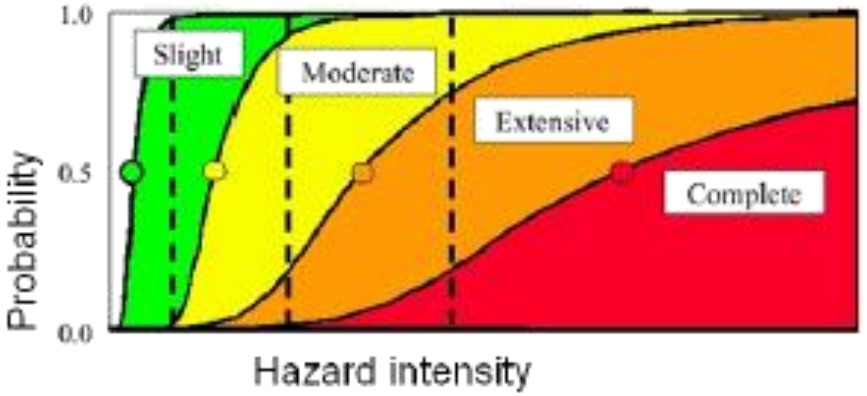
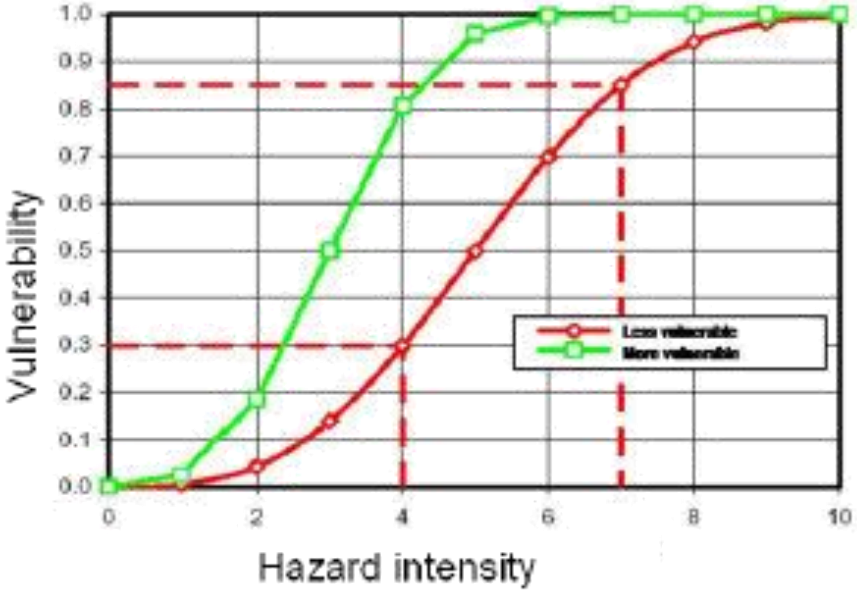
Vulnerability Assessment

Vulnerability Analysis and Fragility Curves





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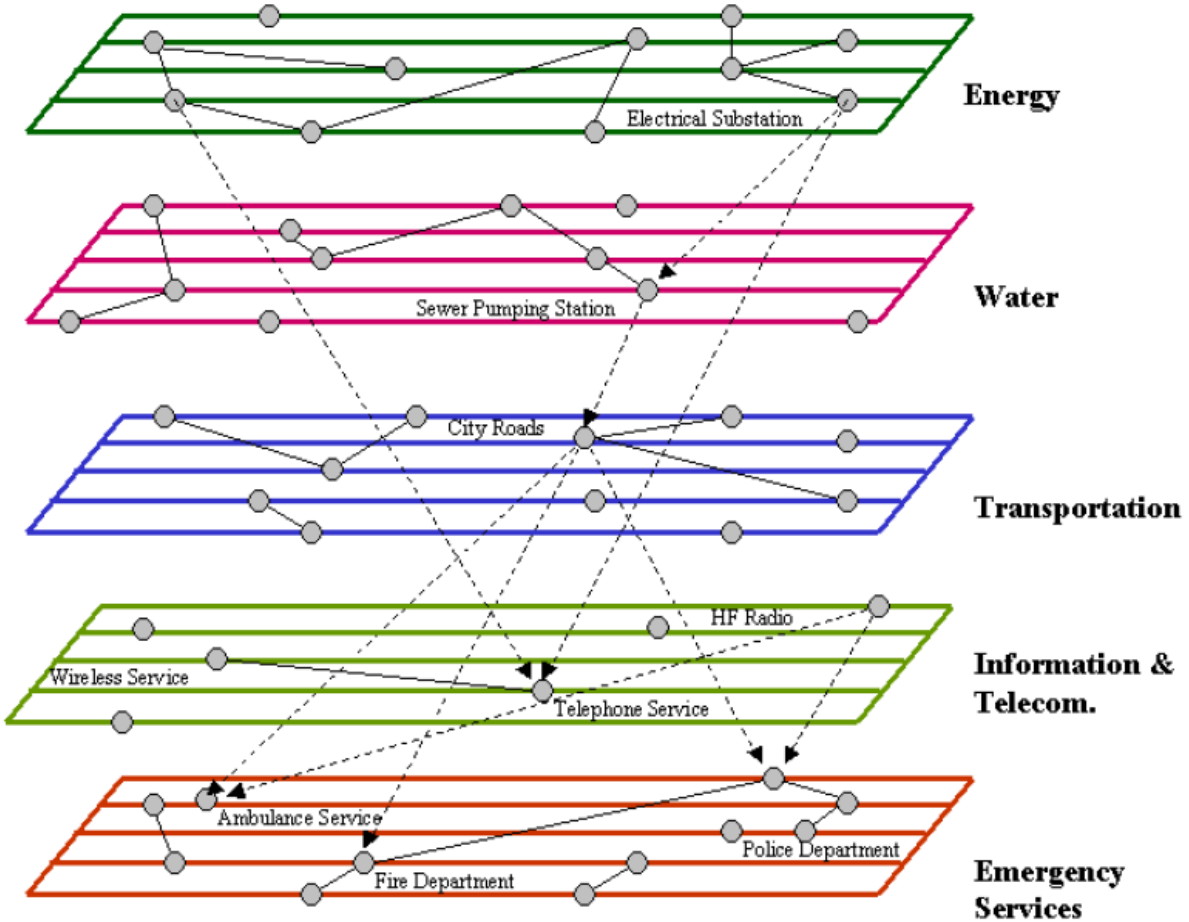
Vulnerability Assessment

Identifying (inter)dependencies



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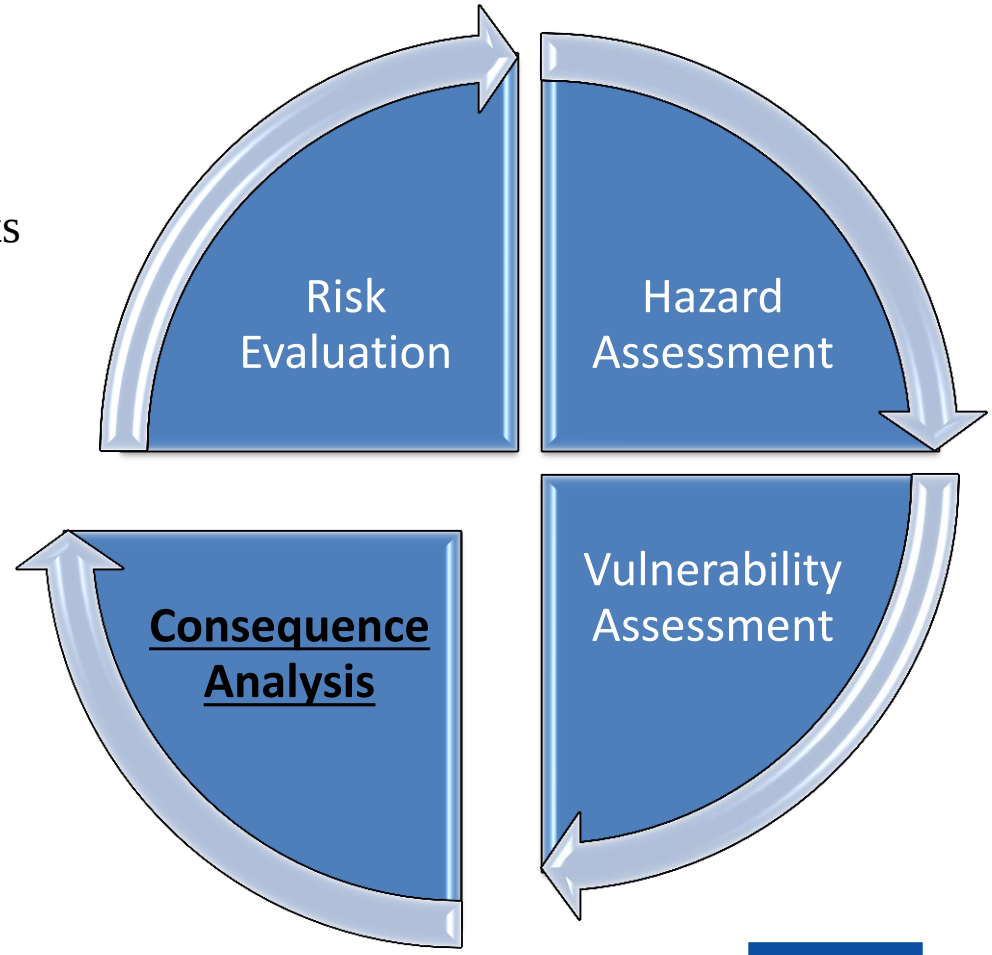
Risk Assessment Framework

- Identifying Consequences
- Identifying key factors and weights
  - Objective Ranking Tool
- Consequence Quantification
  - F-N curves
  - Loss Exceedance Curve
  - Recovery time Analysis



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Consequence Analysis

Identifying Consequences

- Consequences
  - Societal
    - Fatalities
    - Injuries
  - Security
    - Fresh Water Supply
    - Food Supply
    - Energy Supply
  - Economic
    - Cost of Repair/Replacement
    - Cost of Labour
    - Availability of Materials
    - Age of the Existing Infrastructure

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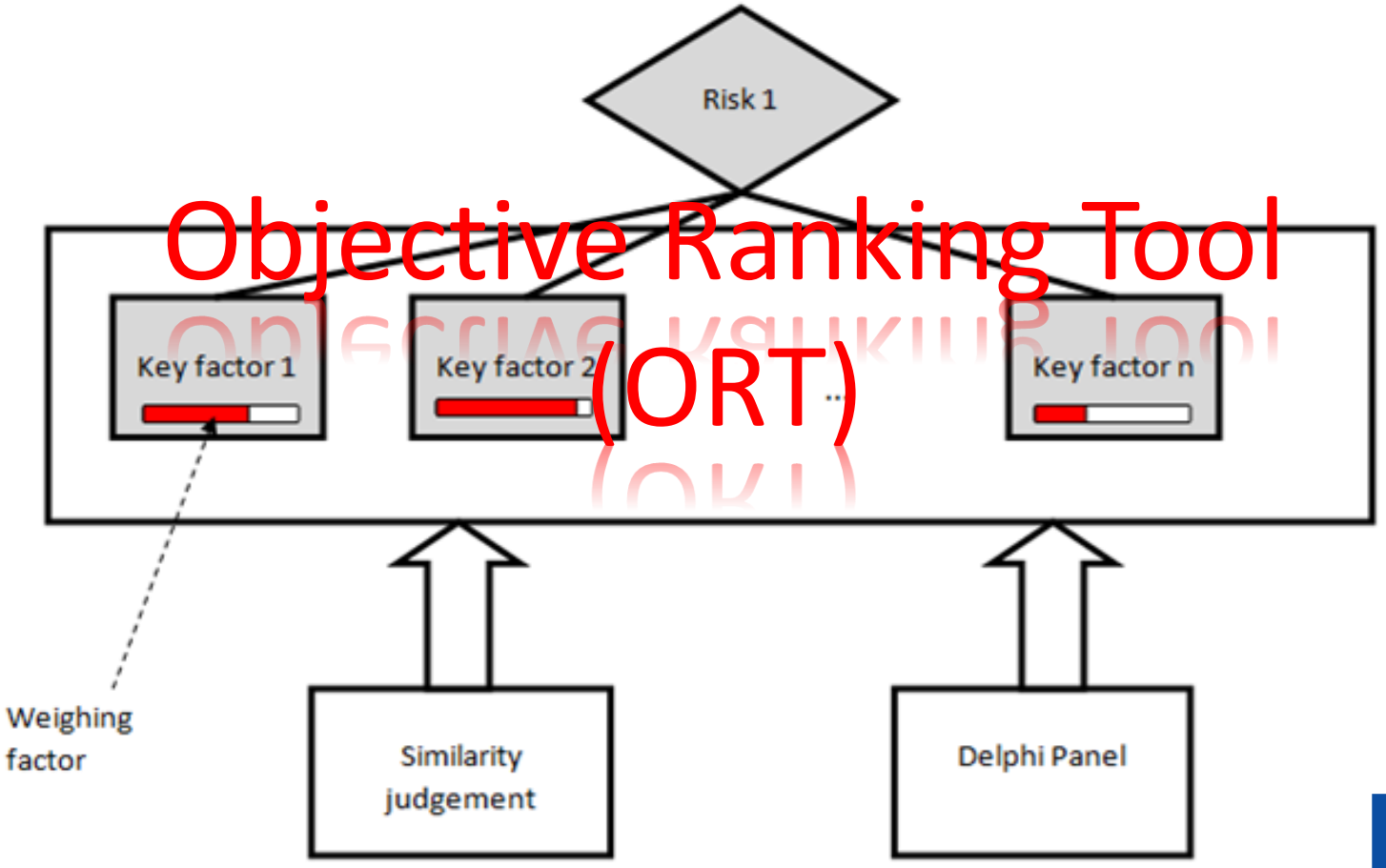
Consequence Analysis

Identifying key factors and weights



Objective Ranking Tool (ORT)

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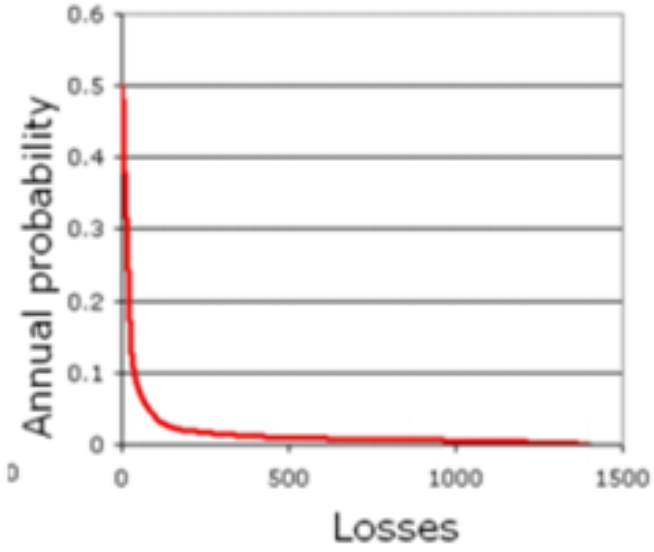
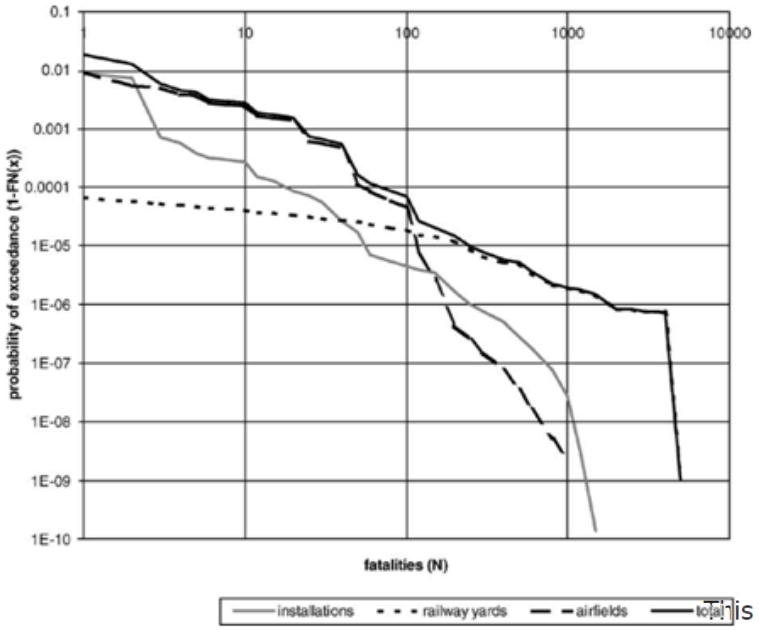
Consequence Analysis

Step 10- Quantifying consequences





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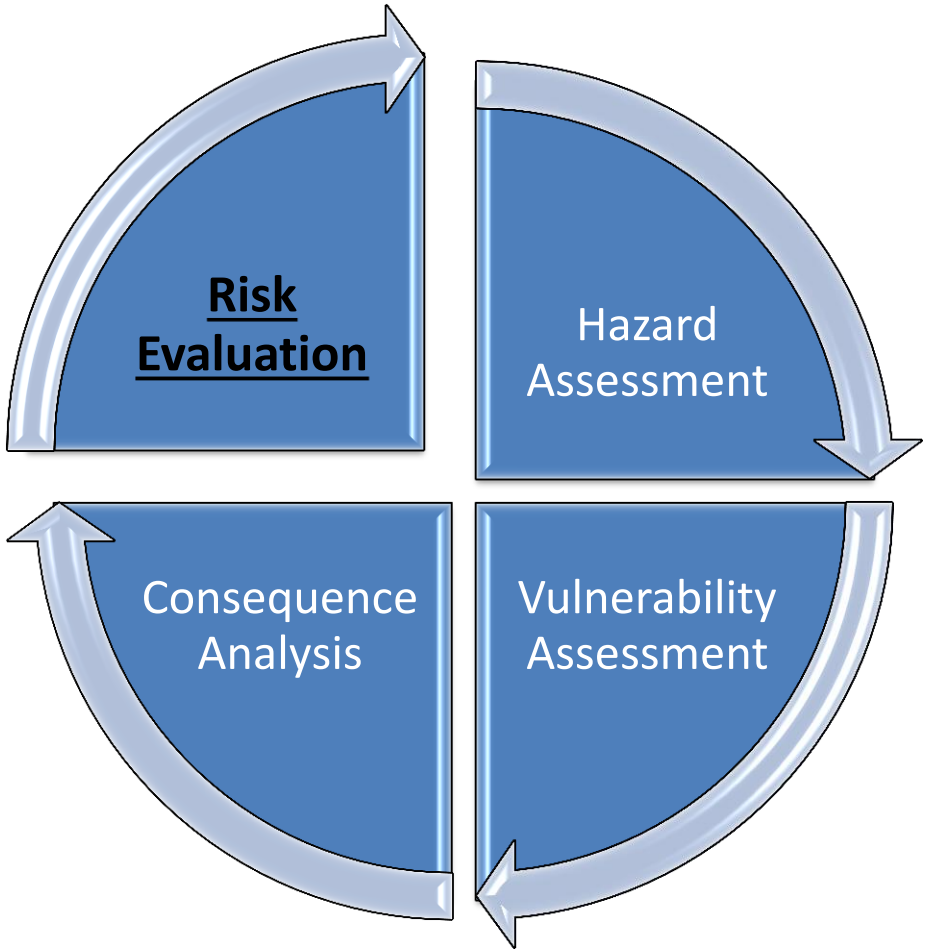
Risk Assessment Framework

- Identifying Risk Scenarios
  - Inference Network
- Quantifying Risks
  - Bayesian Probability Theory
  - Markovian Process
- Quantifying Benefits of Mitigation
  - Technical engineering solutions
  - Early warning systems



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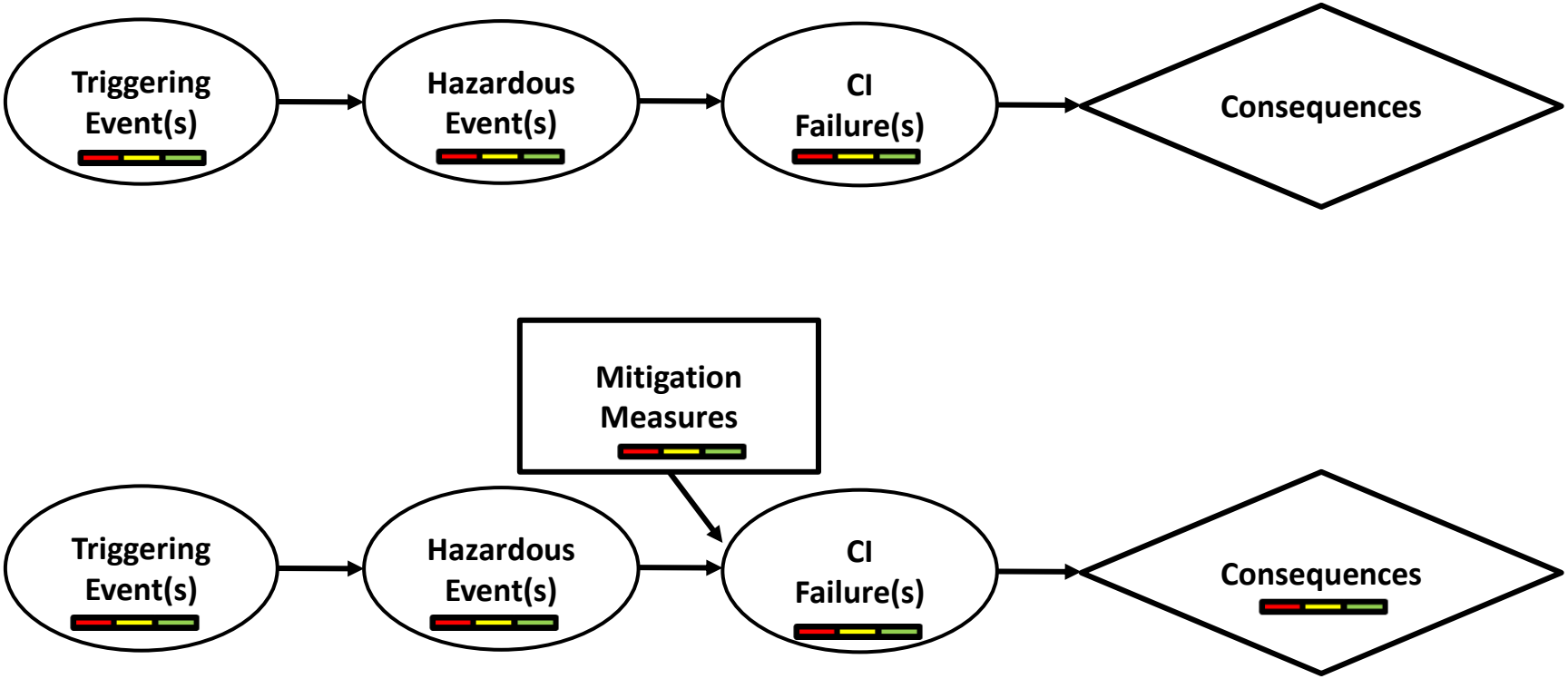
Risk Evaluation

Generating Inference Network



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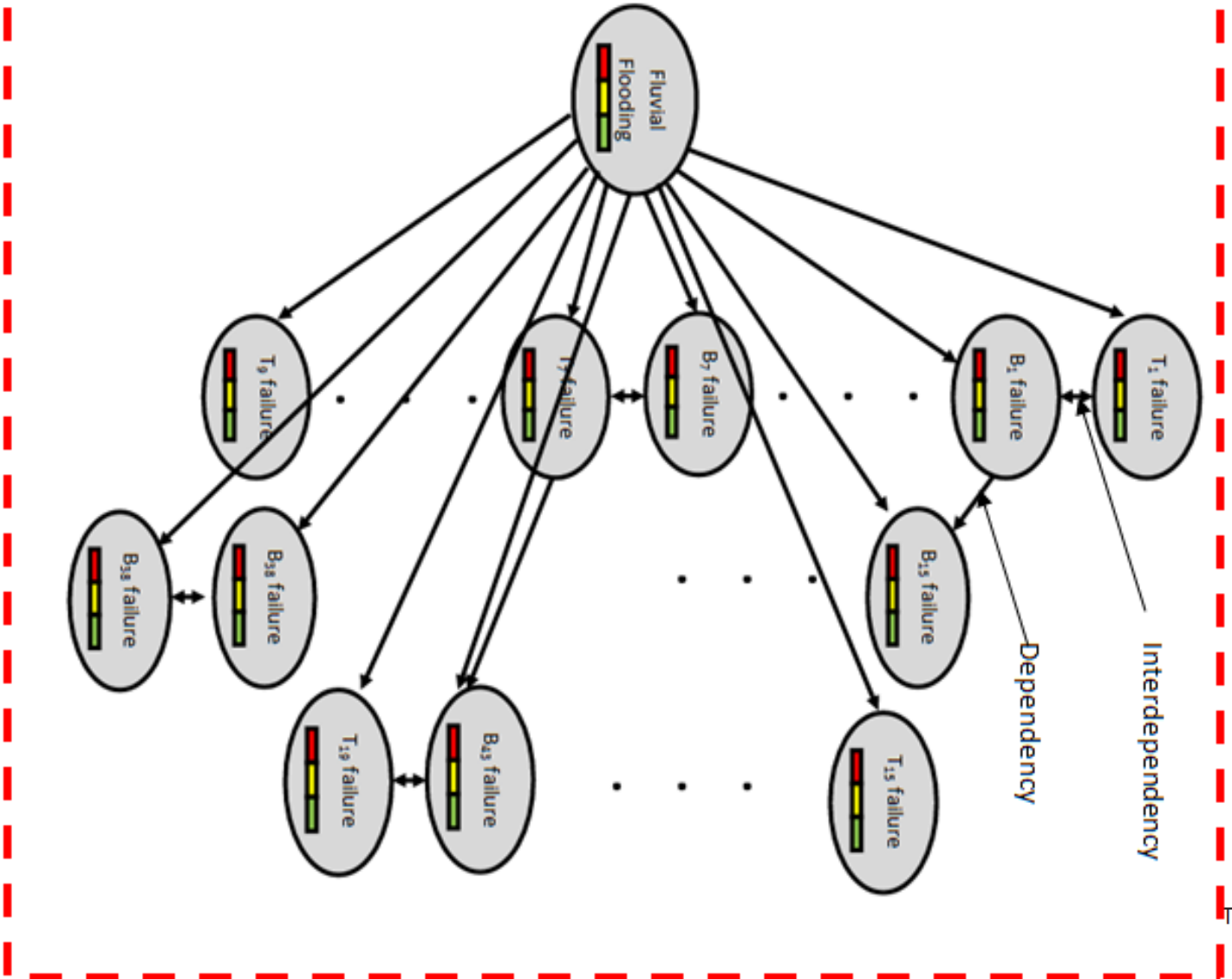
Risk Evaluation

Combining Infrastructure Network and Inference Network



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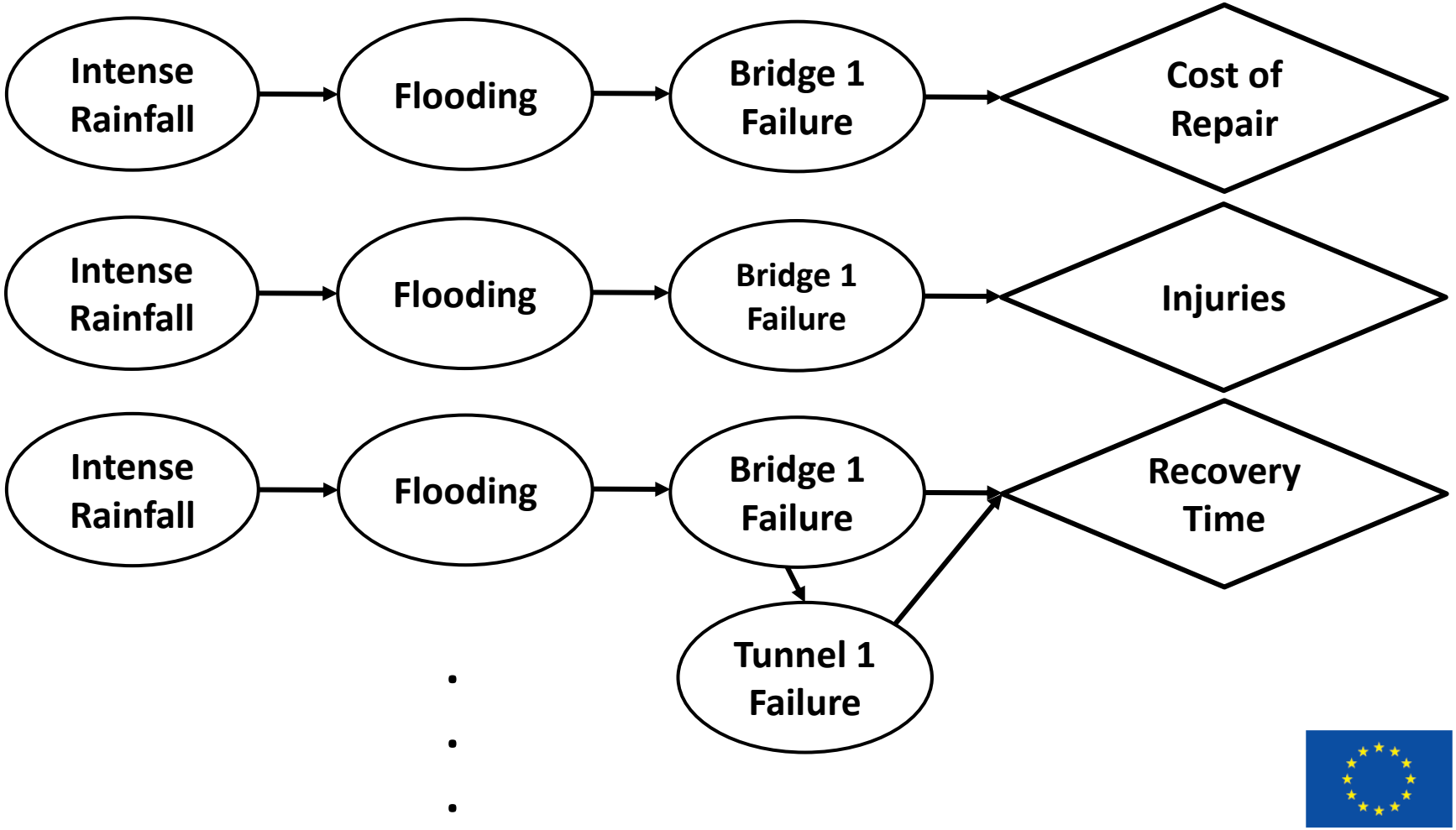
Risk Evaluation

Identifying all risk scenarios with assigned probabilities and outcomes



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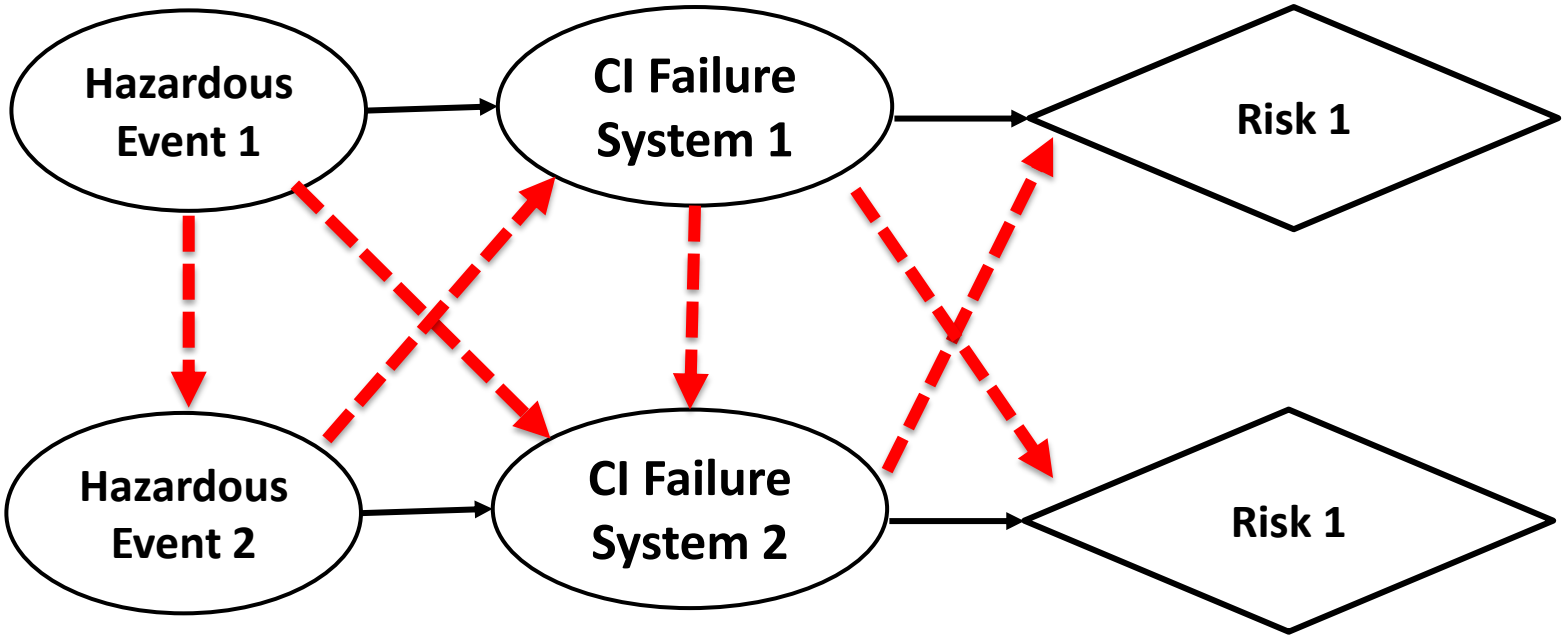
Risk Evaluation

Distinguishing between Single Mode risks and Multi Mode Risks



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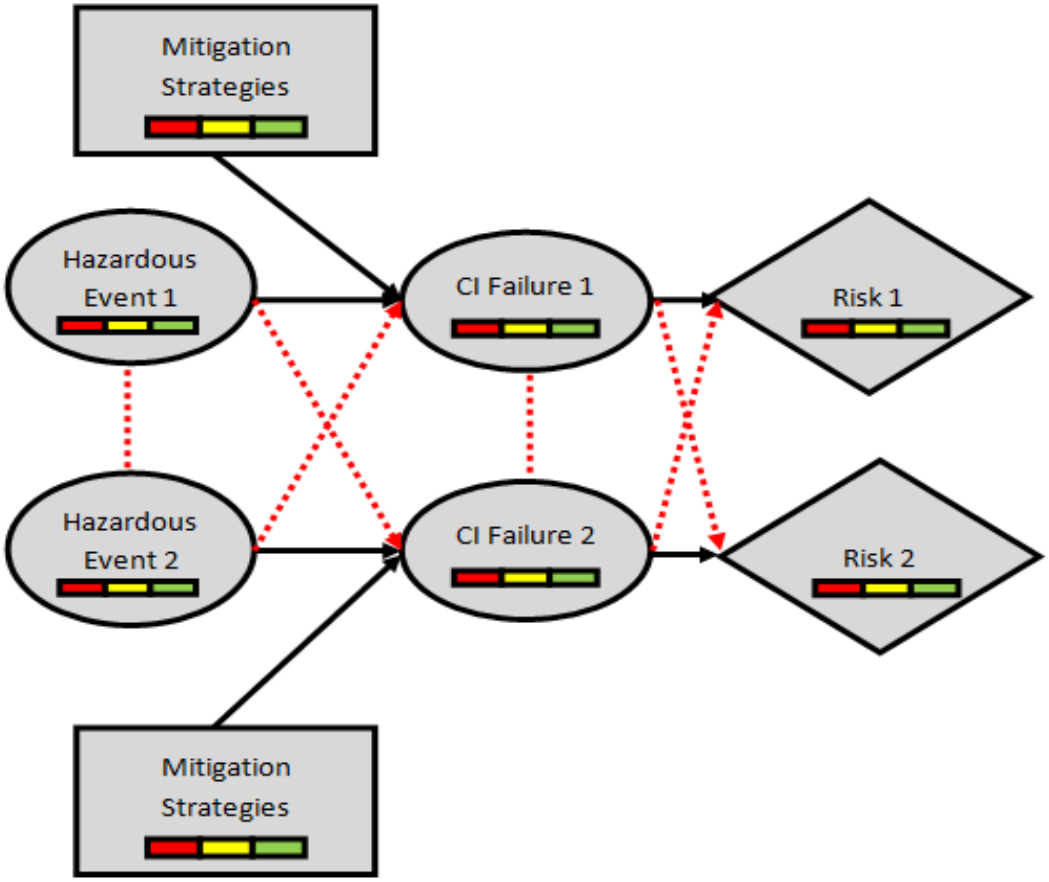
Mitigation



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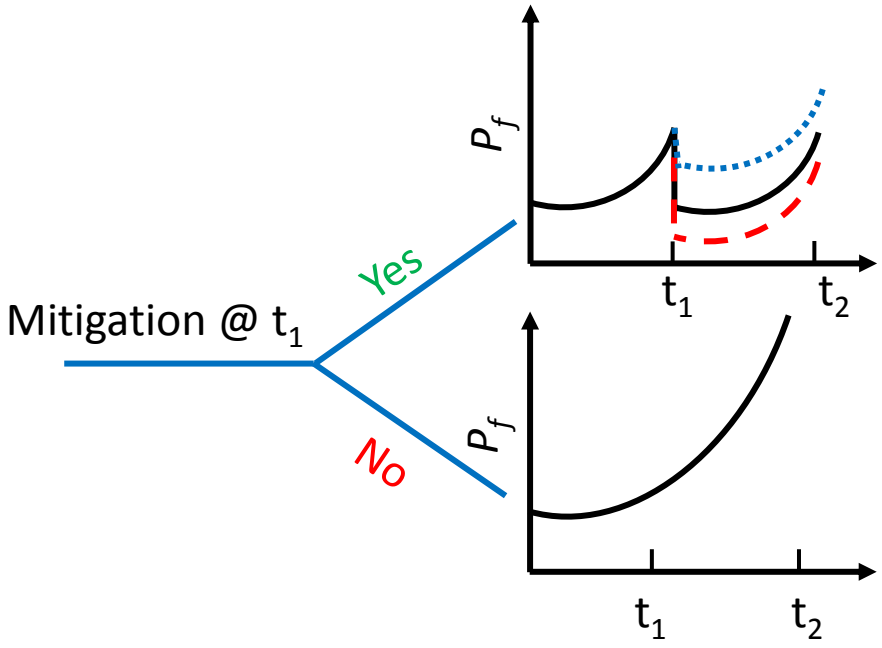
Risk Evaluation

Step 15- Developing Mitigation Strategies



P_f = Probability of Failure
t_i = Time

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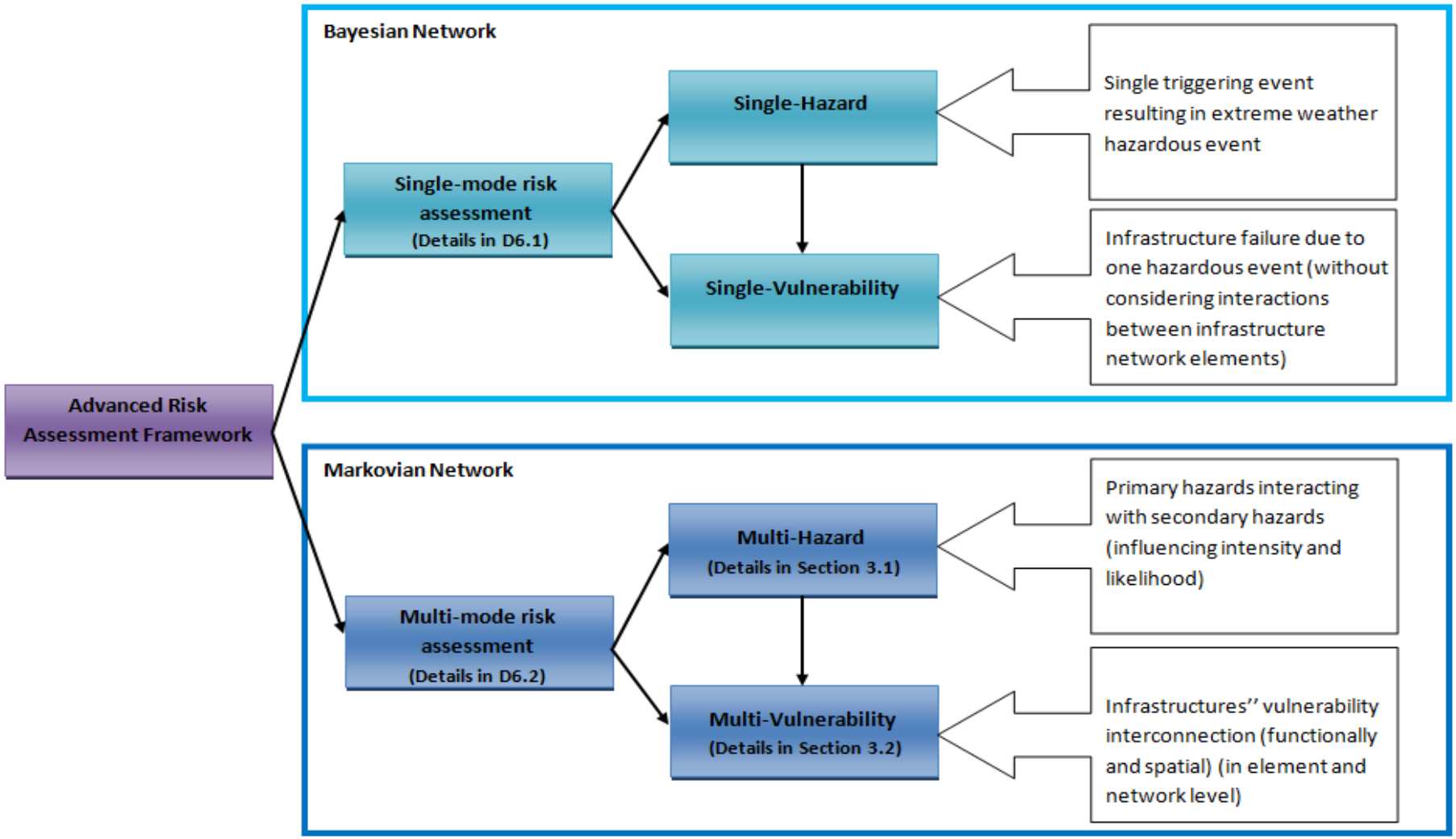

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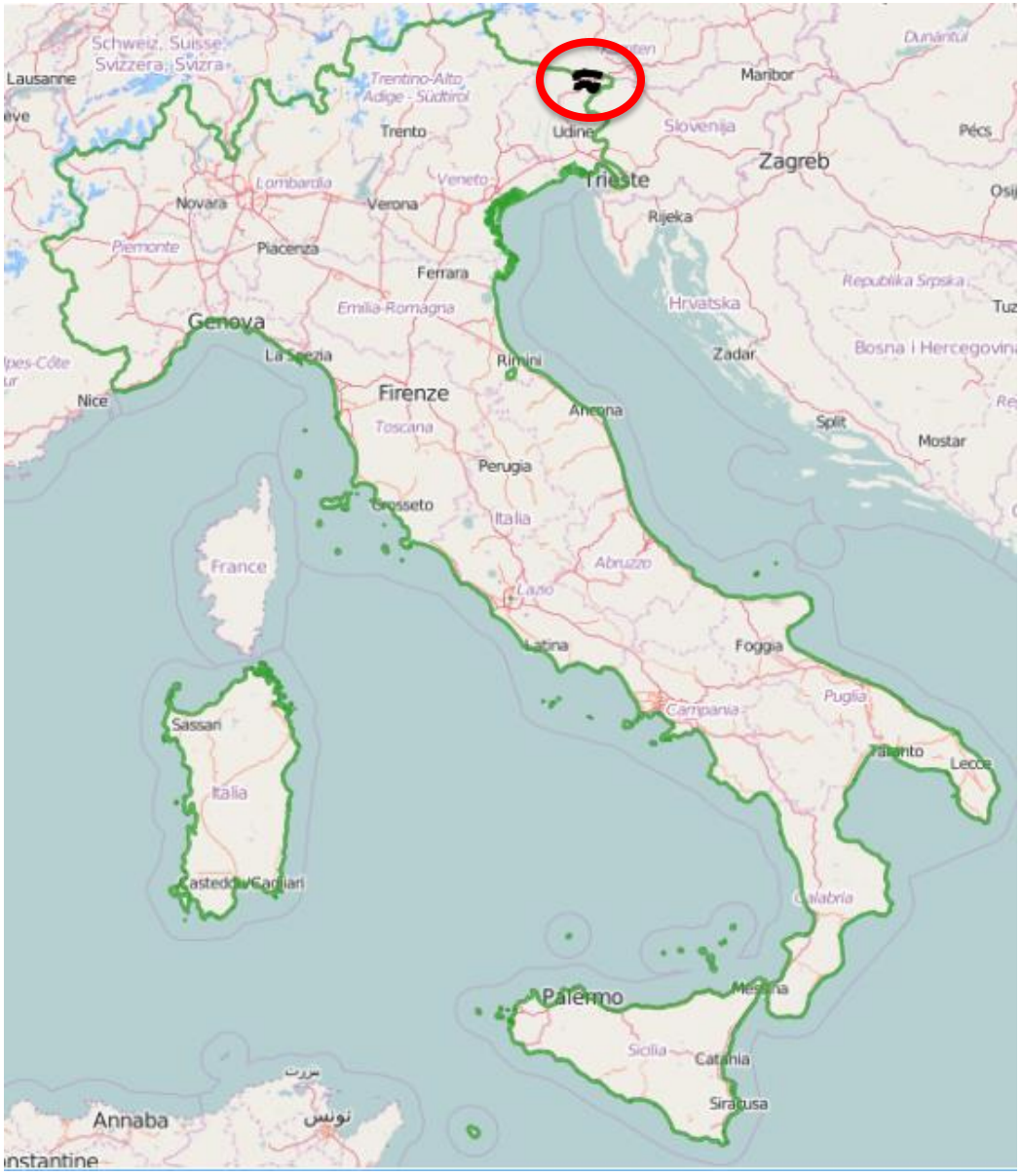
RAIN case study 1



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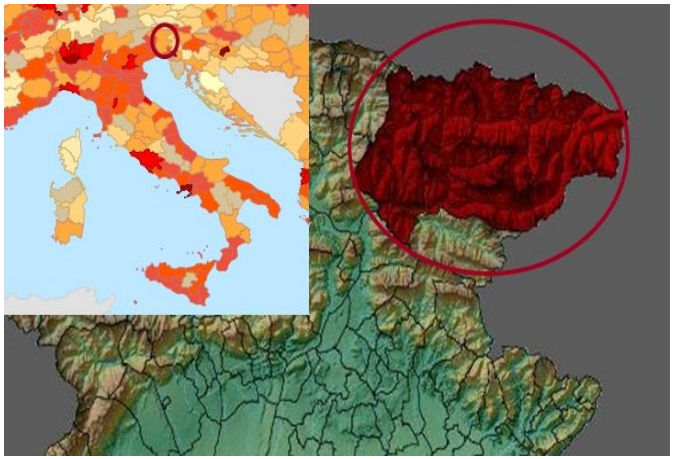
Example of Risk Assessment

Alpine Region

- Flash flooding in 2003
- 600 residents were evacuated
- Estimated damage of €190 million



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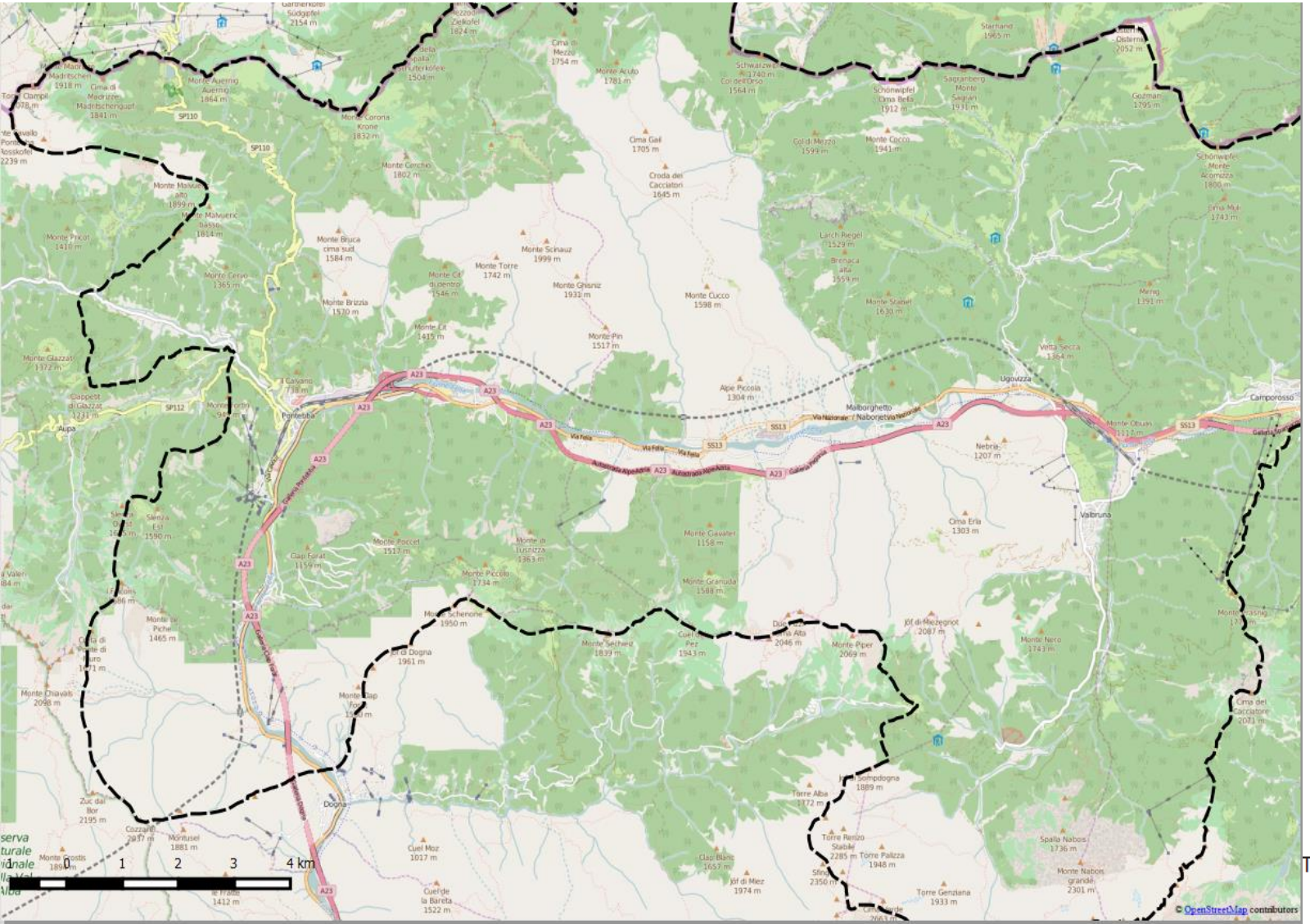
Establishing the Context

RAIN PROJECT

Case Study Area



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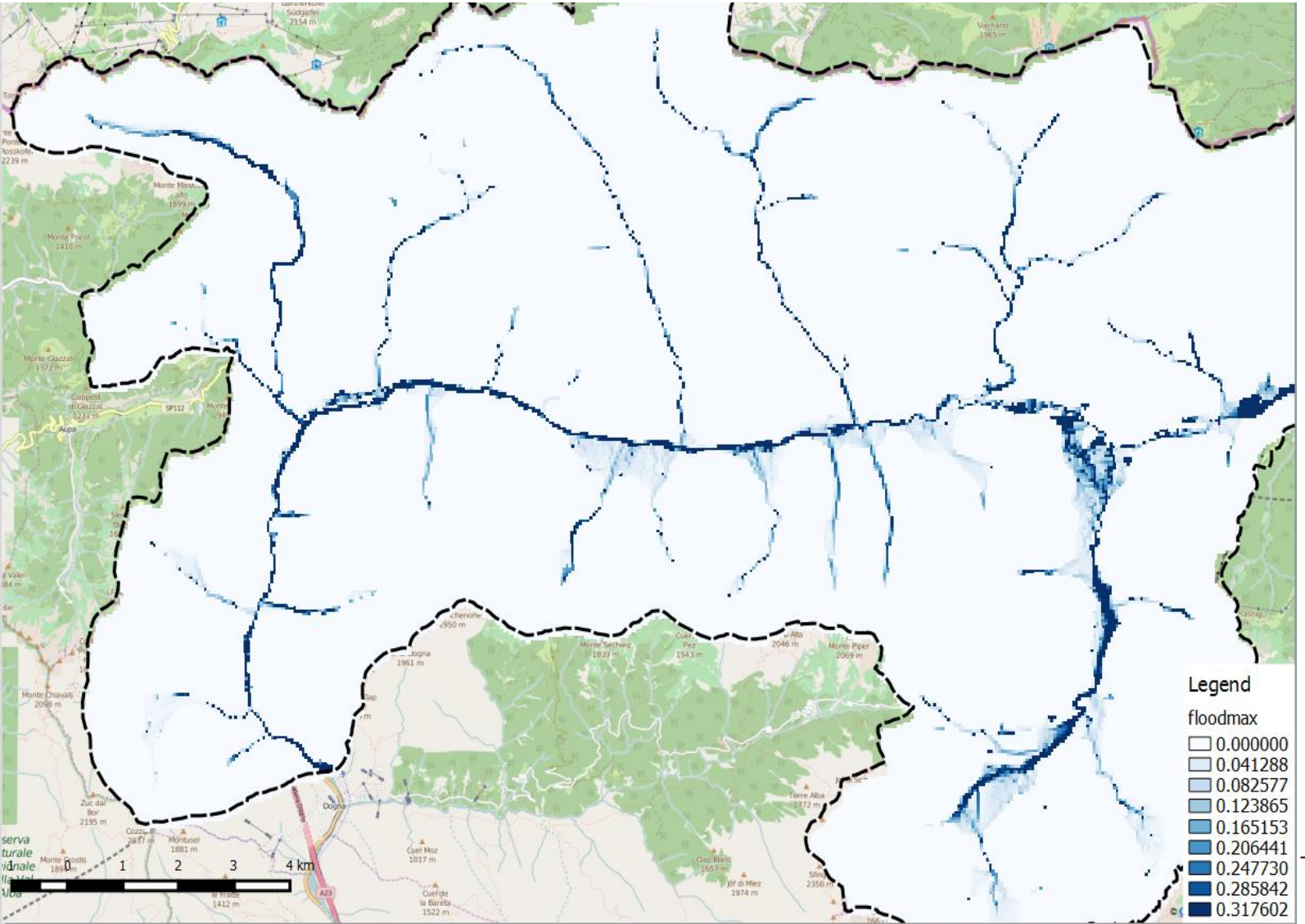
Hazard Assessment

Identifying hazards, thresholds and corresponding probabilities



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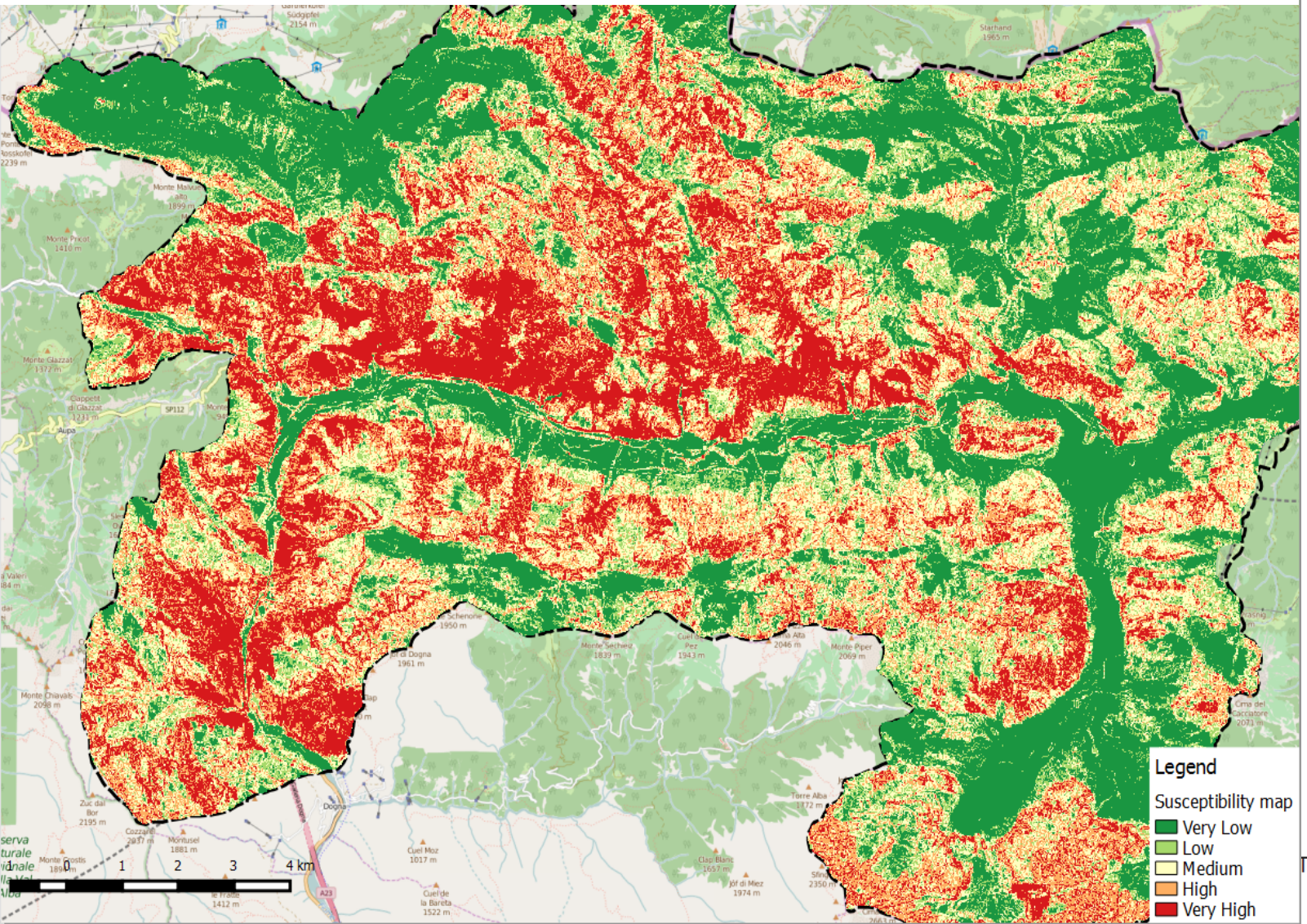
Hazard Assessment

Identifying hazards, thresholds and corresponding probabilities



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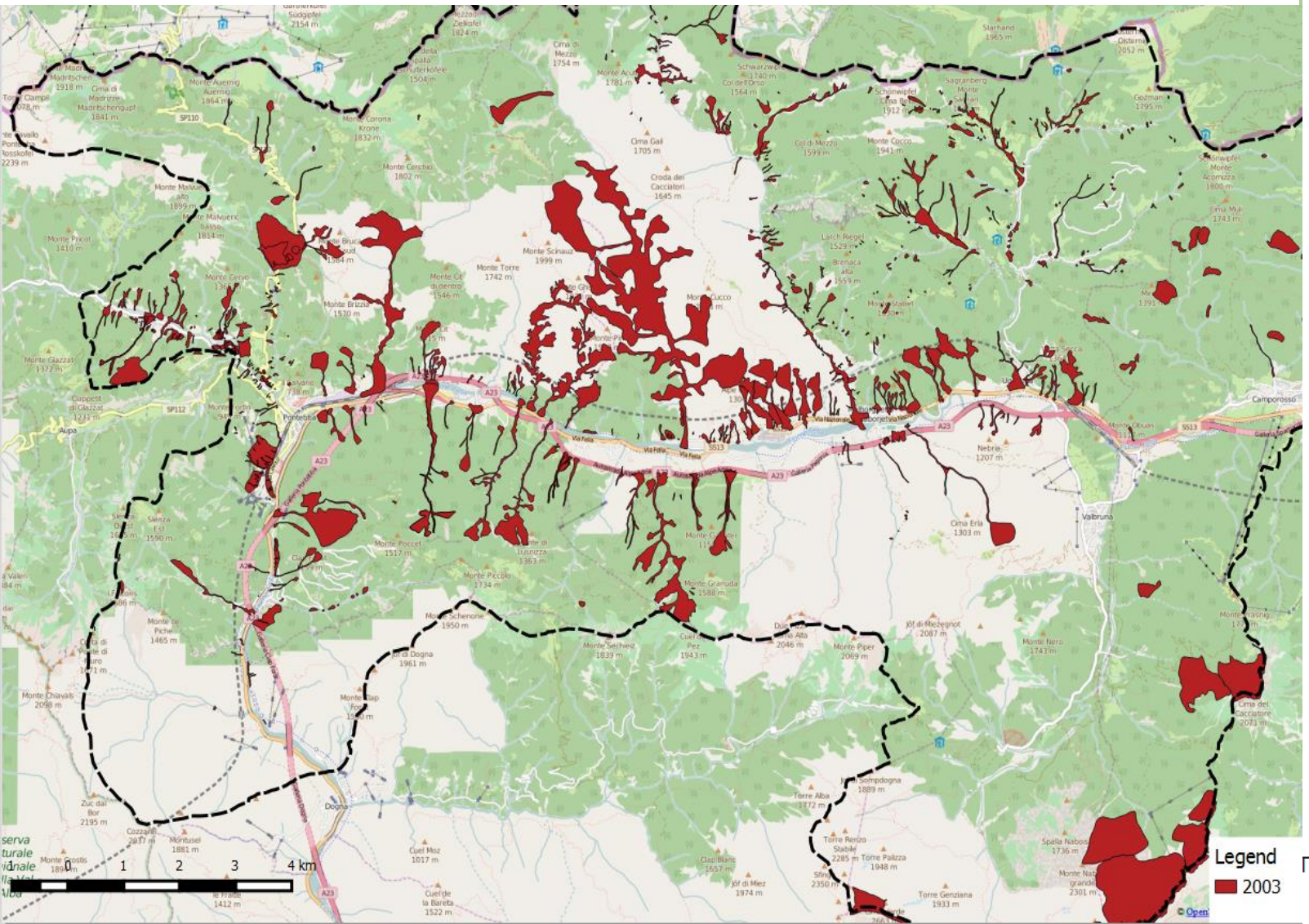
Hazard Assessment

Identifying hazards, thresholds



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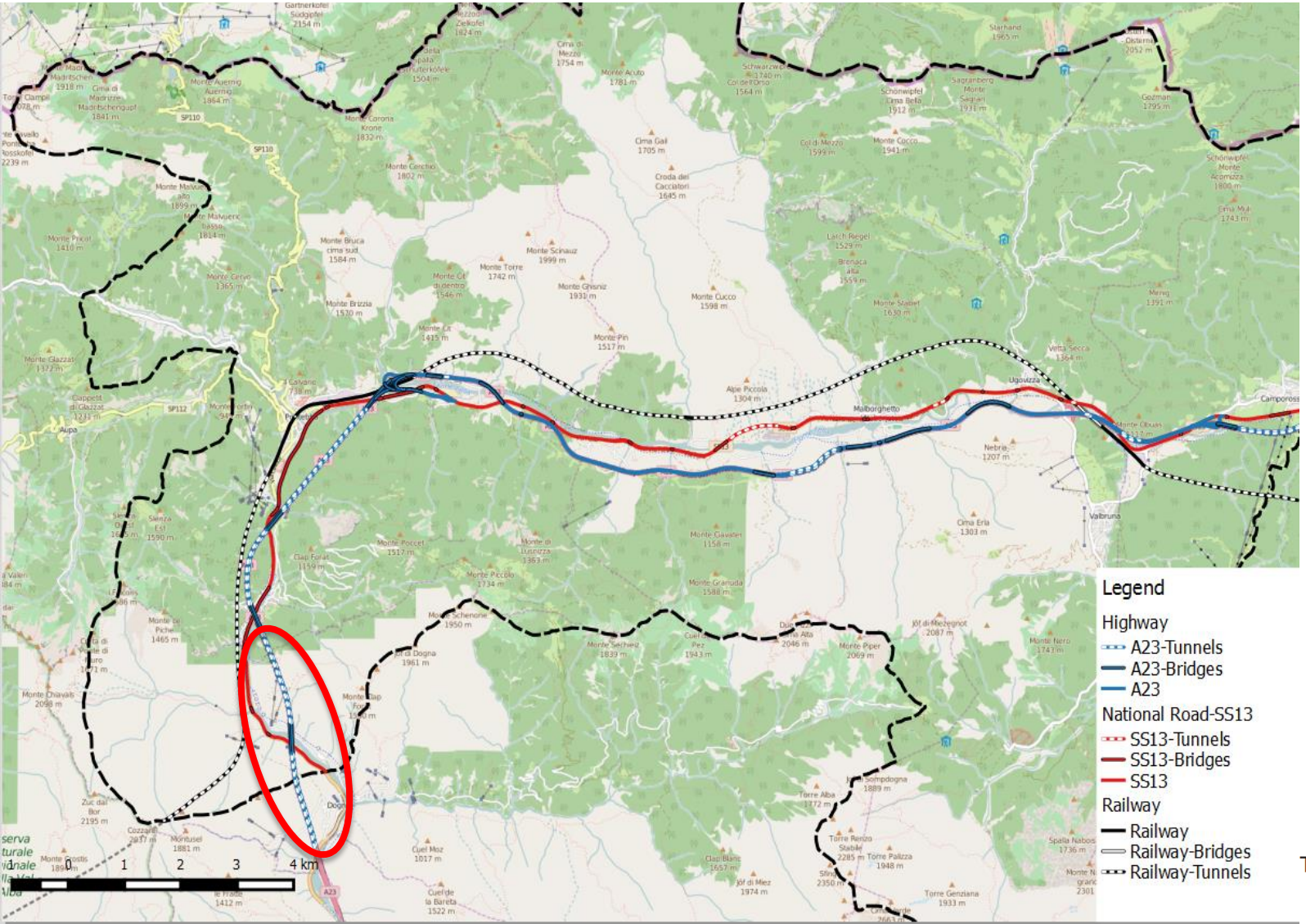
Risk Evaluation

Example of Bayesian Network Development



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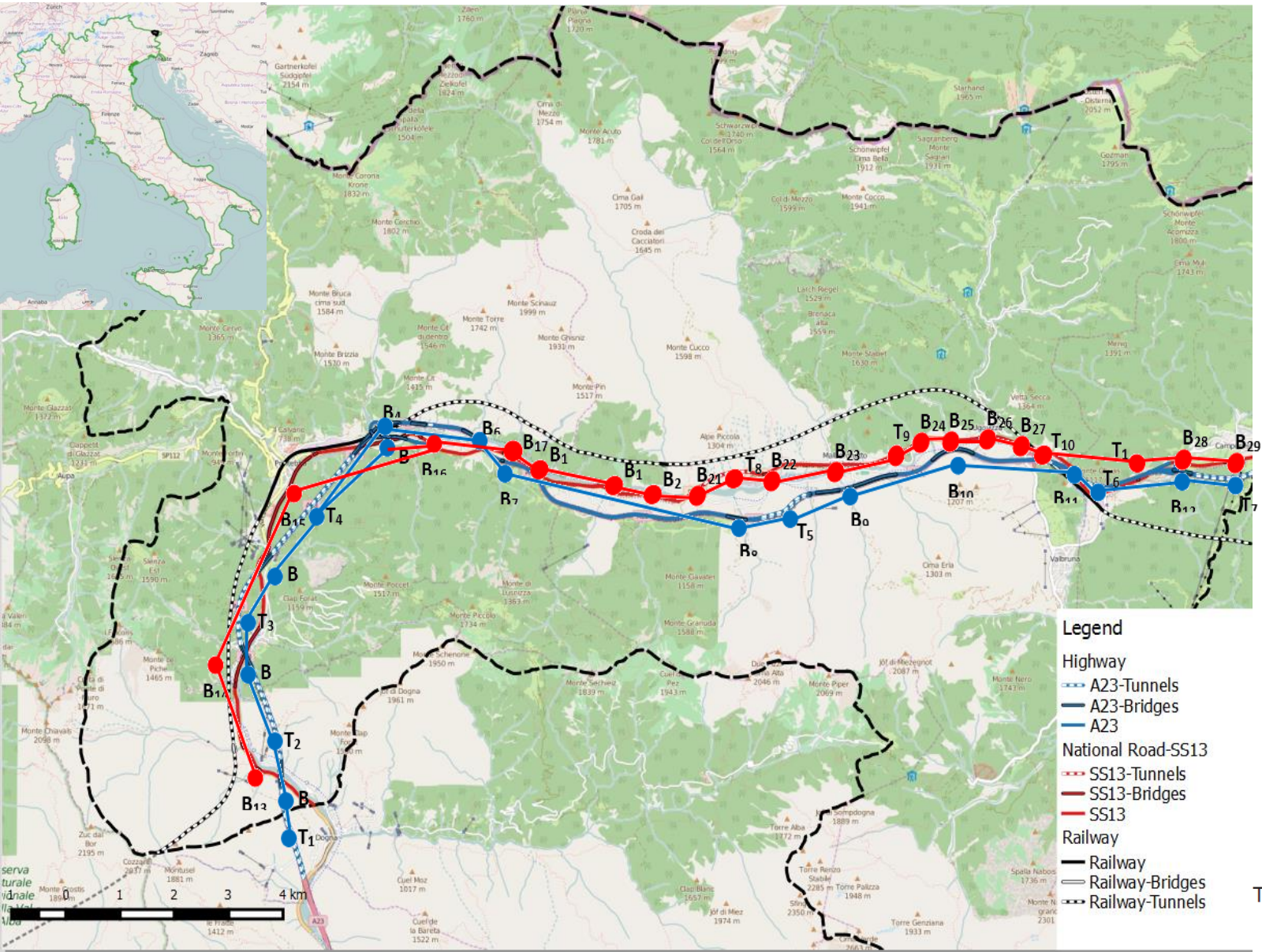
Vulnerability Assessment



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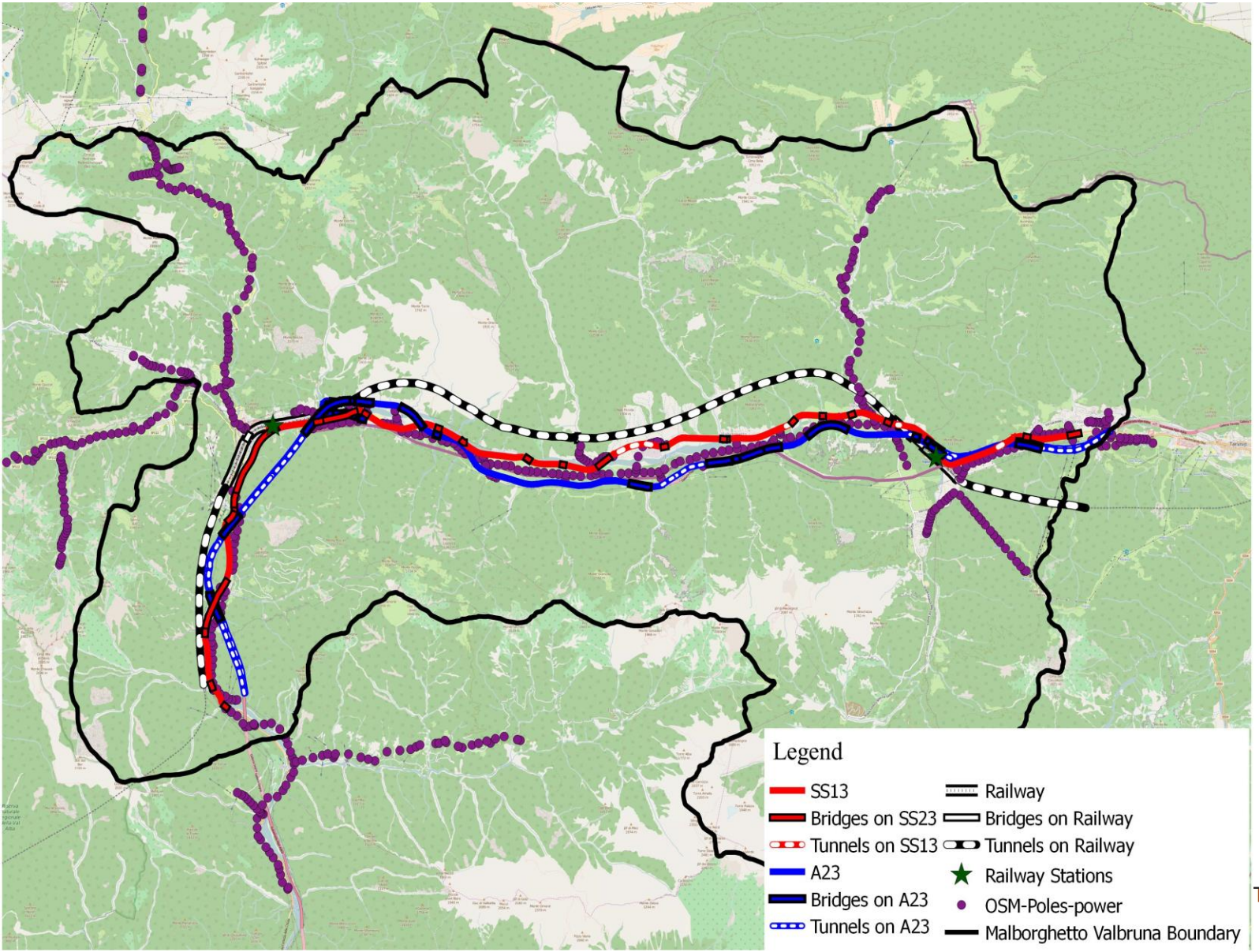

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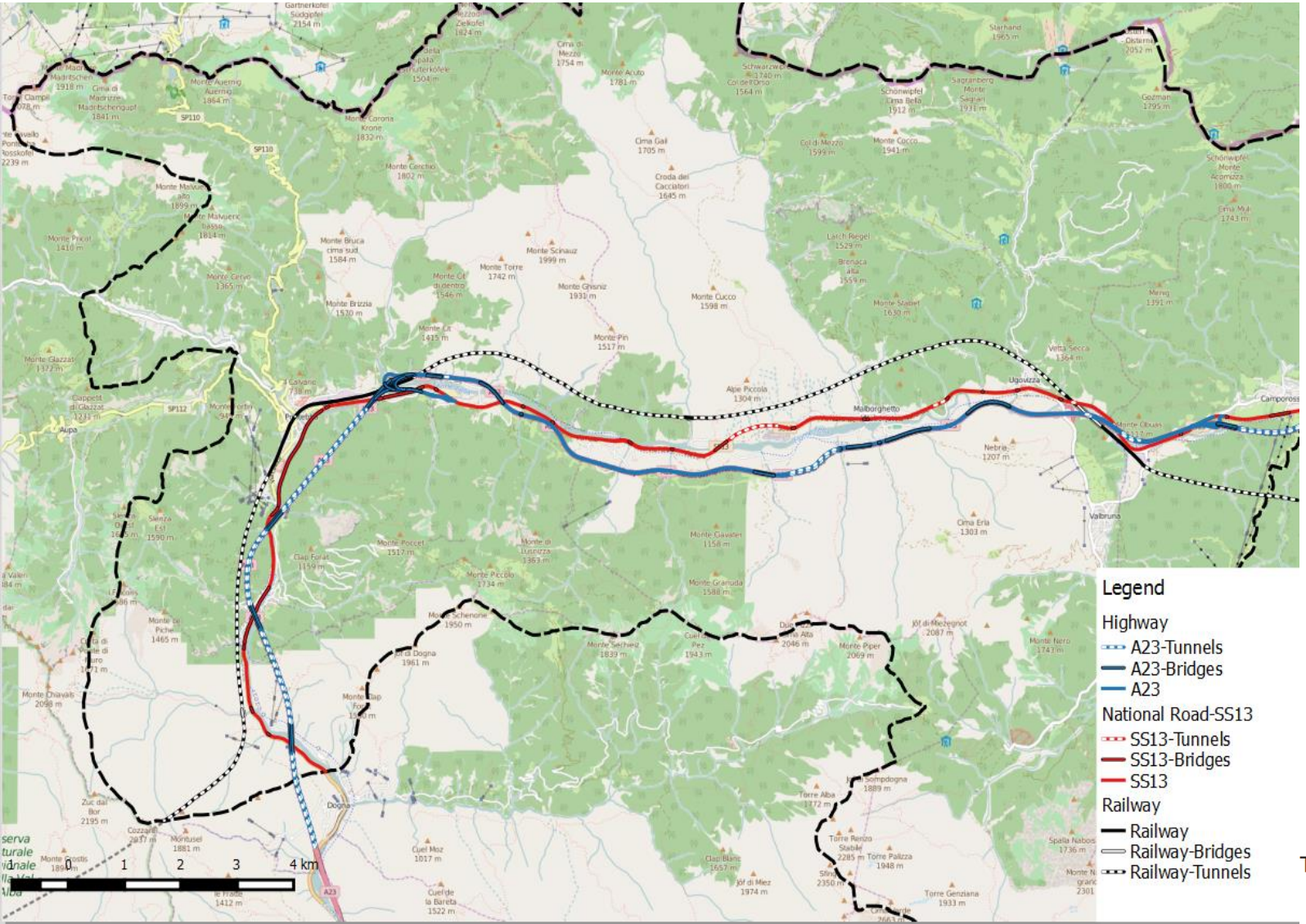
Vulnerability Assessment

Step 4- Identifying vulnerable elements



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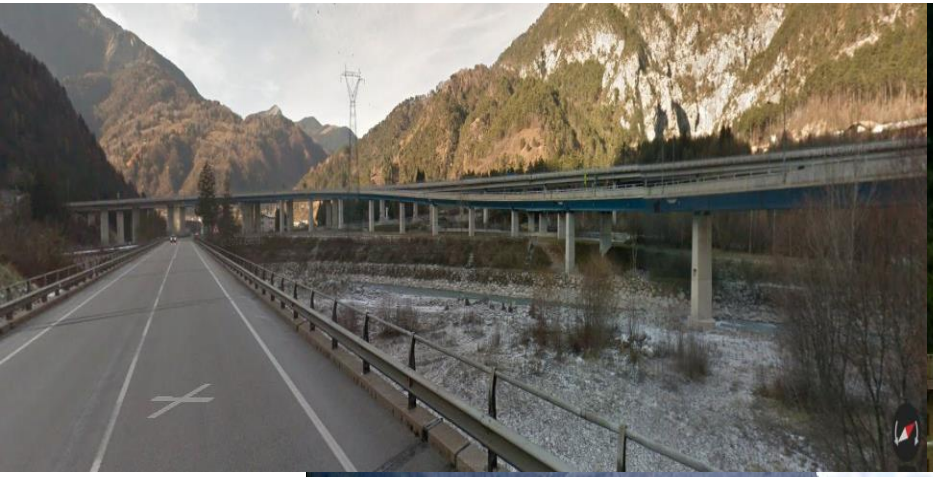
Vulnerability Assessment

Step 4- Identifying vulnerable elements



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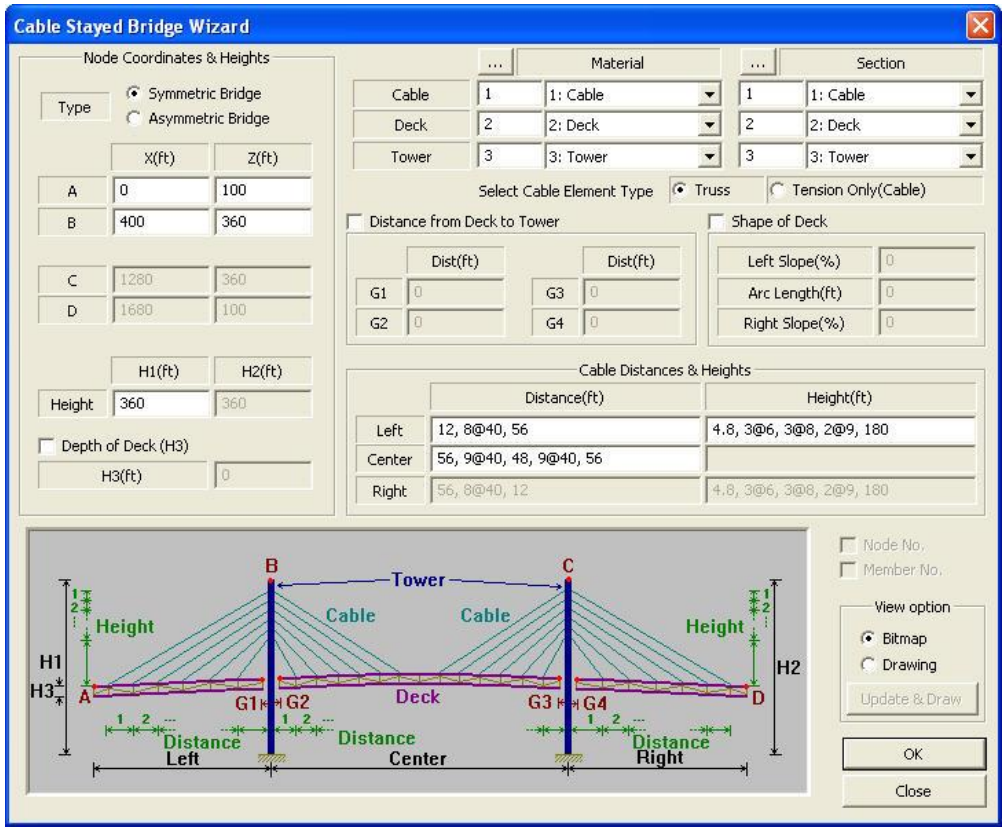
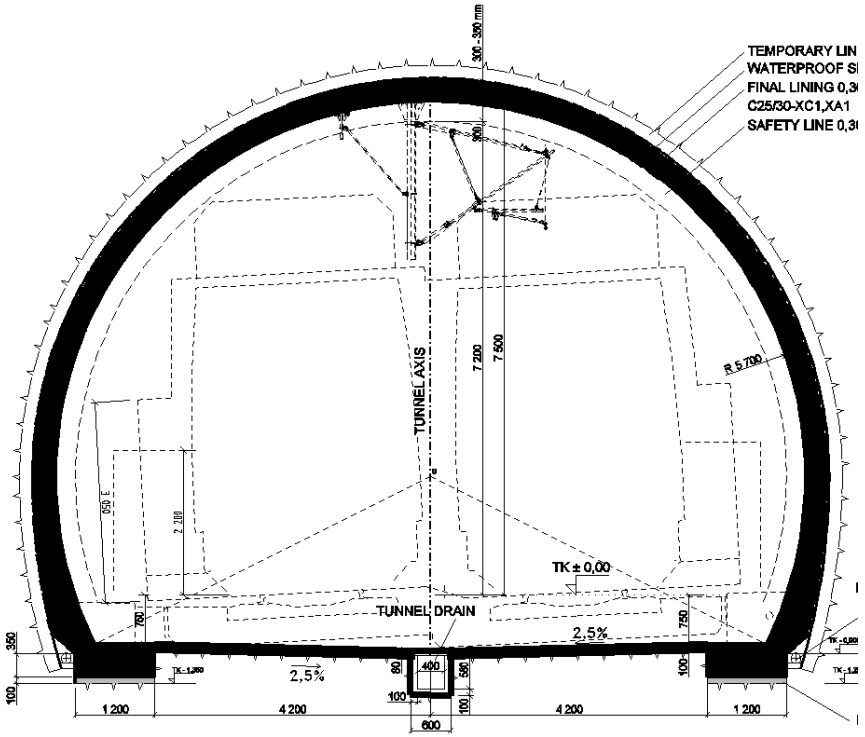
Vulnerability Assessment

Step 4- Identifying vulnerable elements





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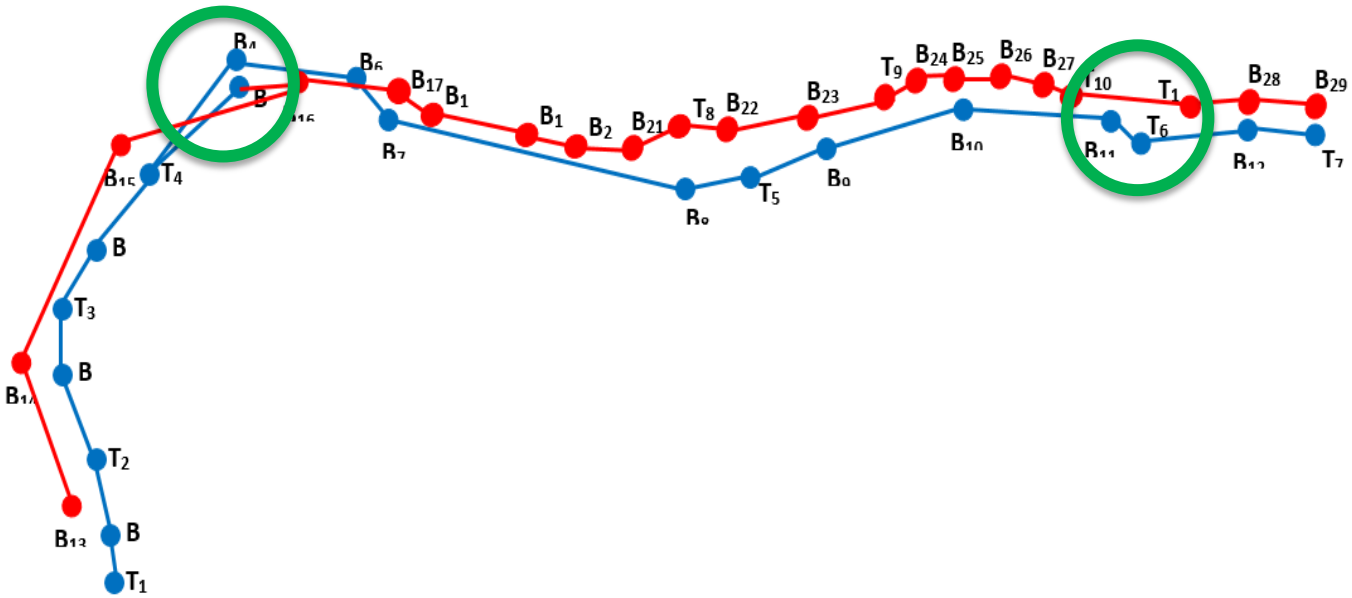
Vulnerability Assessment

Step 5- Identifying critical locations



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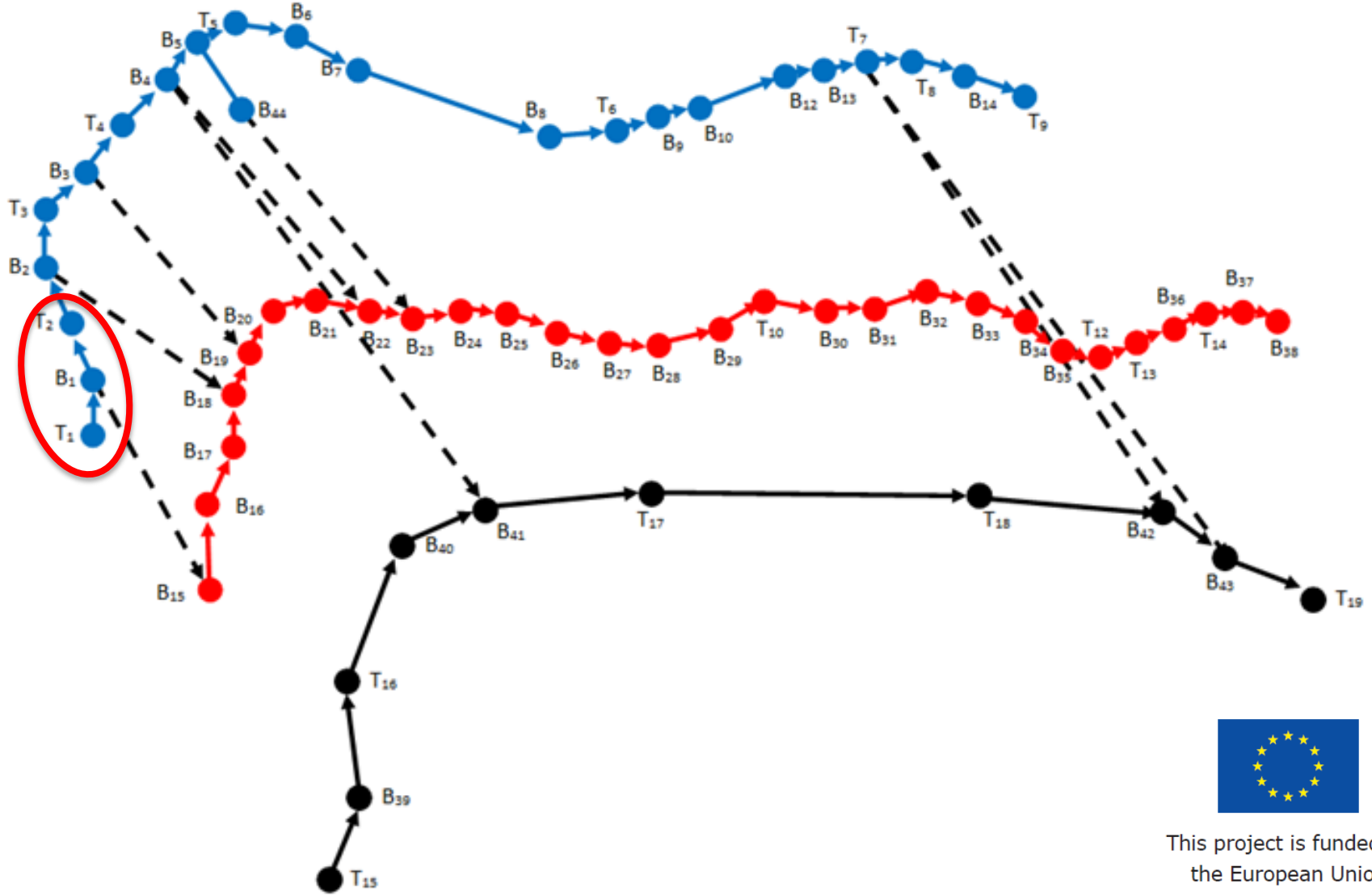
Risk Evaluation

Example of Bayesian Network Development



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Risk Evaluation

Example of Bayesian Network Development

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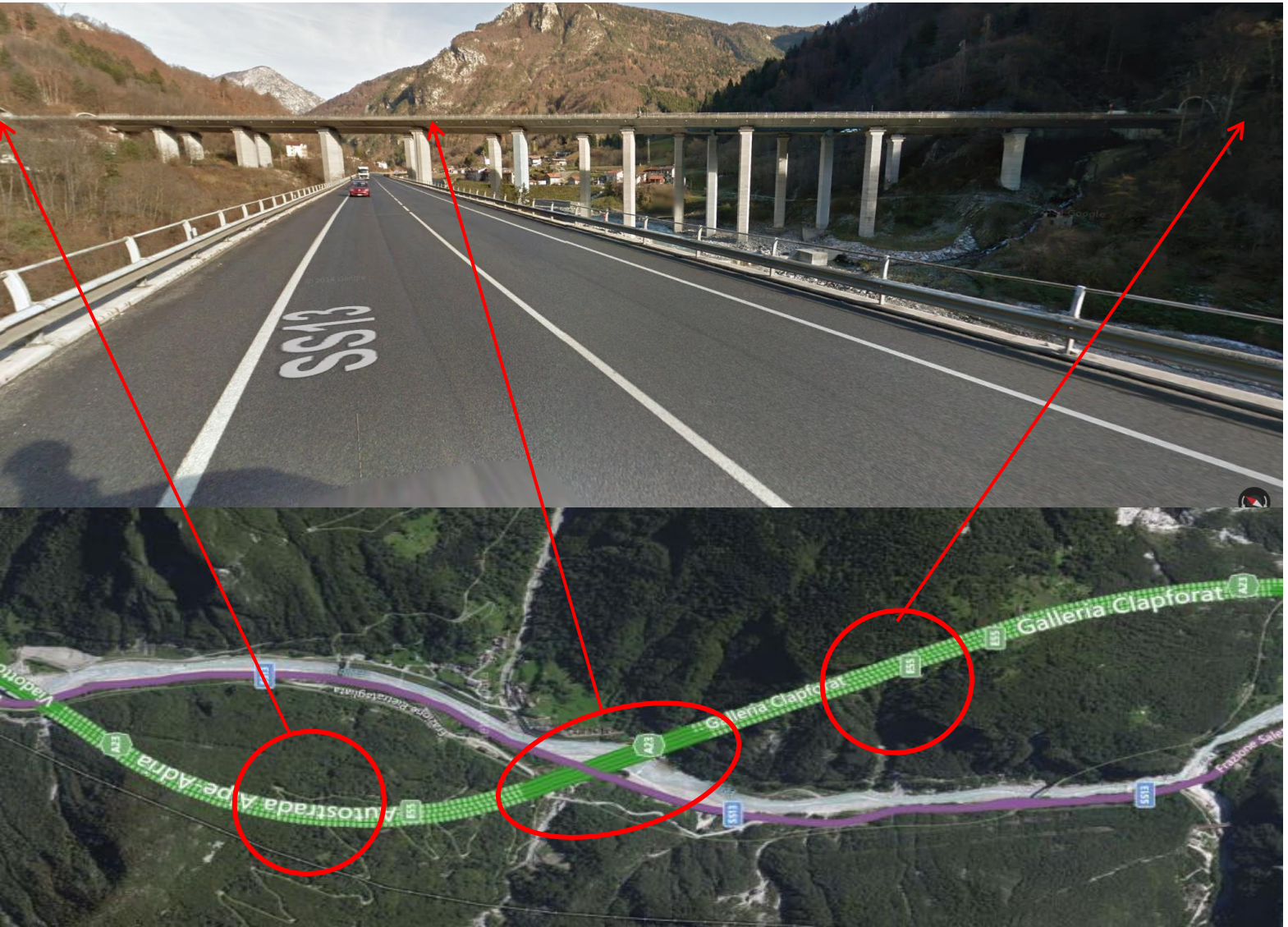
Risk Evaluation

Example of Bayesian Network Development



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Risk Evaluation

Example of Bayesian Network Development

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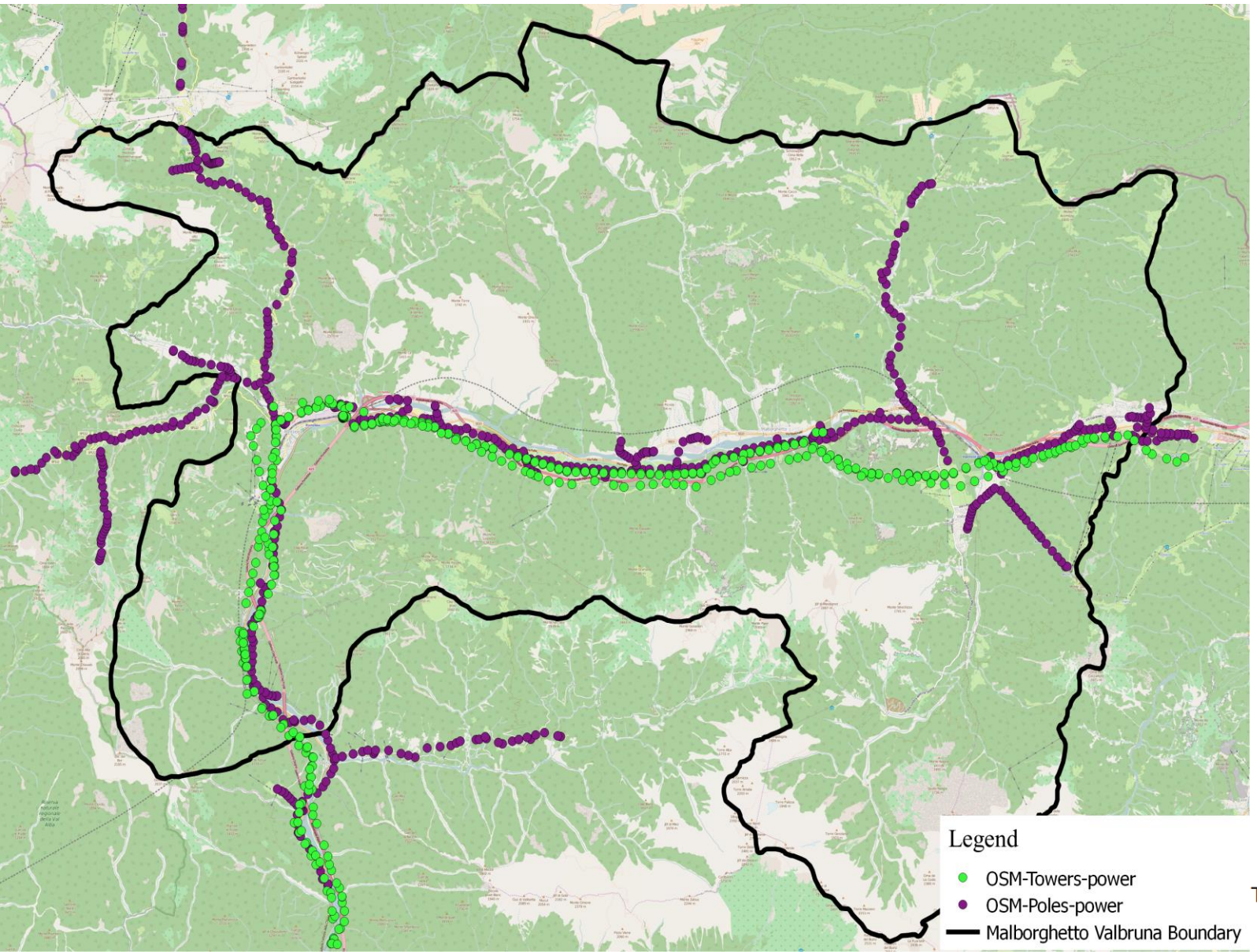
Electricity Network



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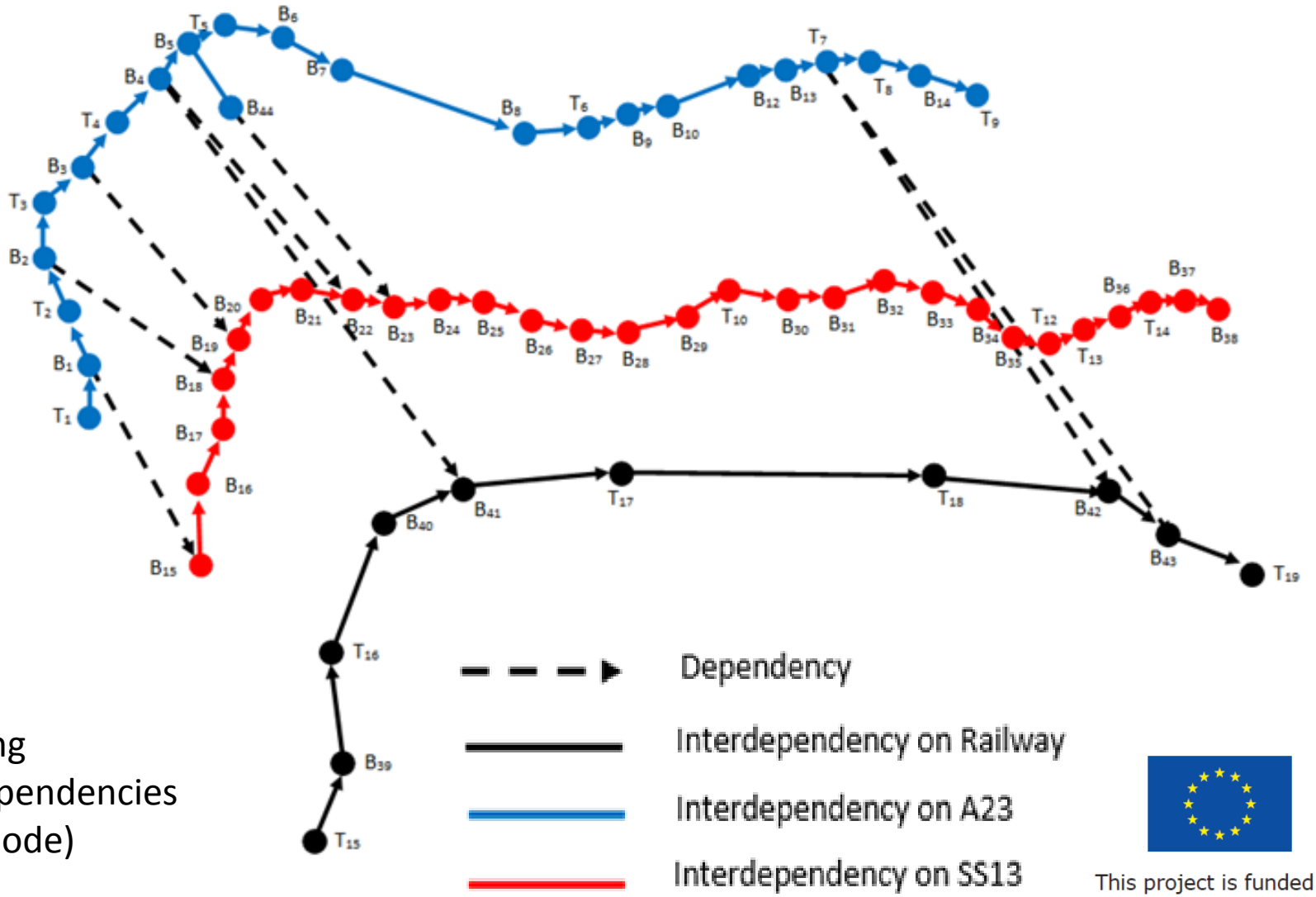
Vulnerability Assessment



Identifying (inter)dependencies (single Mode)

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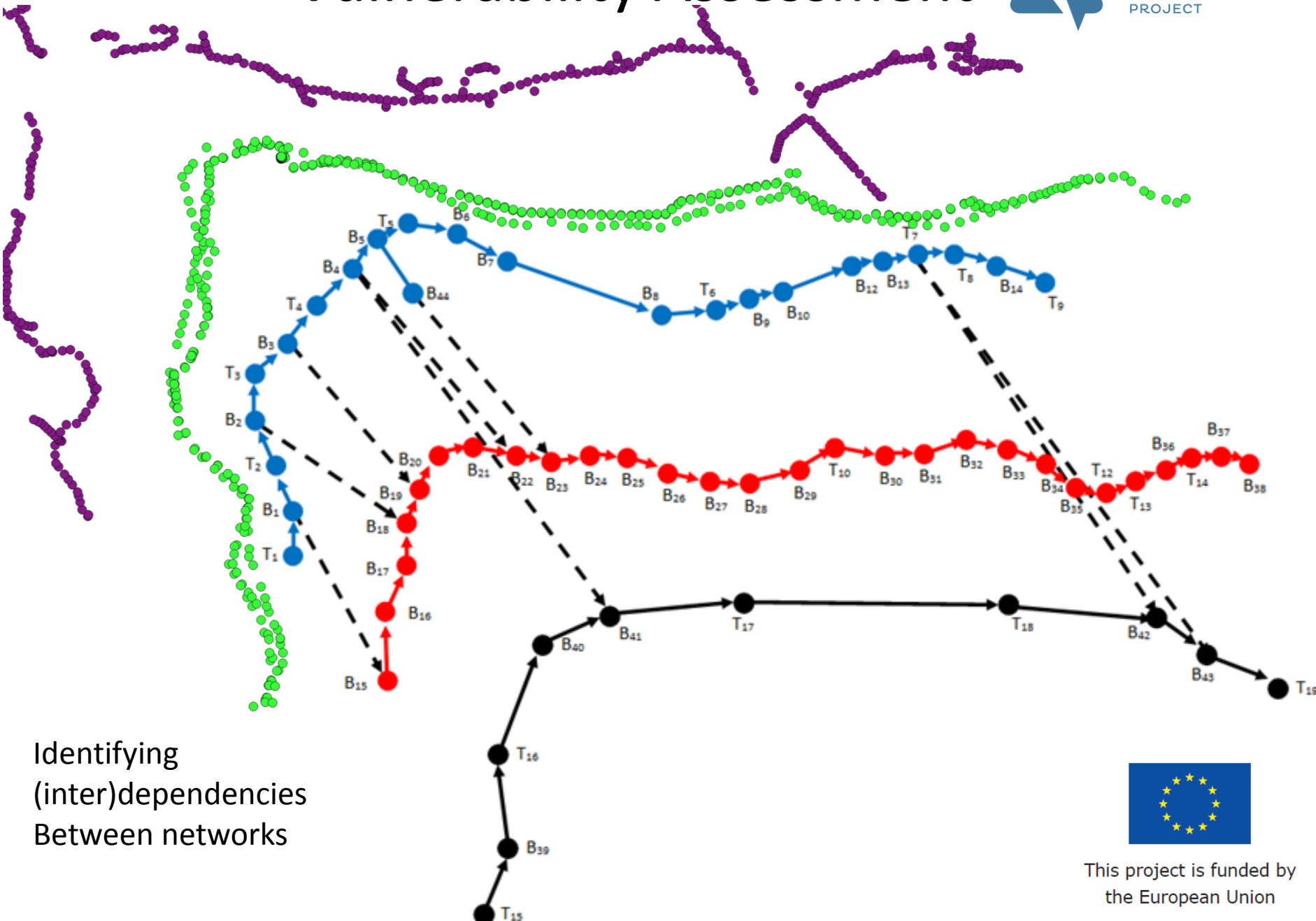
Vulnerability Assessment

RAIN PROJECT



Identifying
(inter)dependencies
Between networks

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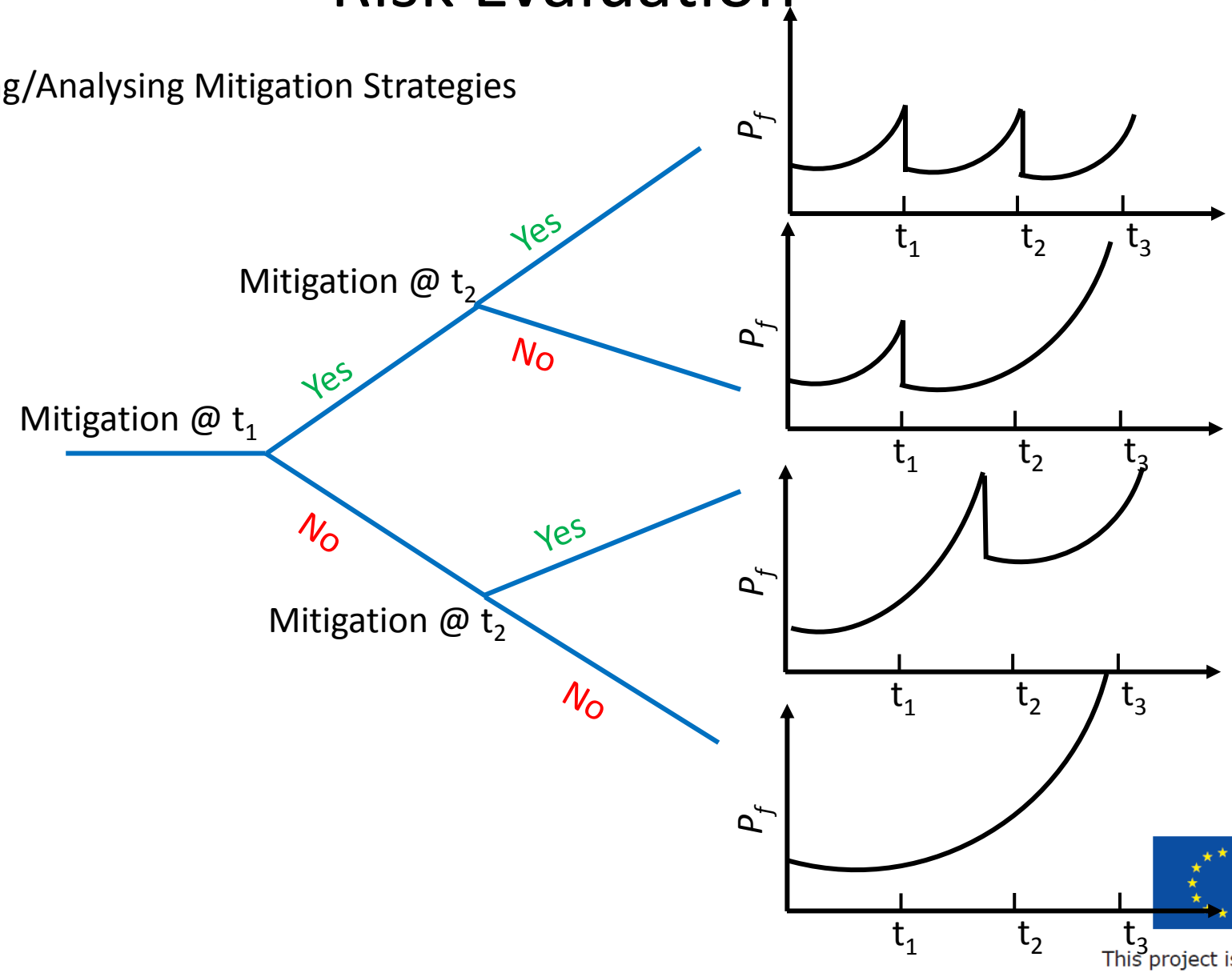
Risk Evaluation

Developing/Analysing Mitigation Strategies



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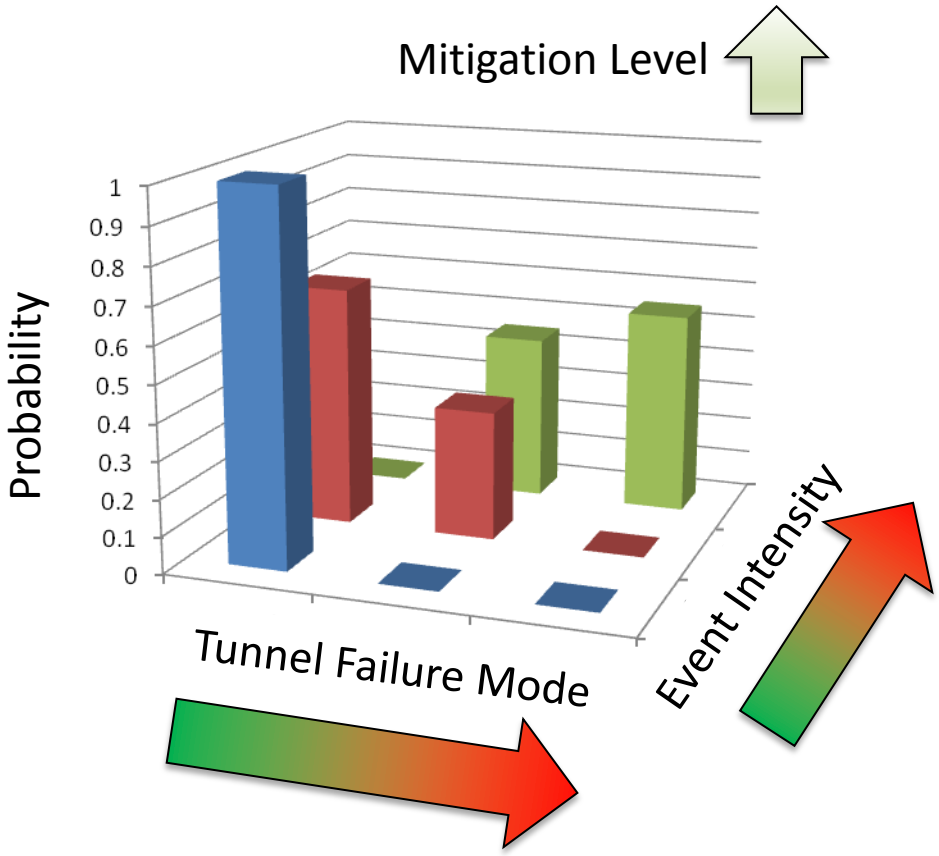
Risk Evaluation



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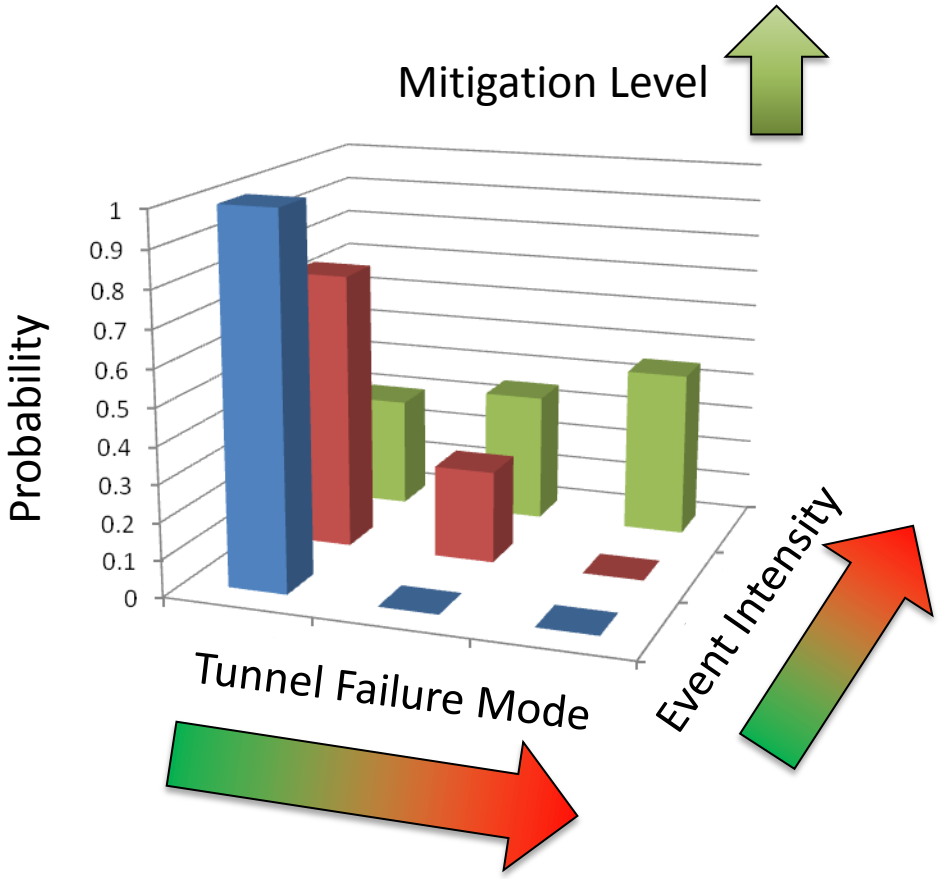
Risk Evaluation



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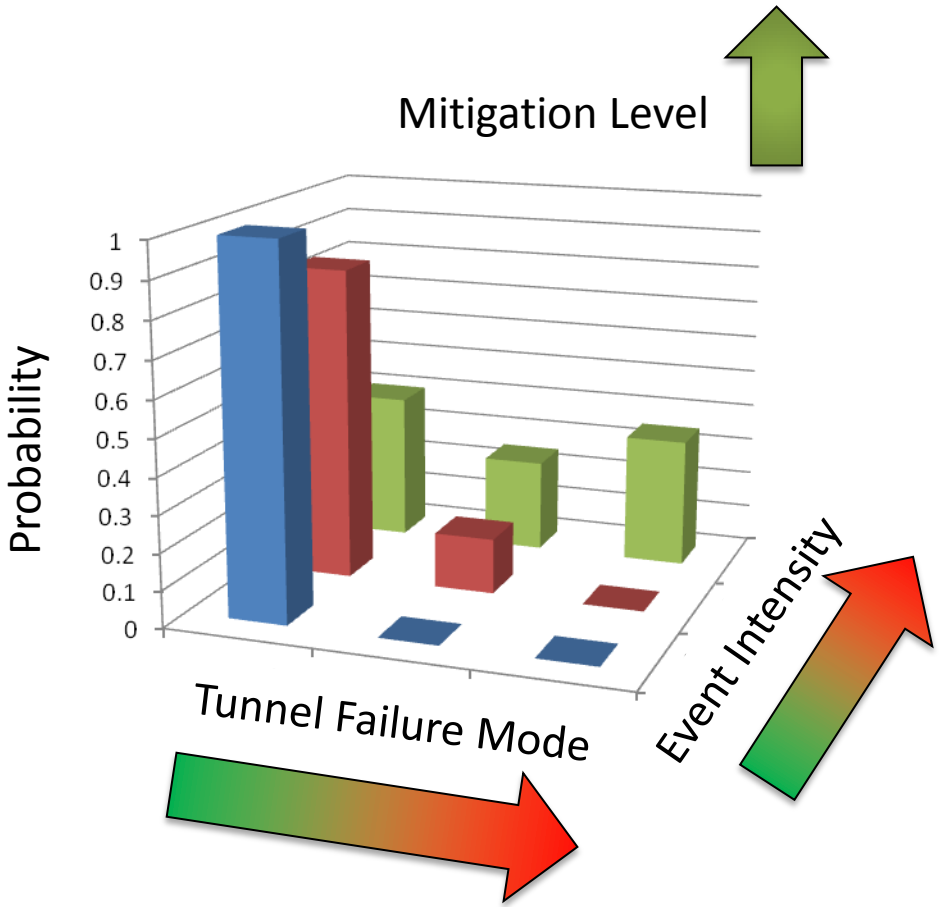
Risk Evaluation



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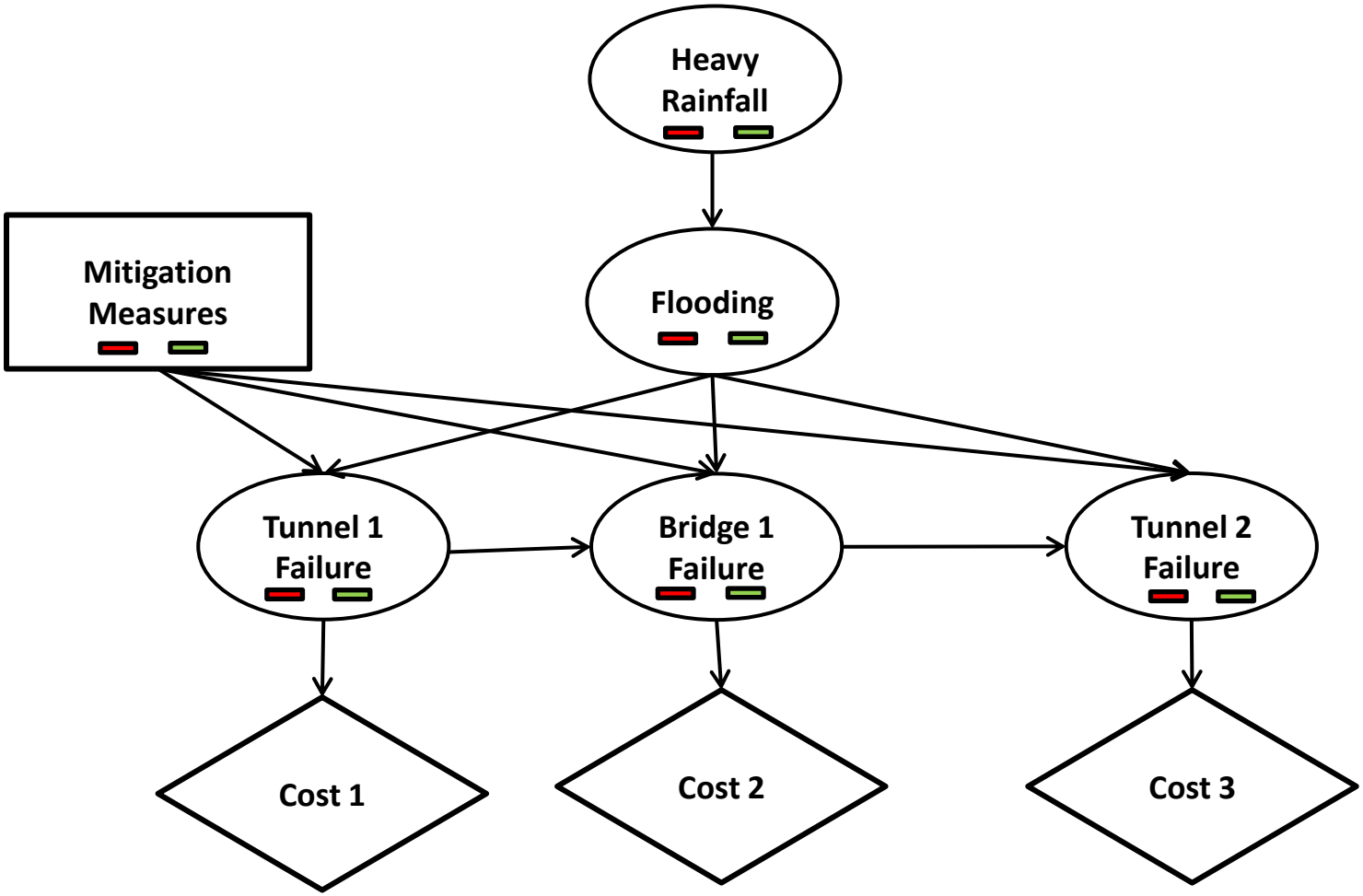
Risk Evaluation

Example of Bayesian Network Development



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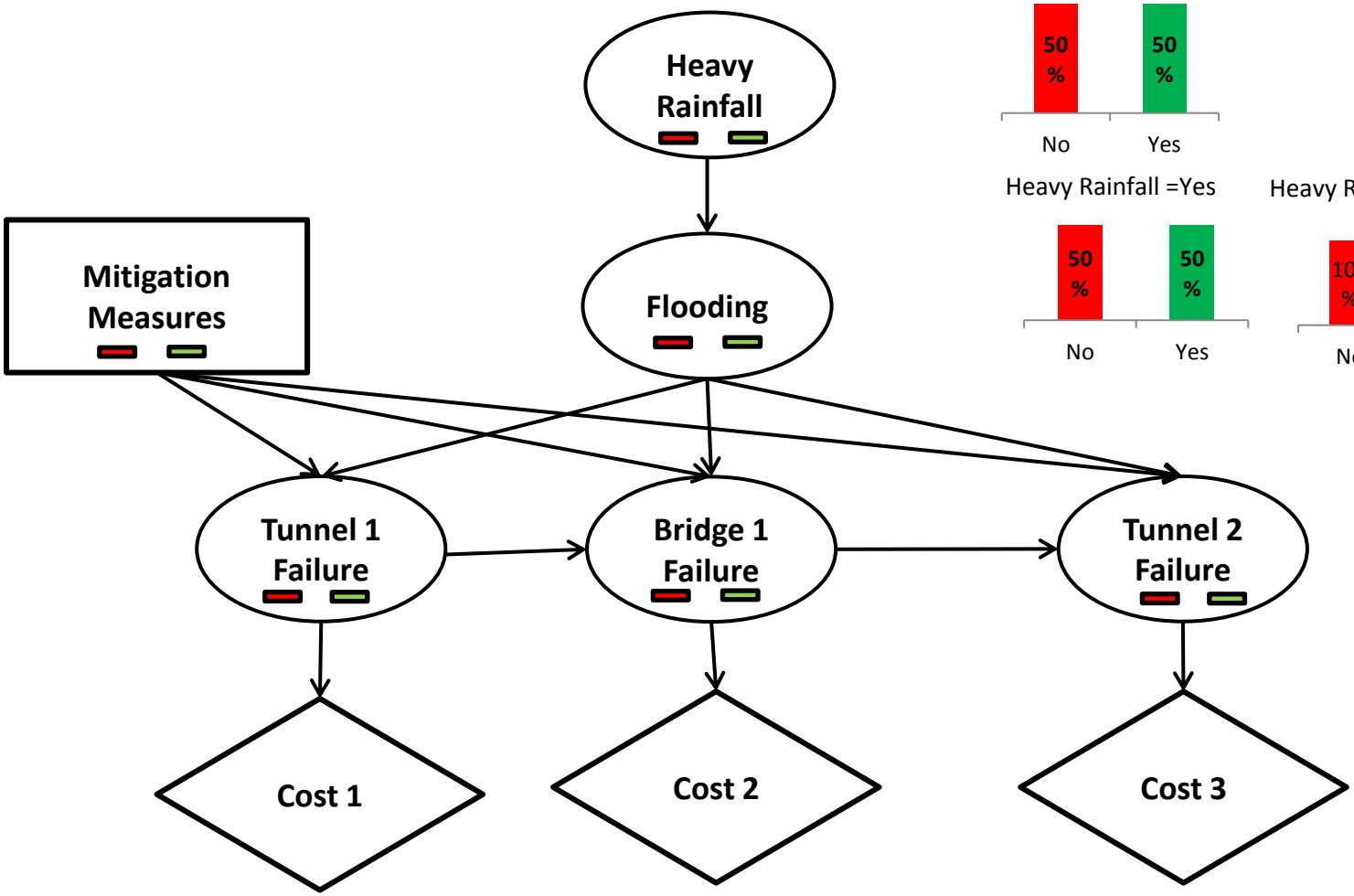
Risk Evaluation

Example of Bayesian Network Development



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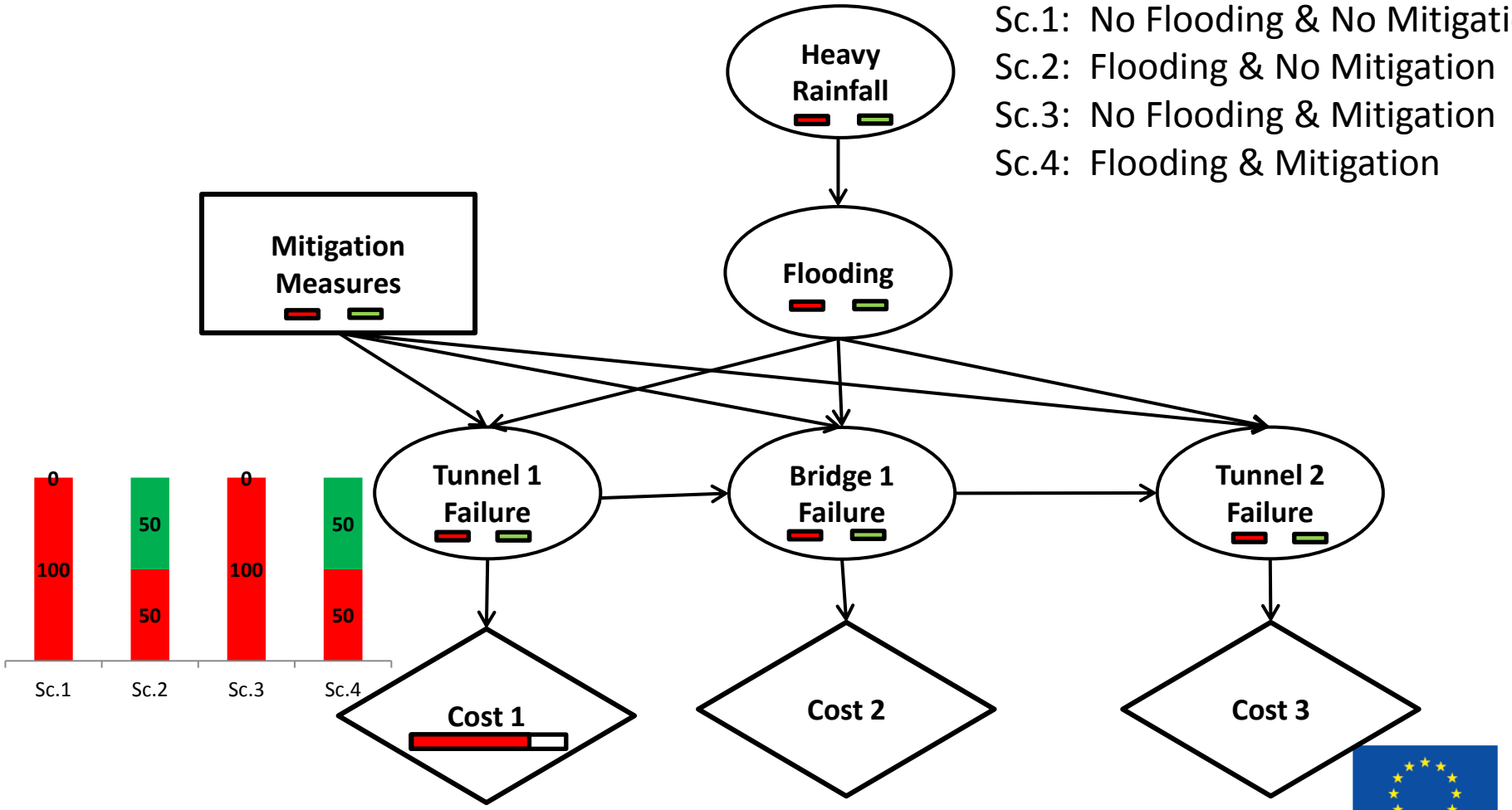
Risk Evaluation

Example of Bayesian Network Development

Sc.1: No Flooding & No Mitigation
Sc.2: Flooding & No Mitigation
Sc.3: No Flooding & Mitigation
Sc.4: Flooding & Mitigation



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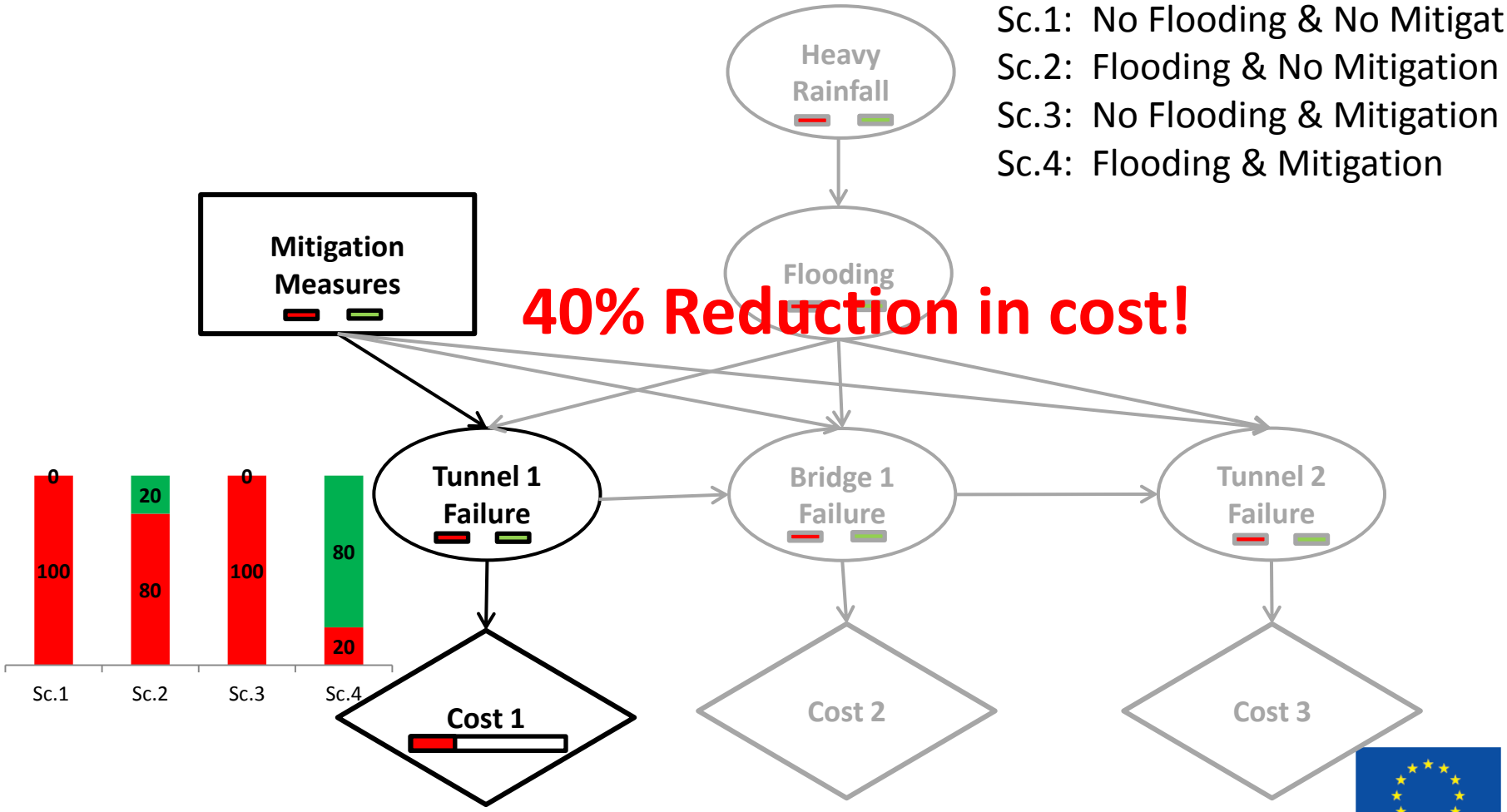
Risk Evaluation

Example of Bayesian Network Development

Sc.1: No Flooding & No Mitigation
Sc.2: Flooding & No Mitigation
Sc.3: No Flooding & Mitigation
Sc.4: Flooding & Mitigation



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Challenges

- Data management
  - Need to find optimal scope to provide robust analysis while balancing computational demand
- Data acquisition
  - Multi-agency proprietary data makes it difficult for research external to various government organizations to access any data.

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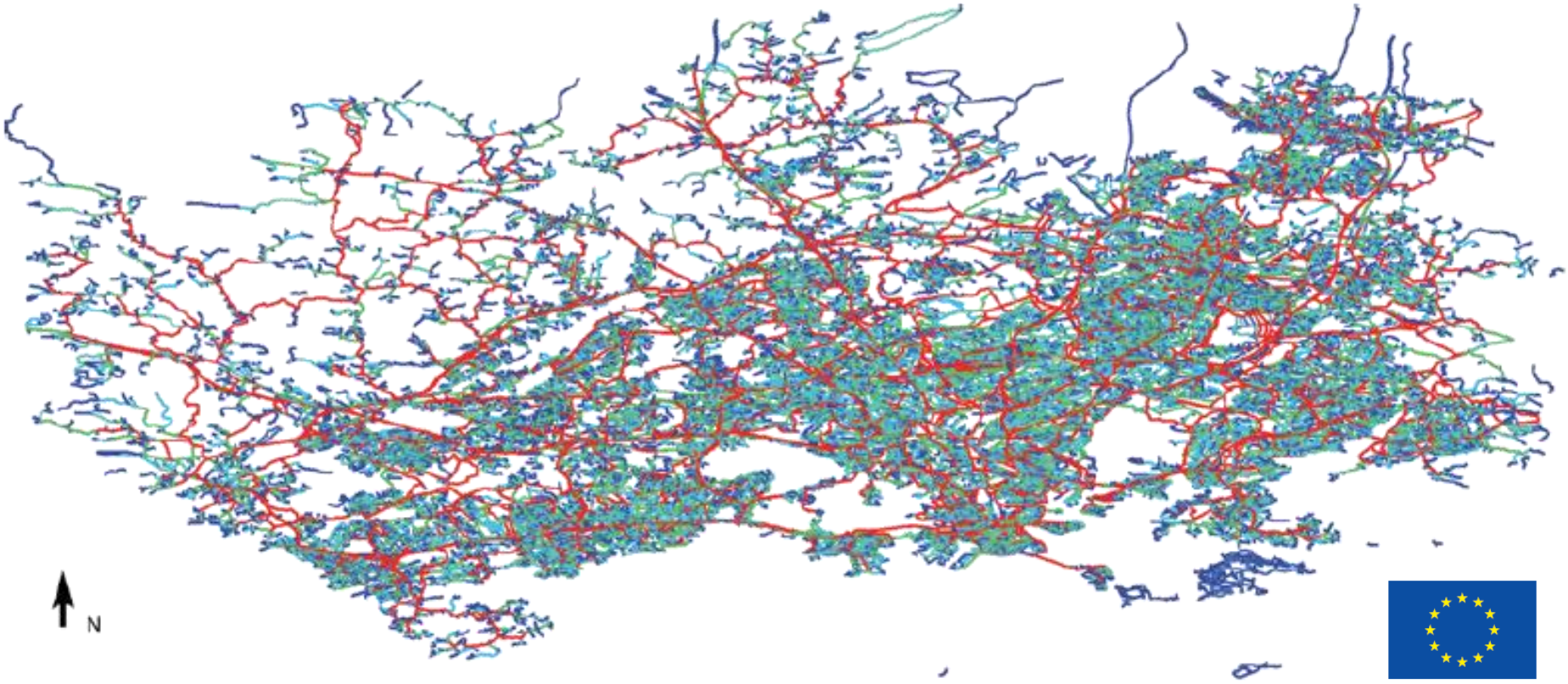
Case Study 2



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RAIN Project

www.rain-project.eu

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THANK YOU FOR YOUR ATTENTION.

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