

Case Studies: TEN-T Road and Rail Networks

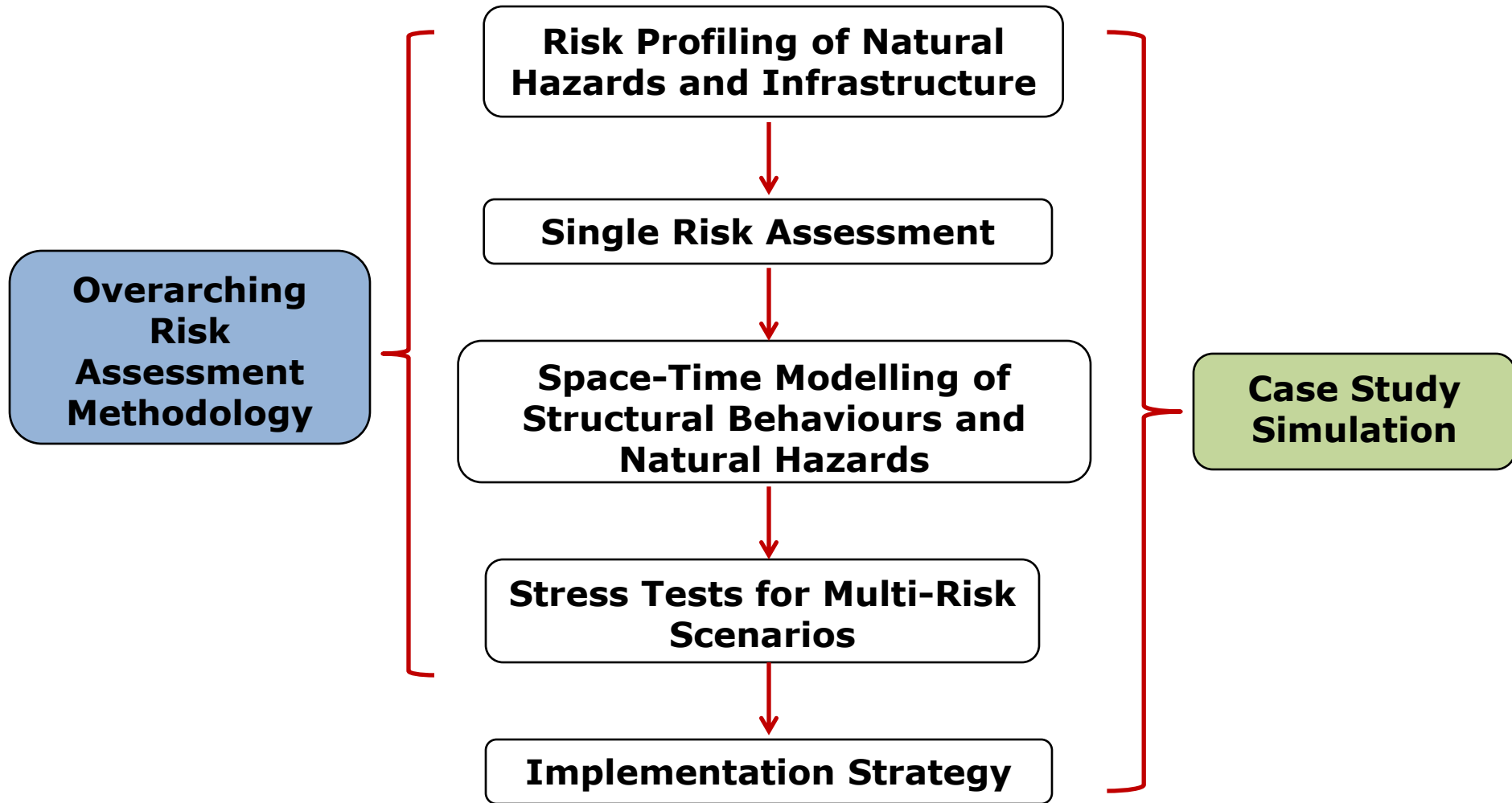
Julie Clarke, Robert Corbally
Roughan & O'Donovan Ltd.
Dublin, Ireland



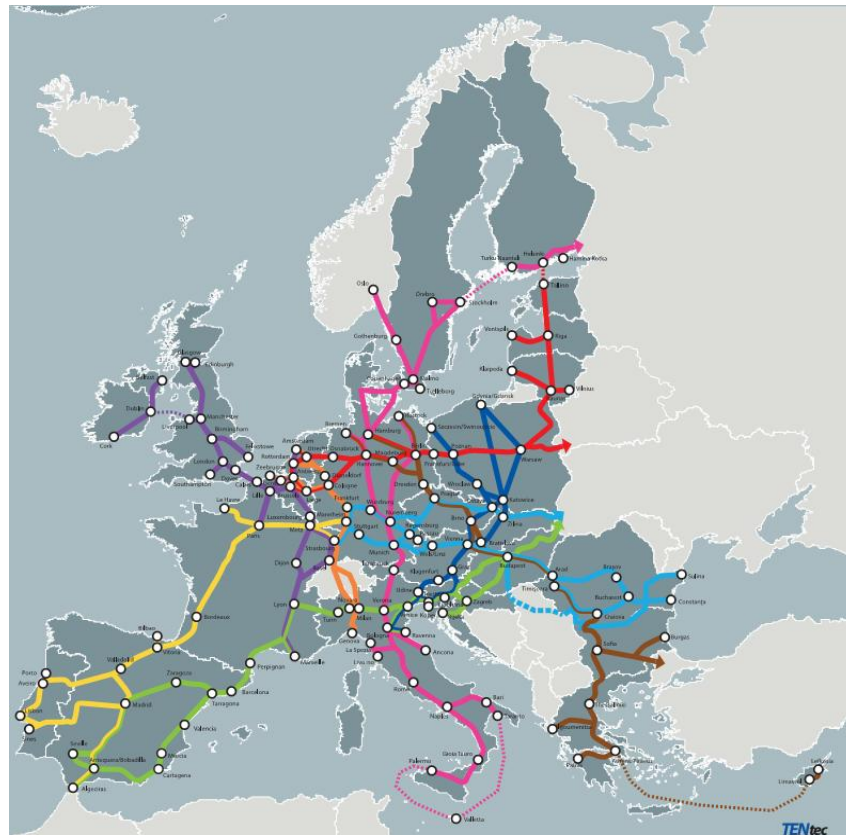
Final Dissemination Conference

**29th September 2016, DRAGADOS, Madrid, Avda. Camino Santiago 50,
28050 Madrid, Spain**

Case Studies: Aims and Objectives



Critical European Road and Rail Infrastructure



Trans-European (TEN-T) Network

Stress Tests due to Natural Hazards

- Physical damage
- Travel disruption
- Losses



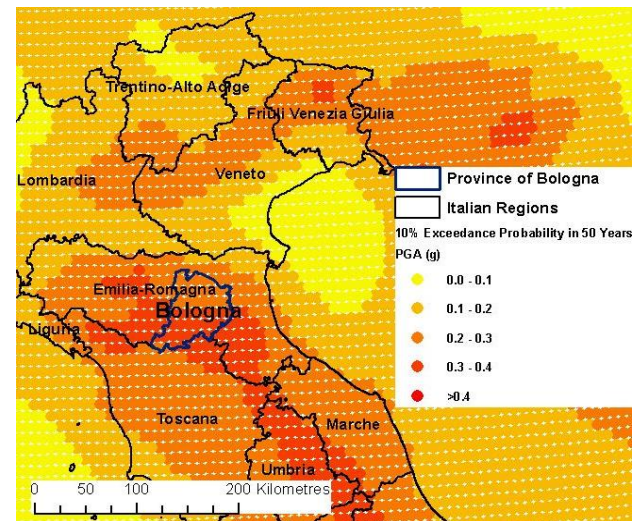
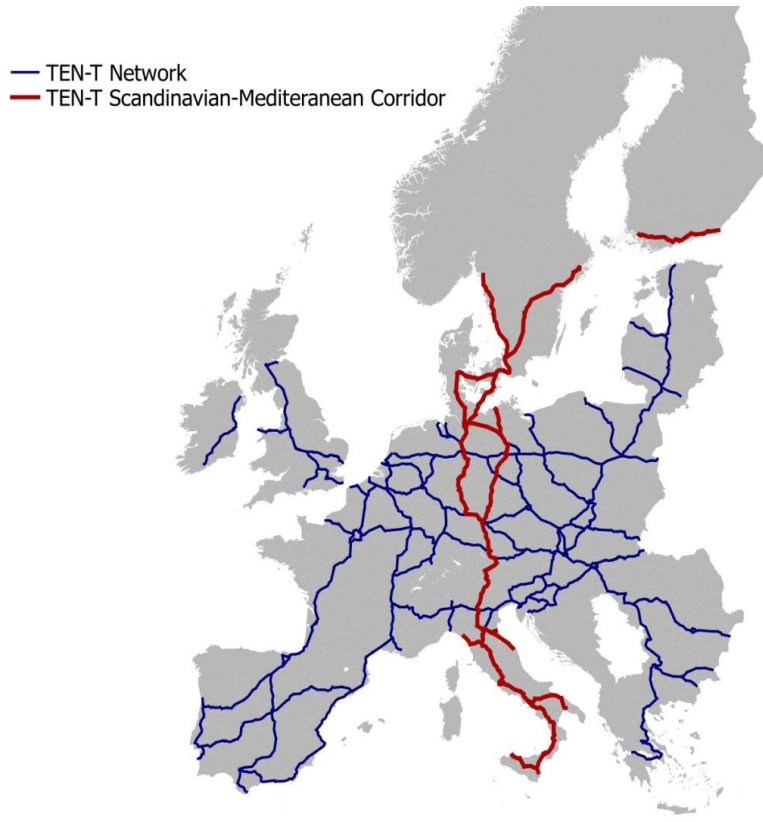
Stress Tests

General process to ensure acceptable levels of risk:



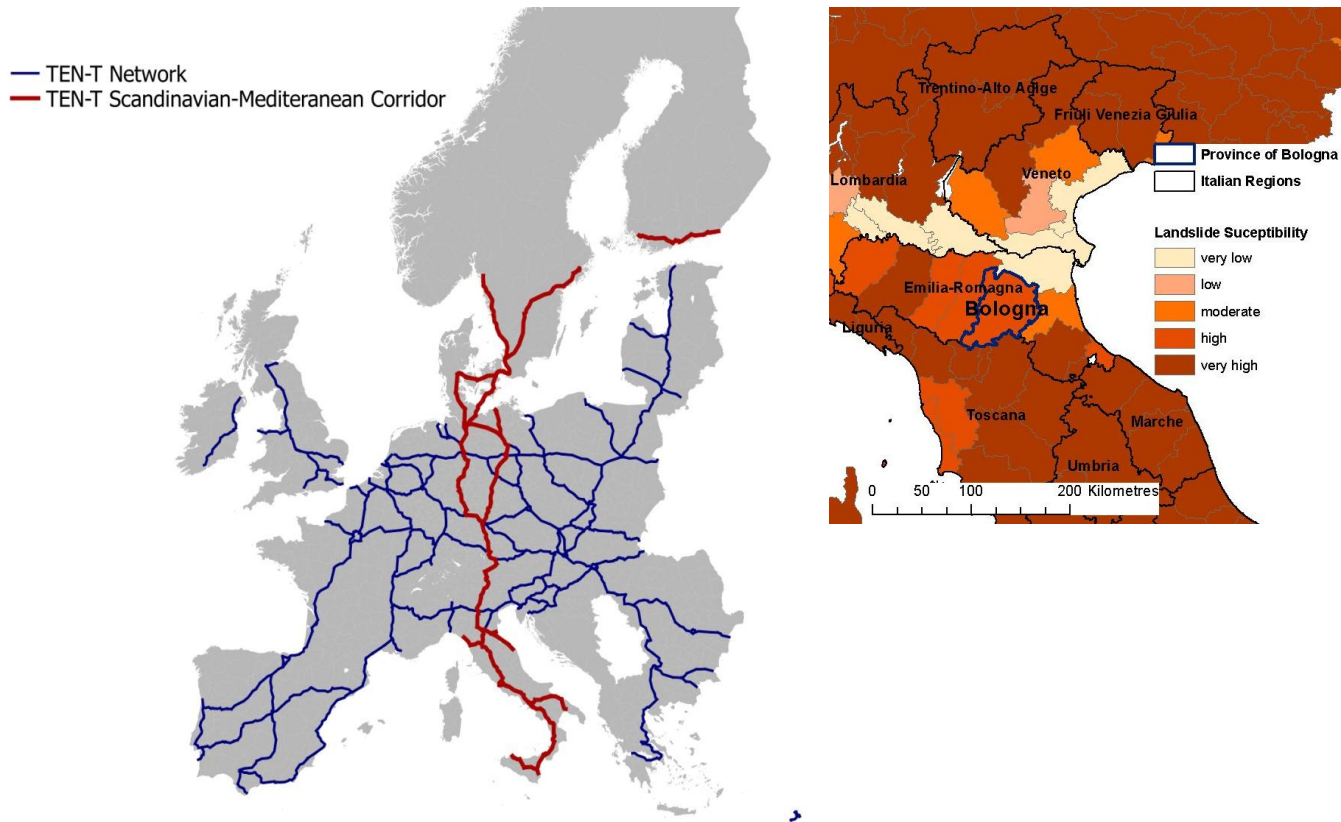
GMA Workshops

• Italian Case Study



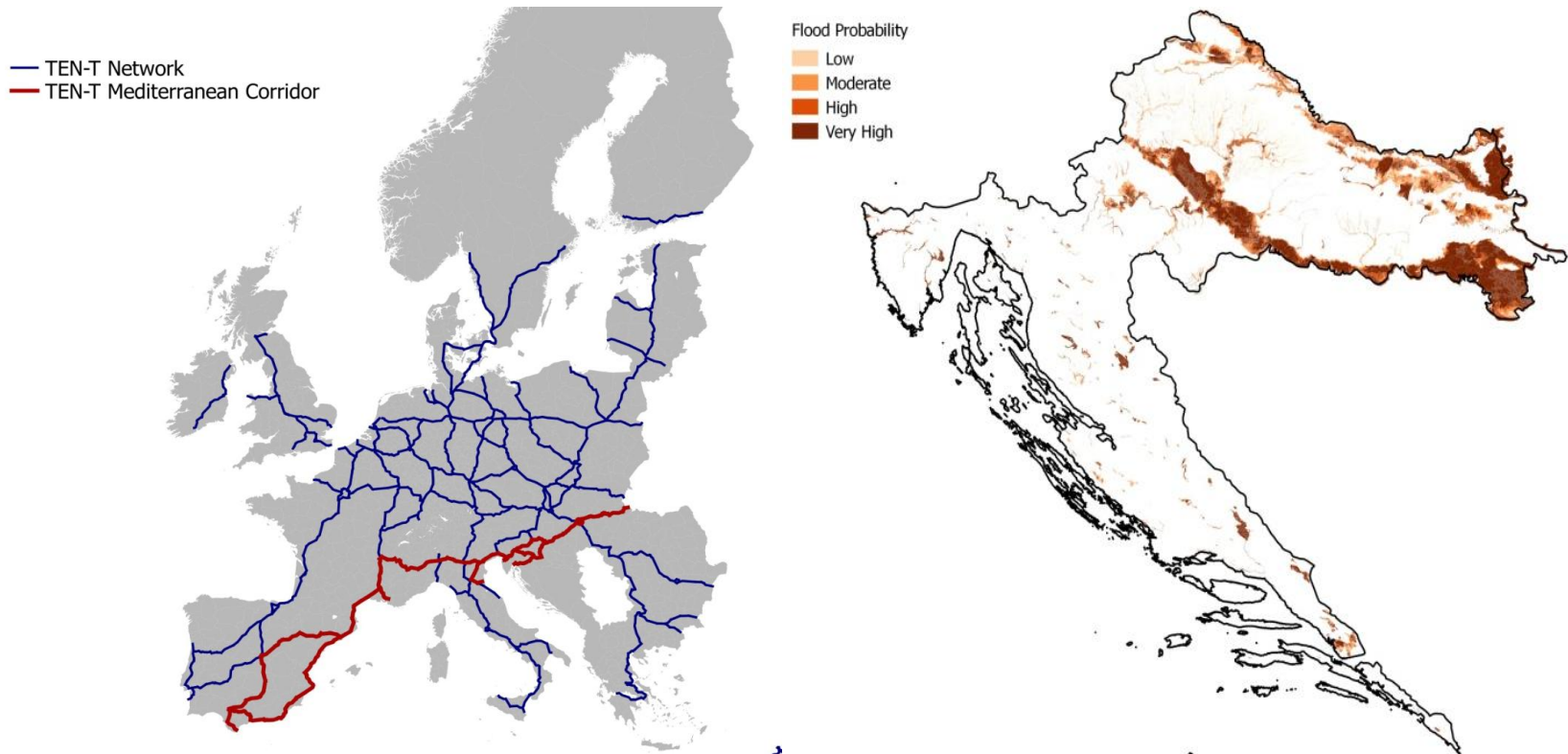
GMA Workshops

• Italian Case Study



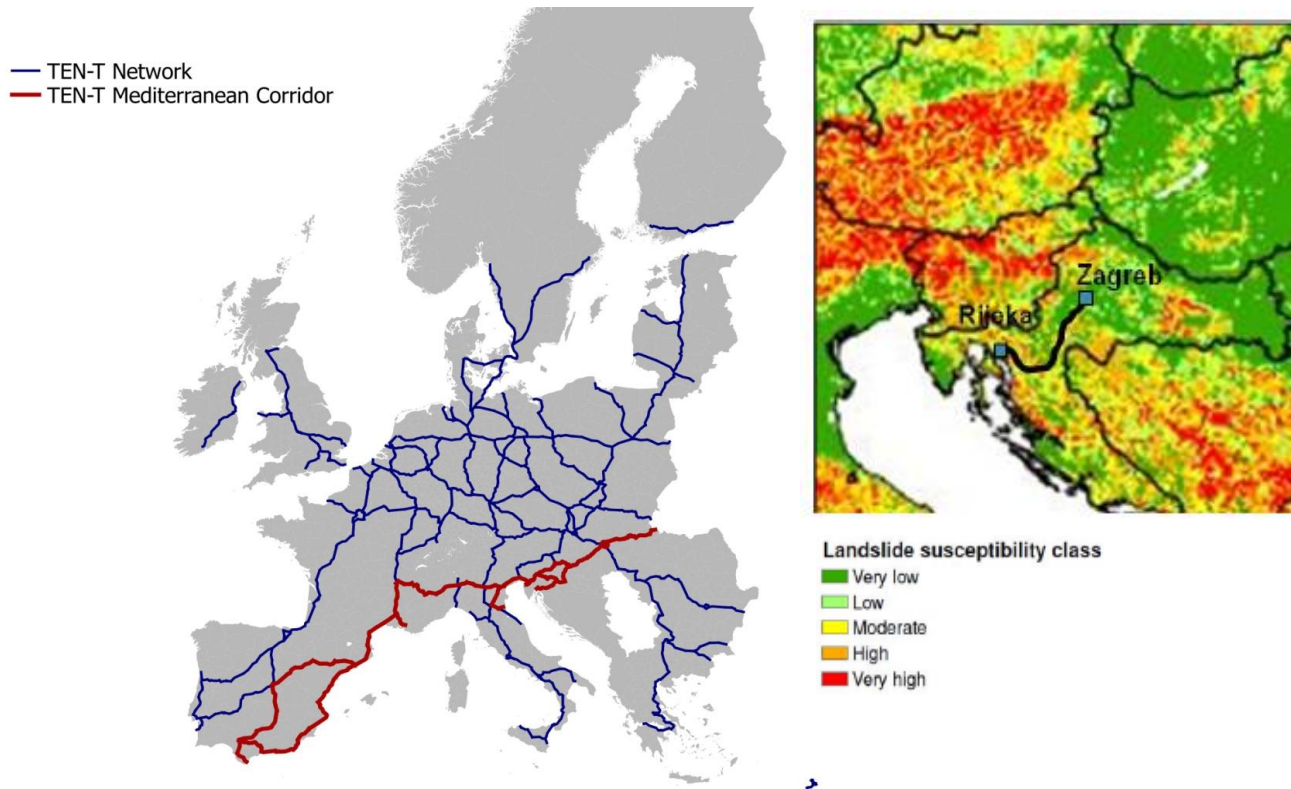
GMA Workshops

- Croatian Case Study



GMA Workshops

- Croatian Case Study



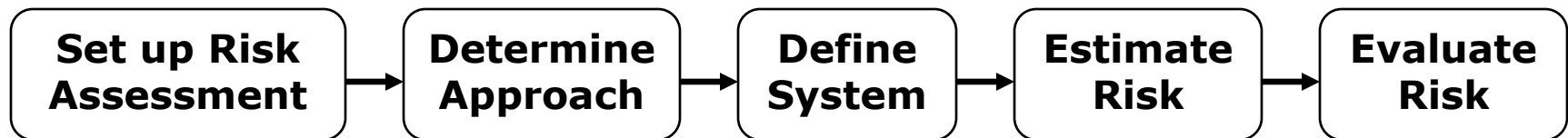
Stress Tests

General process to ensure acceptable levels of risk:

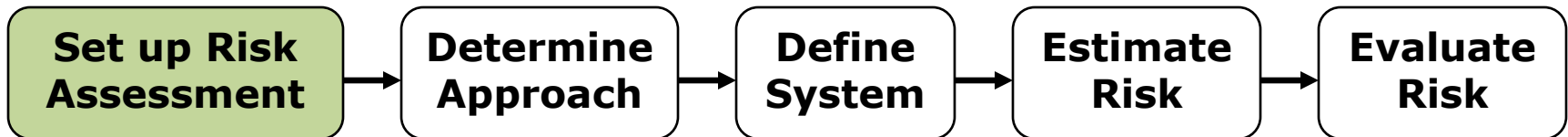


Stress Tests

Conduct Risk Assessment:

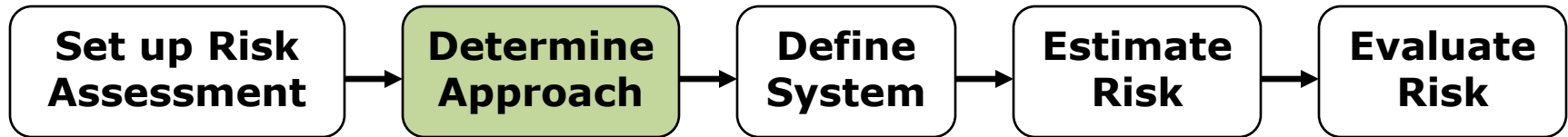


Italian Case Study



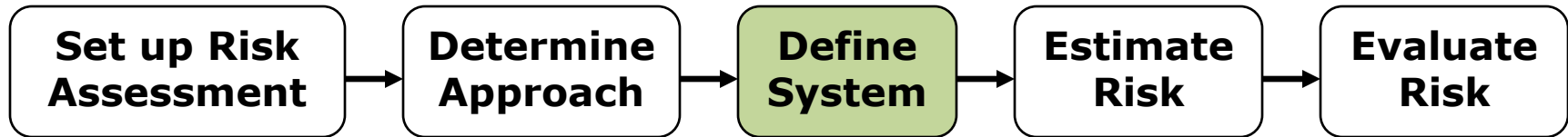
- **Low probability, high consequence seismic scenarios**
- **Cascading landslide hazard effects**
- **Direct and indirect consequences**

Italian Case Study



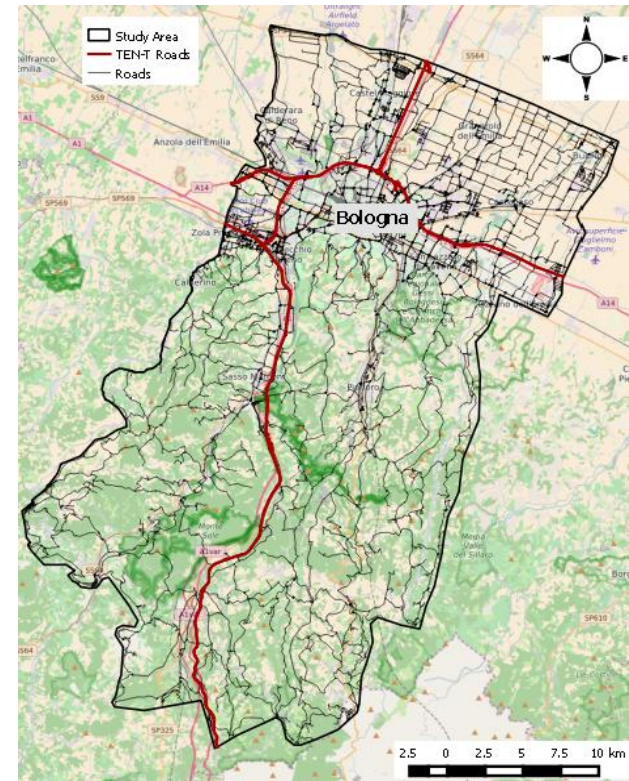
- **Low probability, high consequence seismic scenarios**
- **Cascading landslide hazard effects**
- **Direct and indirect consequences**
- **Quantitative risk assessment**

Italian Case Study

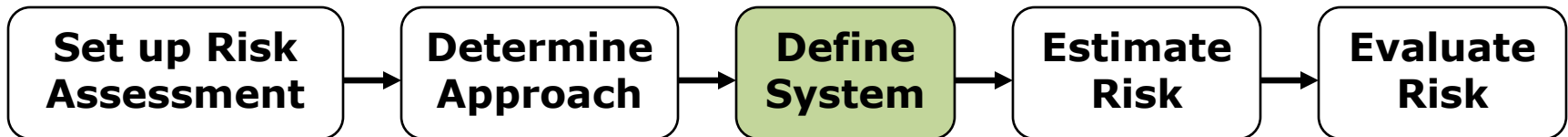


Spatial Boundaries

- 3140 km roads
- Area 990 km²
- Metropolitan area of Bologna



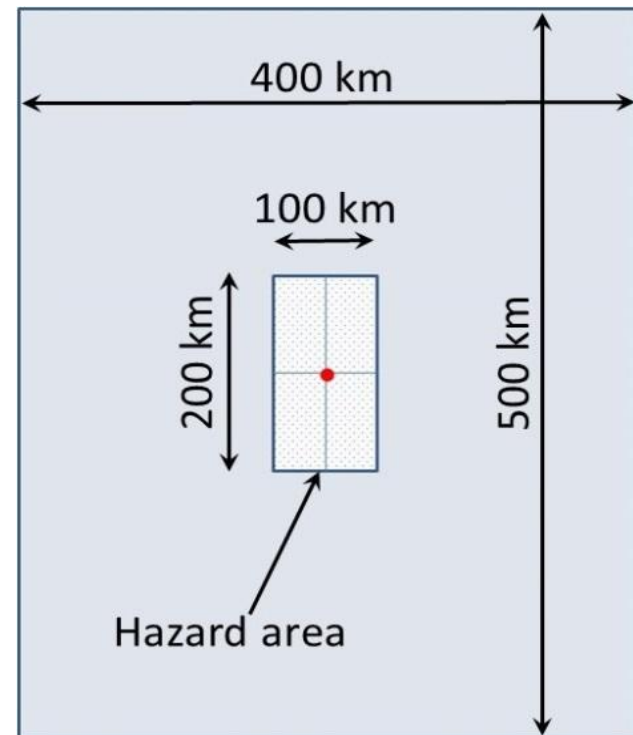
Italian Case Study



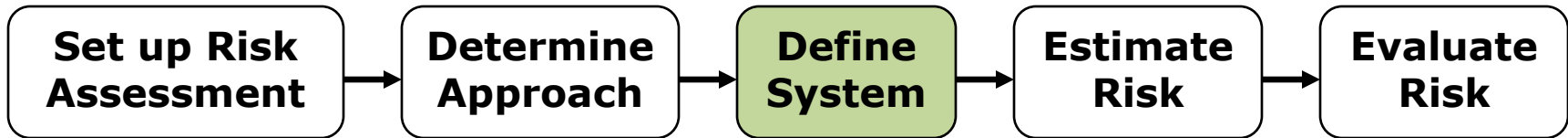
Seismic Hazard Model

• Ground-motion fields

- Seismic activity model
- Ground motion model
- Hazard level
- Percentile of extreme ground motion values at reference site (shown in red)



Italian Case Study



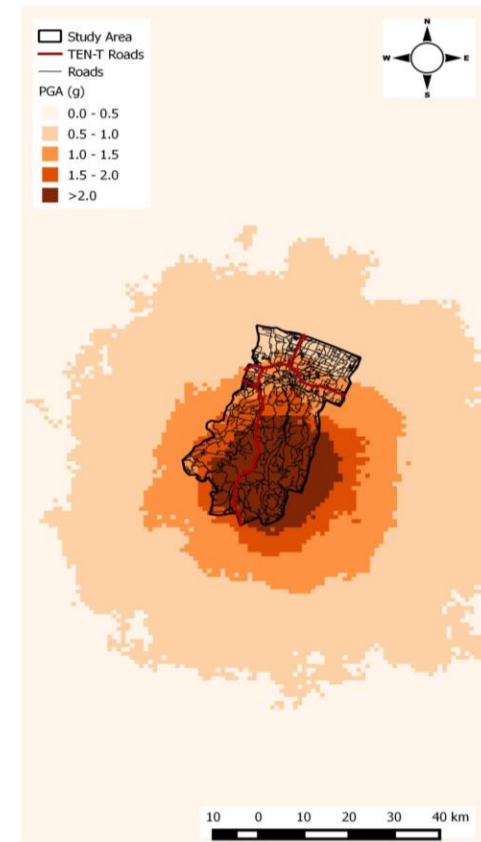
Seismic Hazard Model (Stress Test)

- **Example GM field**

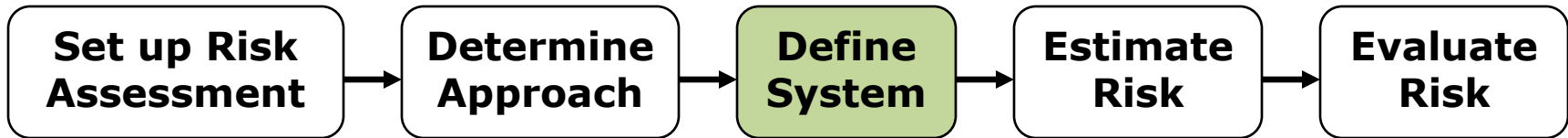
- SHARE Active
- Low attenuation ground motion
- 10,000 year return period
- 90% fractile

- **Linked to 'critical network element'**

- Betweenness centrality method



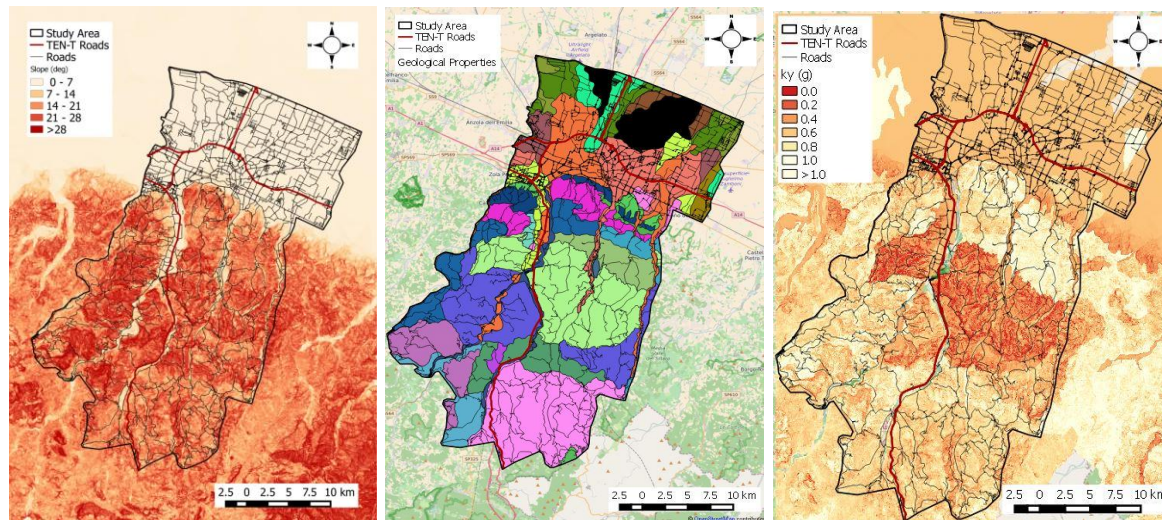
Italian Case Study



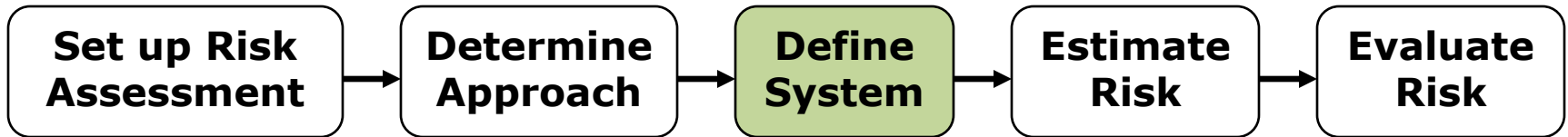
Earthquake-triggered landslides

- **Rigid sliding block approach**

➤ Landslide yield acceleration values (k_y)



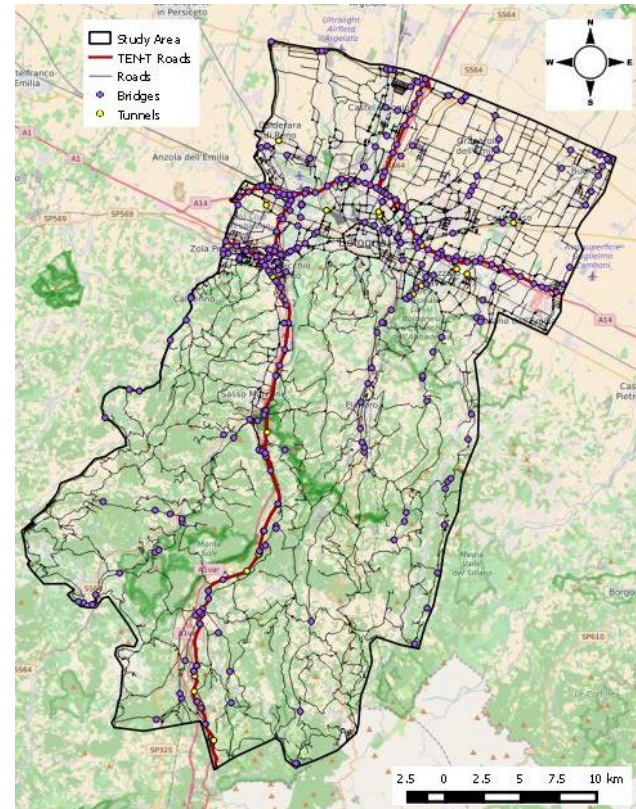
Italian Case Study



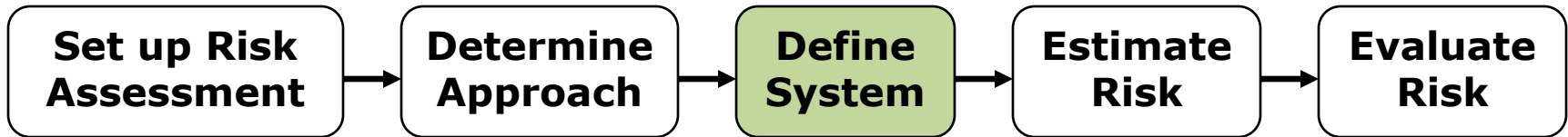
Network Vulnerability

- 340 bridges, 30 tunnels
- 10m road sections on slopes $>10^\circ$

Network Element	Hazard
Bridges	Earthquakes
Tunnels	Earthquakes
Road Sections	Earthquake-triggered landslides



Italian Case Study

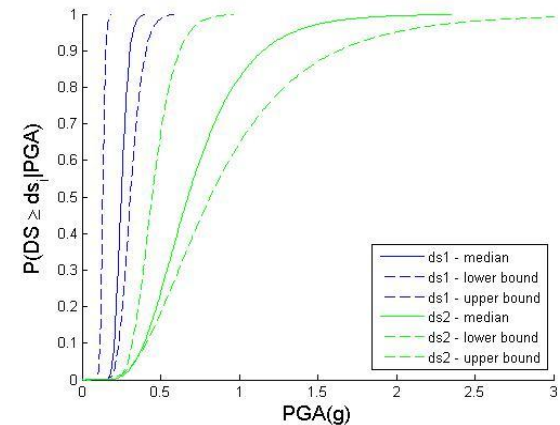


Network Vulnerability – Bridges and Tunnels

- Structural data gathered using Google Maps

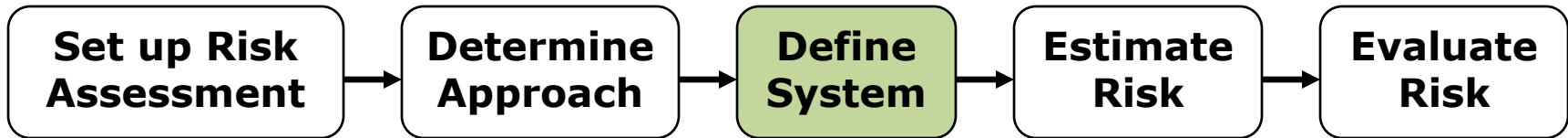
- Four damage states defined

- Slight
- Moderate
- Extensive
- Complete



- Fragility functions assigned based on existing database

Italian Case Study

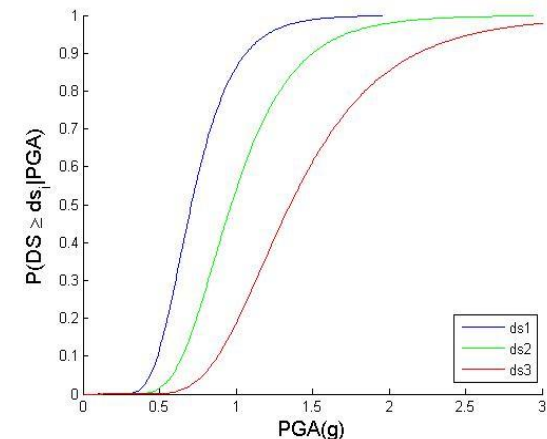


Network Vulnerability – Road Sections

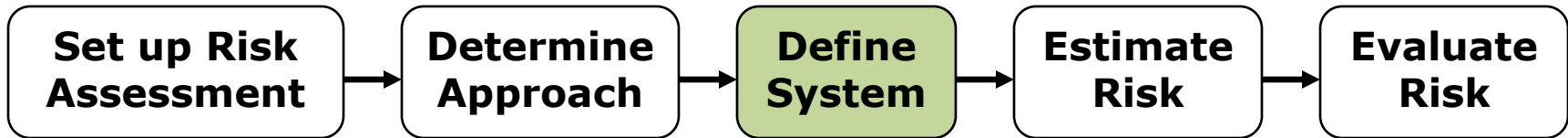
- **Three damage states defined**

- Slight
- Moderate
- Extensive/Complete

- **Fragility functions assigned based on k_y value and road type**



Italian Case Study

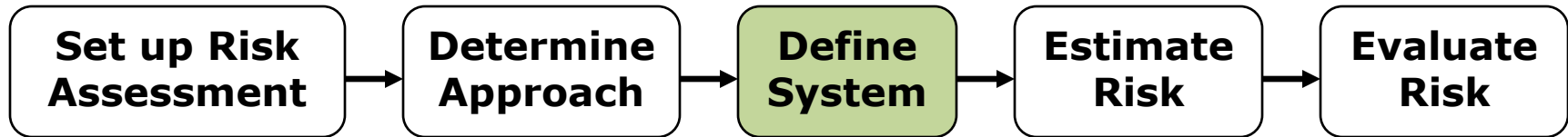


Network Vulnerability – Functionality Loss

• **Defined per network element type in terms of individual damage states**

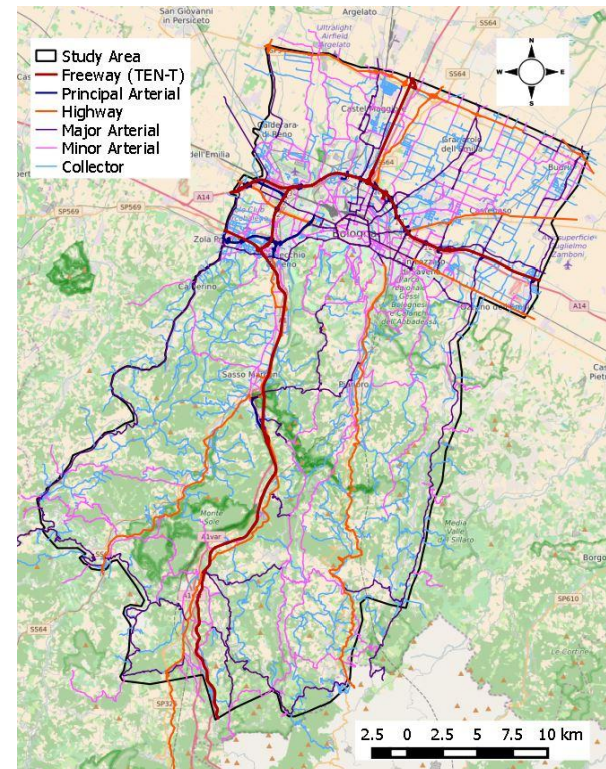
- Functionality capacity loss
- Restoration duration
- Repair cost

Italian Case Study

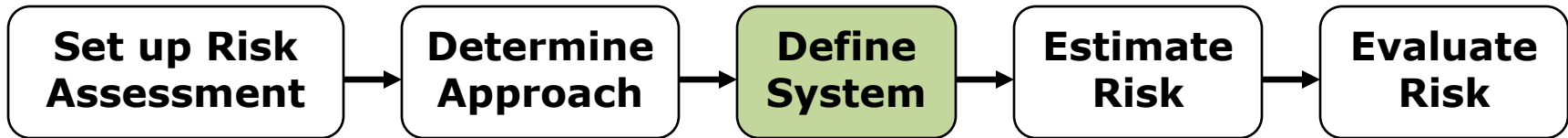


Network Vulnerability – Travel Delays

- Regional traffic analysis
 - NEXTA traffic modelling software



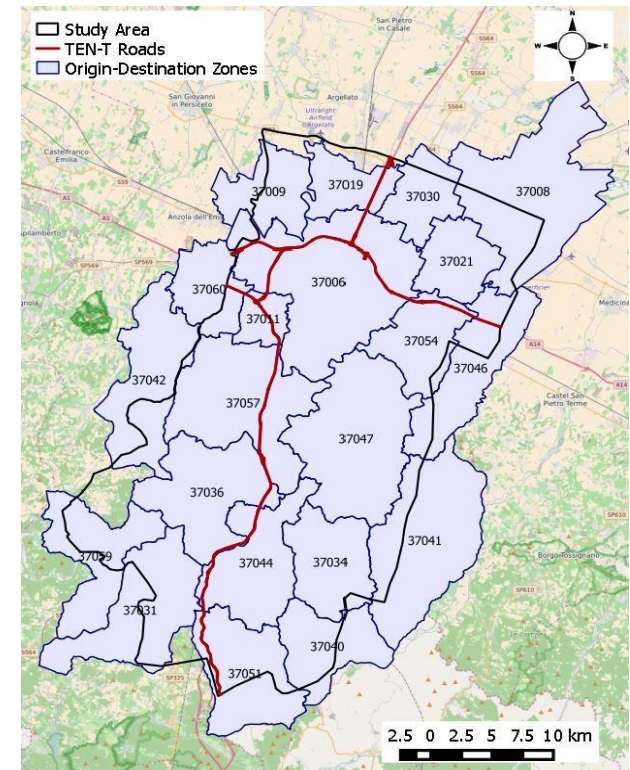
Italian Case Study



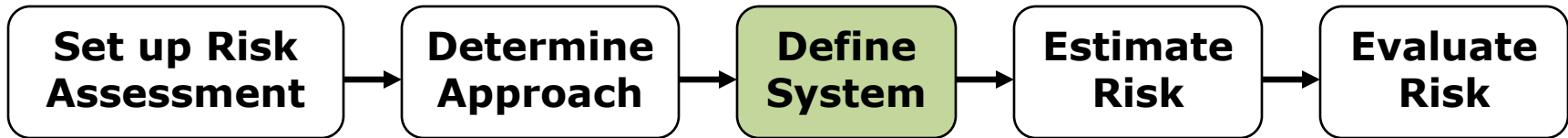
Network Vulnerability – Travel Delays

- Regional traffic analysis

- NEXTA traffic modelling software
- Origin-Destination data obtained from Italian 2011 census data to represent traffic demand



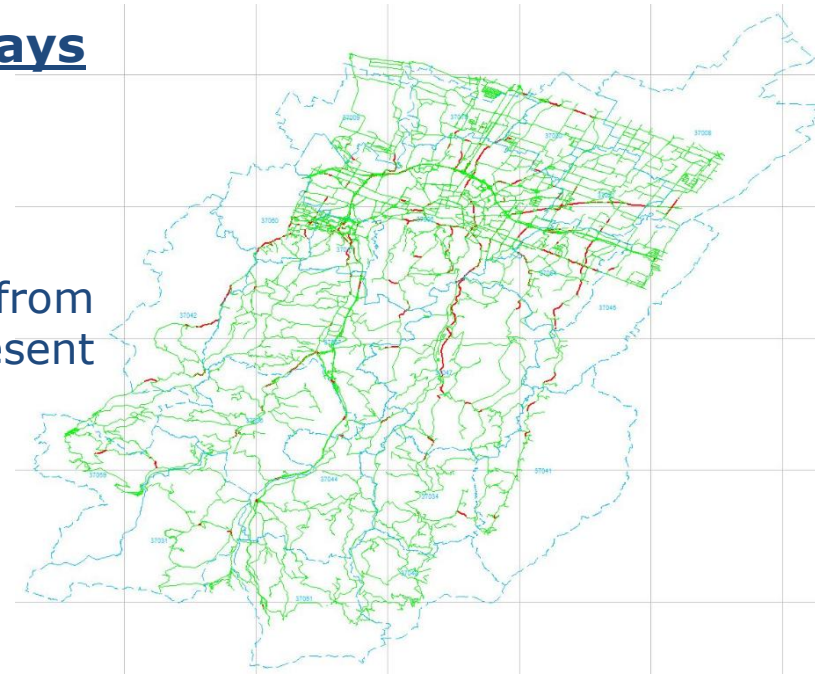
Italian Case Study



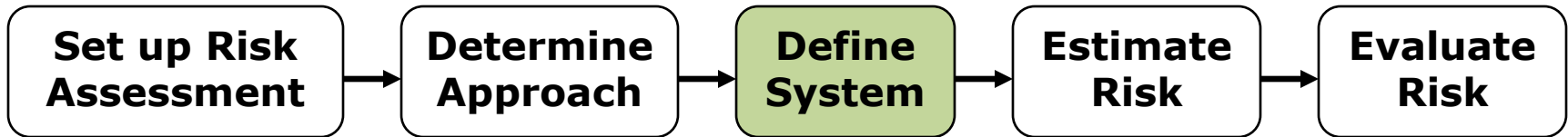
Network Vulnerability – Travel Delays

- **Regional traffic analysis**

- NEXTA traffic modelling software
- Origin-Destination data obtained from Italian 2011 census data to represent traffic demand
- Simulation of post-event traffic



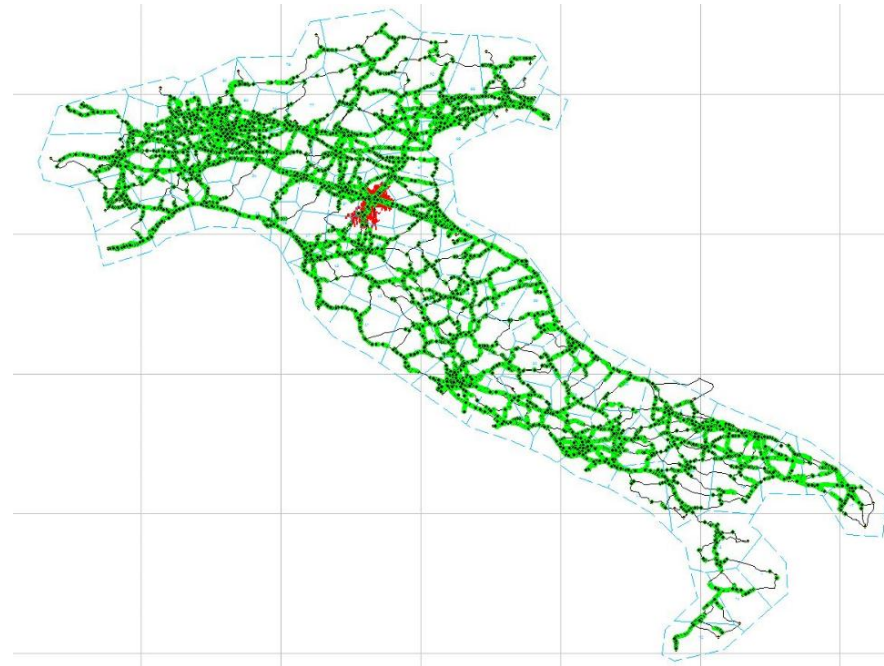
Italian Case Study



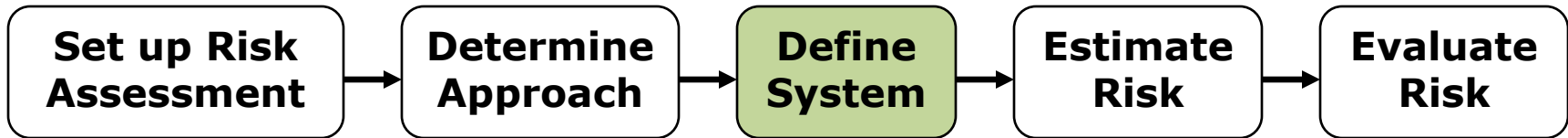
Network Vulnerability – Travel Delays

- **National traffic analysis**

- NEXTA traffic modelling software
- Wider impacts



Italian Case Study



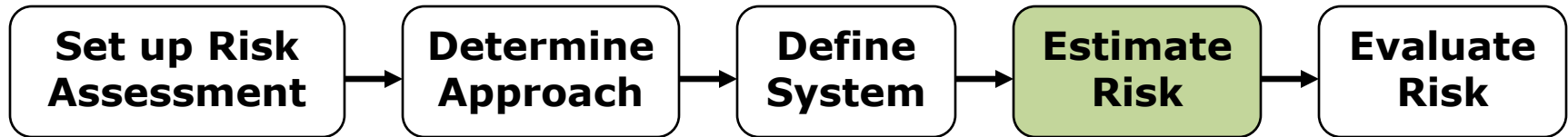
Network Vulnerability – Travel Delays

• National traffic analysis

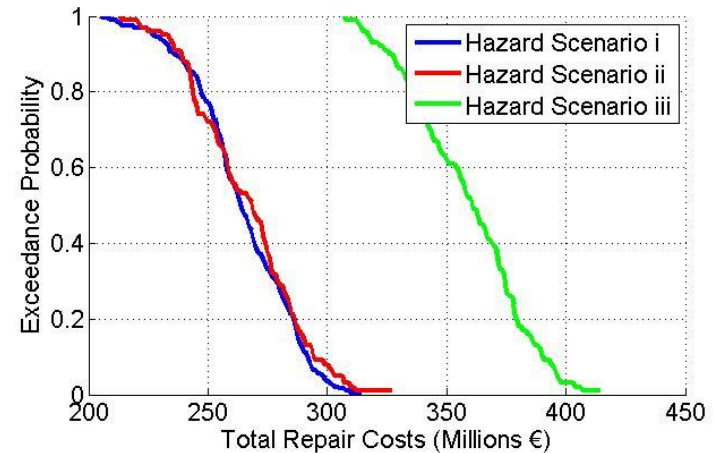
- NEXTA traffic modelling software
- Wider impacts
- Origin-Destination (O-D) data obtained from ETIS project to represent traffic demand



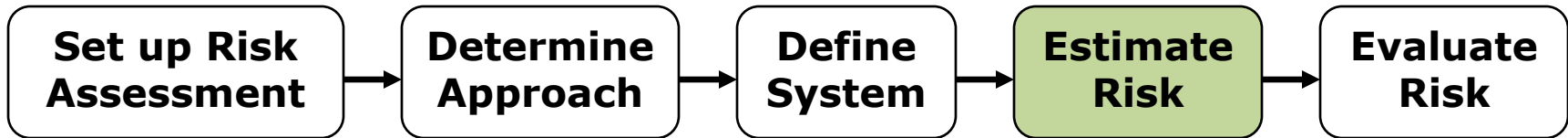
Italian Case Study



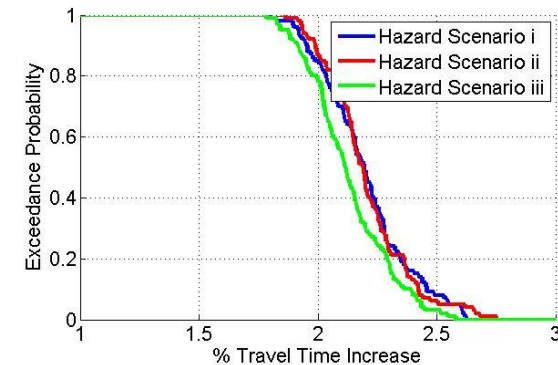
- **Monte Carlo sampling method**
 - **Epistemic uncertainty**
- **Direct consequences**
 - **Total network repair cost**



Italian Case Study

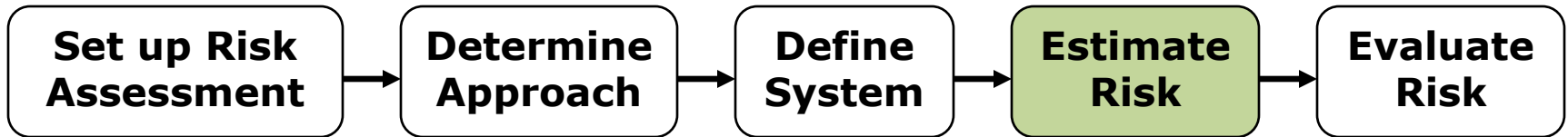


- **Monte Carlo sampling method**
 - **Epistemic uncertainty**
- **Direct consequences**
 - **Total network repair cost**
- **Indirect consequences**
 - **Average increase in travel time**

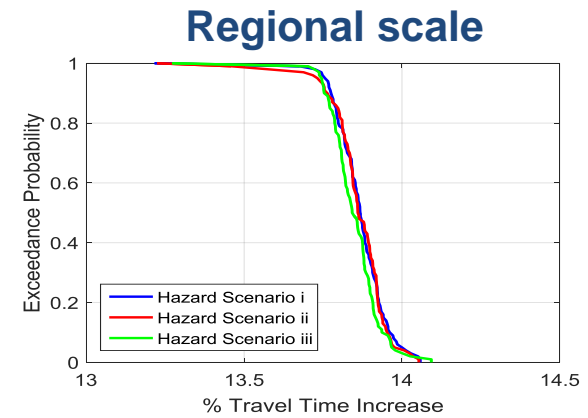
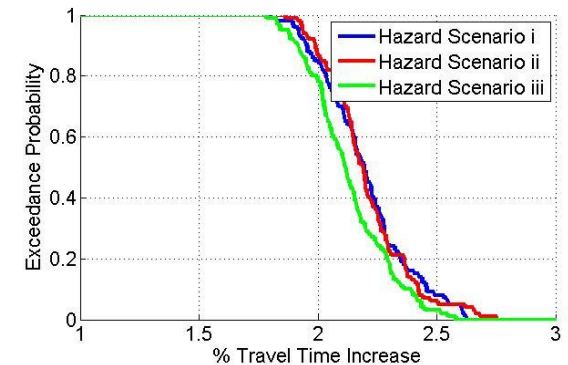


Regional scale

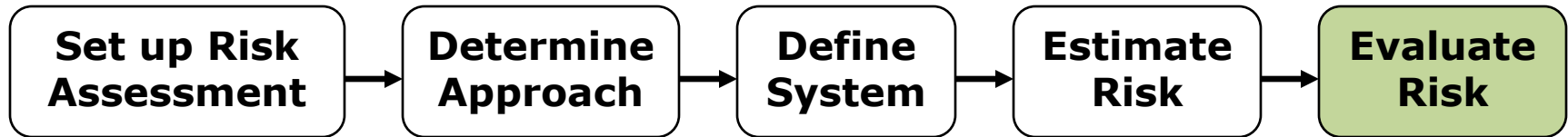
Italian Case Study



- **Monte Carlo sampling method**
 - Epistemic uncertainty
- **Direct consequences**
 - Total network repair cost
- **Indirect consequences**
 - Increase in average travel time



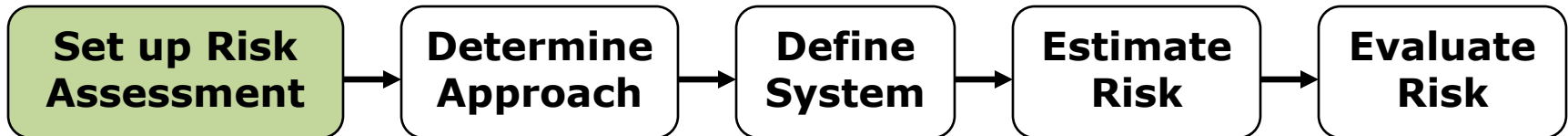
Italian Case Study



- **Adequacy of risk assessment**
- **Determine outcome of stress test**
 - Risk acceptability
 - Interventions (i.e. repair works)

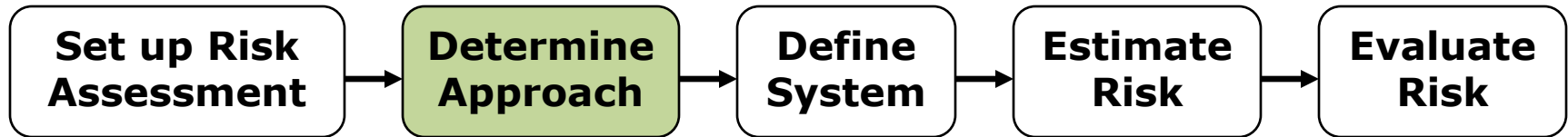
Croatian Case Study

Croatian Case Study



- Low probability, high consequence flood scenarios
- Cascading landslide hazard effects
- Direct and indirect consequences

Croatian Case Study



- Low probability, high consequence flood scenarios
- Cascading landslide hazard effects
- Direct and indirect consequences
- Qualitative – ORT application

Croatian Case Study

• ORT Application

➤ Identification of rail sections most at risk

➤ Based on principles of similarity judgement, the Delphi method and an Analytical Hierarchy Process

ORT | Objective Ranking Tool ↑ Peter Prak ufluggen

Voorpagina Klanten Projecten

InfraRisk (Dublin) - WP 8.2 Croatian Case Study Rail; Hazard: scour scores Bewerken

Criteria Criteriasset Varianten Scores Resultaten Criteriasset vergelijken Analyse Adresboek

Criteria criteria exporteren

Naam	Percentage	Type	Beïnvloedbaar	Subcriteria
Hazards	17.68%			3
+ exposure to the identified hazard	26.84%	substitutive	nee	0
+ no presence of defences against identified hazard	37.28%	substitutive	ja	0
+ exposure to another identified hazard type as well	35.88%	substitutive	nee	0
Vulnerability	28.59%			3
+ affect critical railway process infrastructure manager	39.88%	substitutive	ja	0
+ affect critical railway process Train Operation Company	29.74%	additive	ja	0
+ no redundancy in the network	30.38%	additive	nee	0
Consequences	53.73%			3
+ associated functional capacity loss	18.75%	additive	nee	0
+ potential disruption for the rail network	52.98%	additive	ja	0
+ no contingency planning available	28.27%	additive	ja	0

voeg subcriterium toe

Voorpagina Klanten Projecten

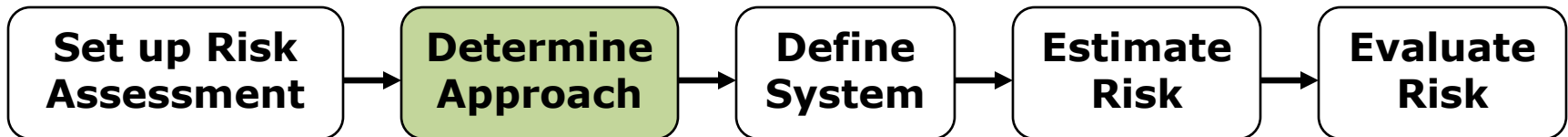
InfraRisk (Dublin) - WP 8.2 Croatian Case Study Rail; Hazard: scour scores Bewerken

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Scores invullen voor Croatian Rail Network TEN-T Corrs scoreblad exporteren

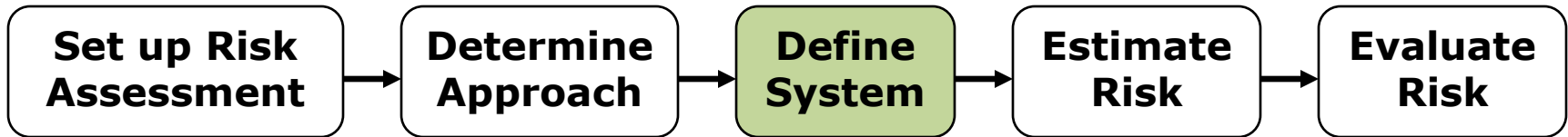
	M202: Zagreb GK - Trešnjevka	M202: Trešnjevka - Delta	M202: Delta - Hrvatski Leskovac	M202: Hrvatski Leskovac - Horvati	M202: Horvati - Zlatina	M202: Zlatina - Jastrebarsko	M202: Jastrebarsko - Draganići	M202: Draganići - Karlovac	M202: Karlovac - Maribor Polje	M202: Maribor Polje - Duga Resa	M202: Duga Resa - Zvečaj	M202: Zvečaj - Generalški Stol	M202: Generalški Stol - Gornje Dubrave	M202: Gornje Dubrave - Kulaša
Hazards														
exposure to the identified hazard	17.68%	26.84%	1 -	0 -	0 -	0 -	0 -	0 -	1 -	0 -	1 -	0 -	0 -	1 -
no presence of defences against identified hazard	37.28%	1 -	0 -	0 -	0 -	0 -	1 -	0 -	1 -	0 -	0 -	0 -	1 -	0 -
exposure to another identified hazard type as well	35.88%	0 -	0 -	0 -	0 -	0 -	1 -	0 -	1 -	0 -	1 -	1 -	1 -	1 -
Vulnerability														
affect critical railway process infrastructure manager	28.59%	39.88%	1 -	0 -	0 -	0 -	0 -	1 -	0 -	1 -	0 -	0 -	0 -	1 -
affect critical railway process Train Operation Company	29.74%	1.0 -	0.0 -	0.0 -	0.0 -	0.0 -	1.0 -	0.0 -	1.0 -	0.0 -	0.0 -	0.0 -	1.0 -	0.0 -
no redundancy in the network	30.38%	0.0 -	0.0 -	0.0 -	0.0 -	0.0 -	1.0 -	0.0 -	1.0 -	0.0 -	0.0 -	0.0 -	1.0 -	0.0 -
Consequences														
associated functional capacity loss	53.73%	18.75%	1.0 -	0.0 -	0.0 -	0.0 -	0.0 -	1.0 -	0.0 -	1.0 -	0.0 -	0.0 -	0.0 -	1.0 -
potential disruption for the rail network	52.98%	0.6 -	0.0 -	0.0 -	0.0 -	0.0 -	0.6 -	0.0 -	0.6 -	0.0 -	0.0 -	0.0 -	0.6 -	0.0 -
no contingency planning available	28.27%	1.0 -	0.0 -	0.0 -	0.0 -	0.0 -	1.0 -	0.0 -	1.0 -	0.0 -	0.0 -	0.0 -	1.0 -	0.0 -

Croatian Case Study



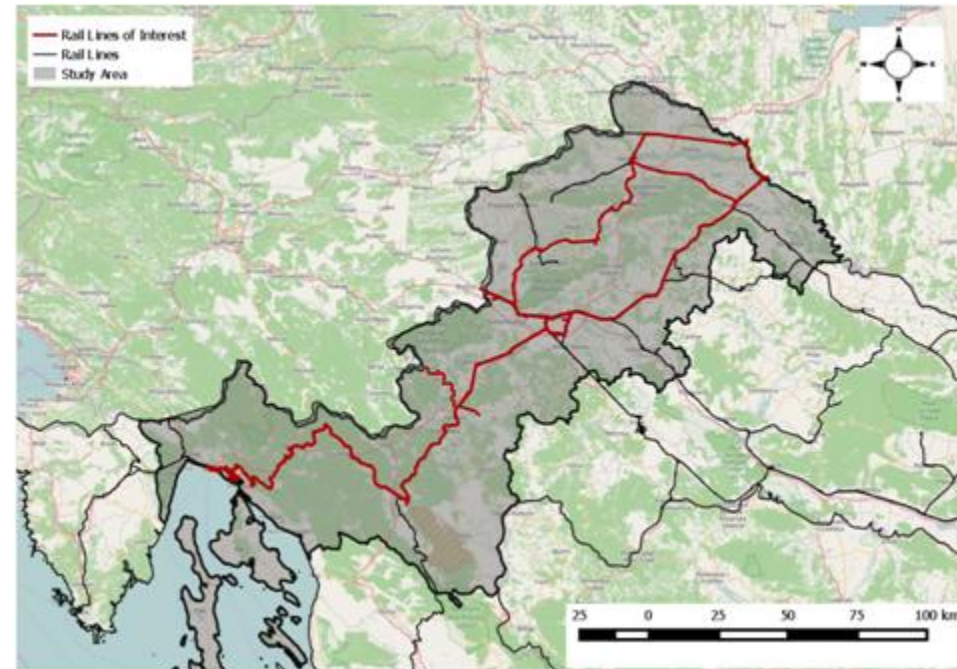
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Croatian Case Study

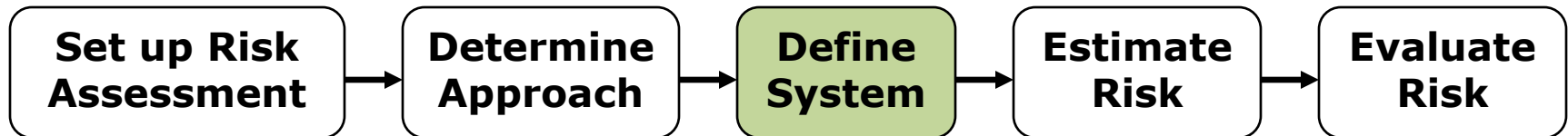


Spatial Boundaries

- 800 km of rail
- Area of 35,000 km²
- Vital link from port of Rijeka to city of Zagreb
- International connections to Slovenia and Hungary



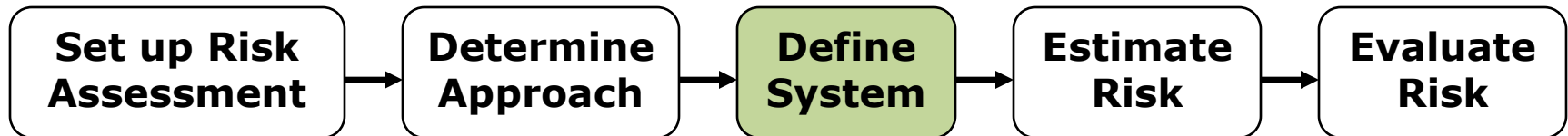
Croatian Case Study



Flood Hazard Model

- Bridge scour
- Track inundation
- Track blockages due to rainfall-triggered landslides

Croatian Case Study

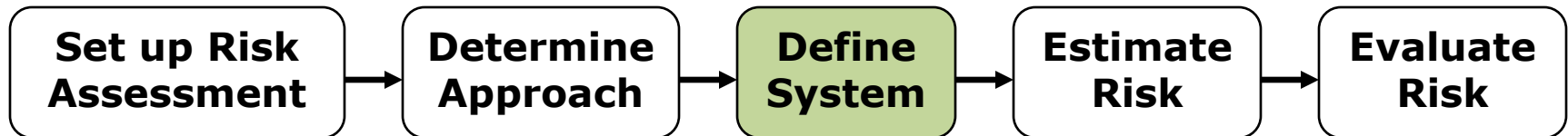


Flood Hazard Model – Bridge Scour

- Kupa Karlovac bridge

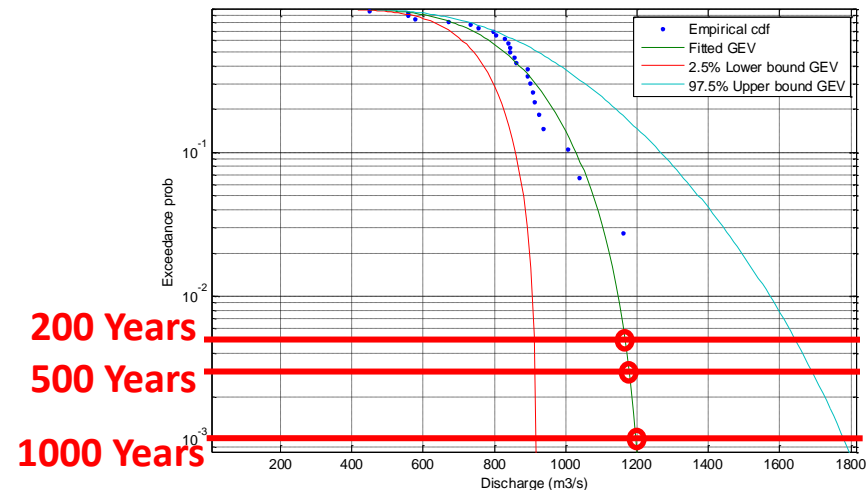


Croatian Case Study

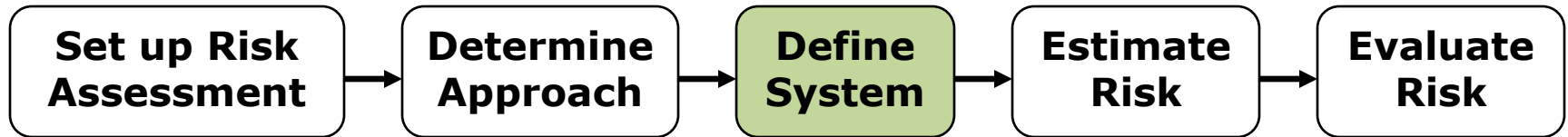


Flood Hazard Model – Bridge Scour

- Kupa Karlovac bridge
- Historical daily max. values of water flow (m^3/s)

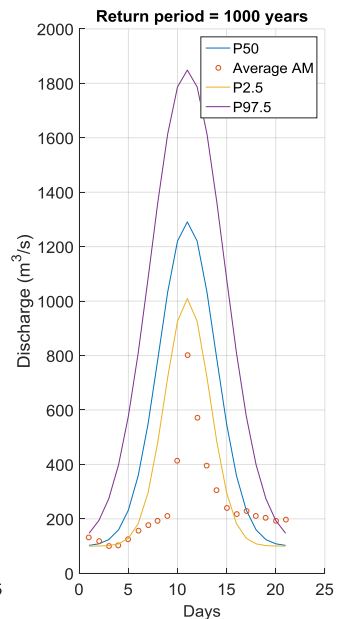
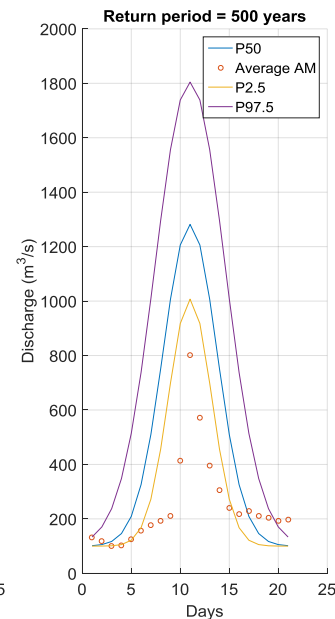
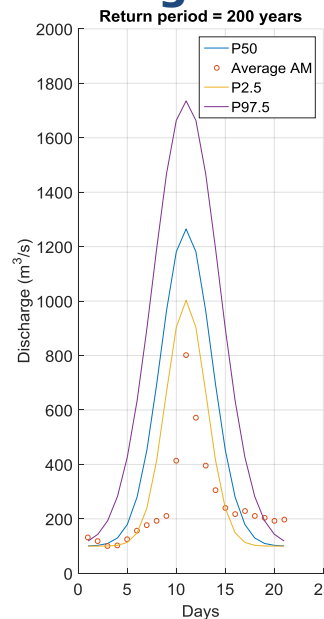
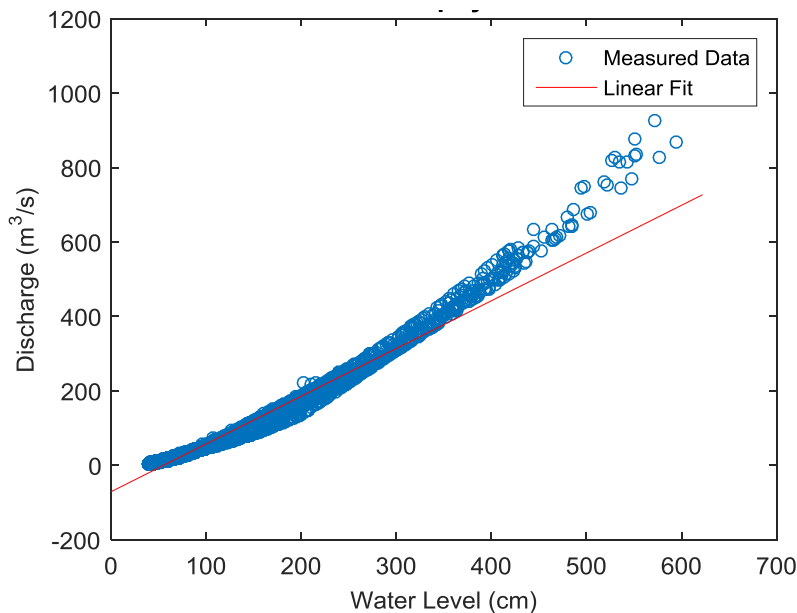


Croatian Case Study

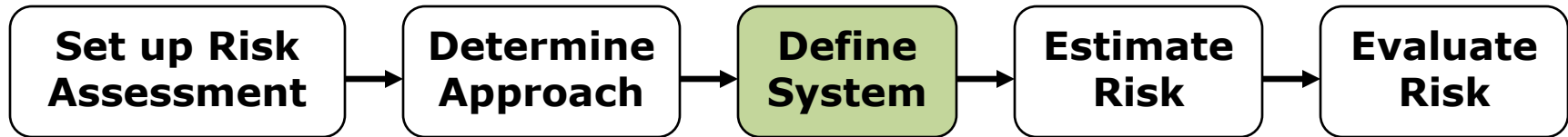


Flood Hazard Model – Track Inundation

• Linear relationship between Discharge and Water Level

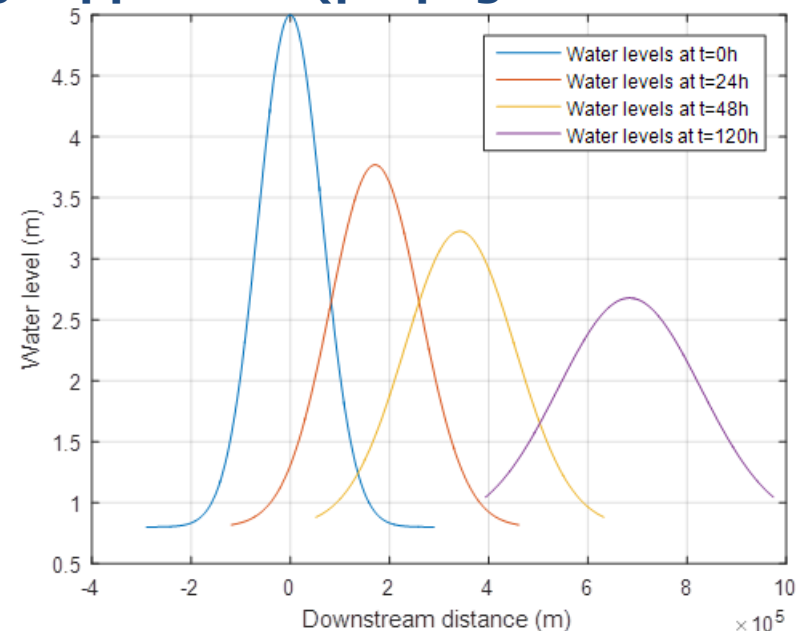


Croatian Case Study

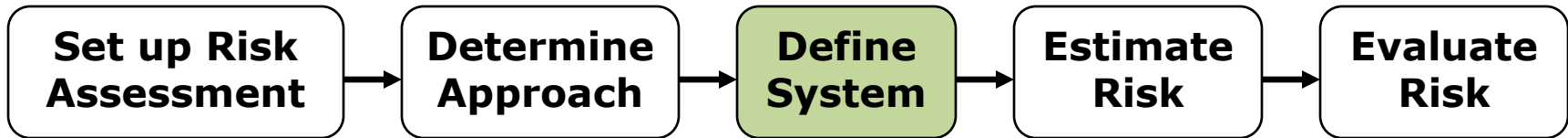


Flood Hazard Model – Track Inundation

- Linear hydrodynamic modelling approach (propagation of flood wave downstream)

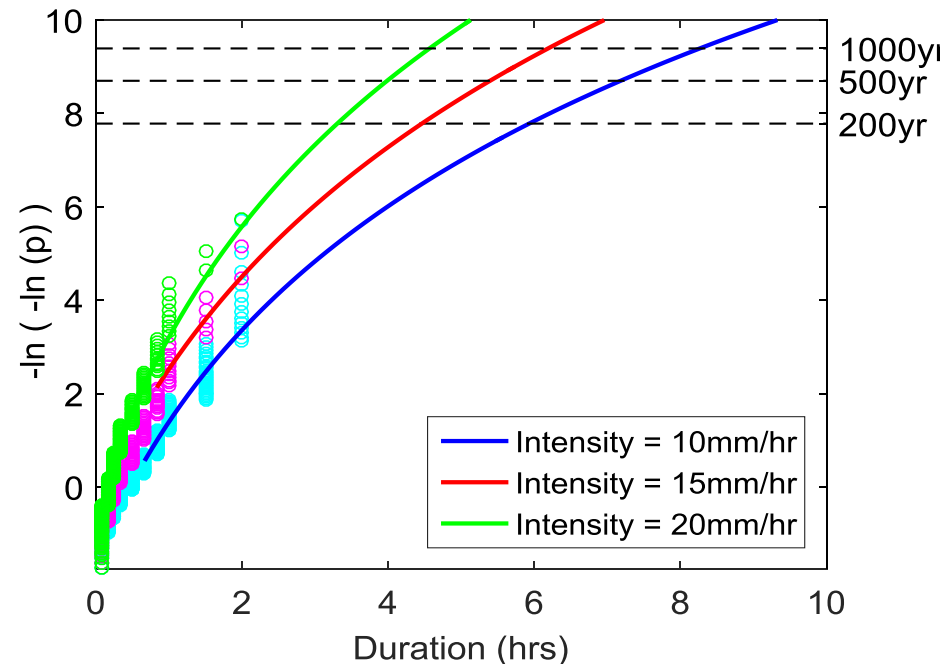


Croatian Case Study

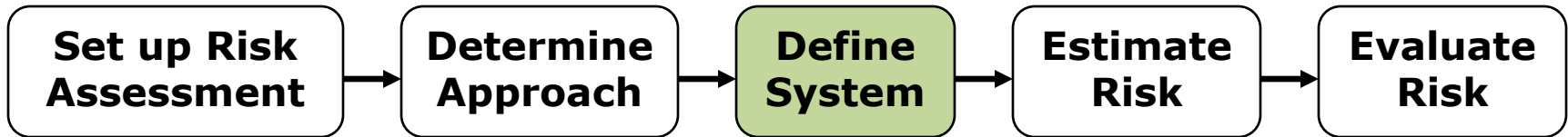


Rainfall Hazard Model – Rainfall Triggered Landslides

- Daily rainfall data
- Probabilistic extrapolation
- 200, 500 & 1000 yr durations

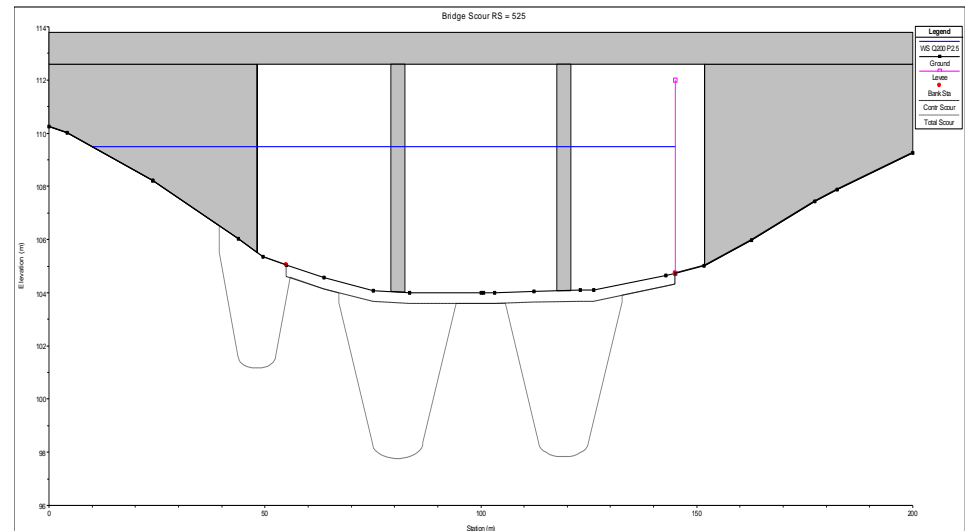


Italian Case Study

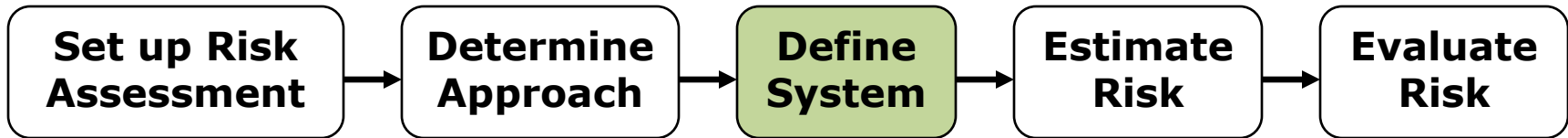


Network Vulnerability – Karlovac Bridge

- Historical daily max. values of water flow (m^3/s)
- Kupa Karlovac bridge
- Scour calculation
 - General scour
 - Contraction scour
 - Local scour



Italian Case Study



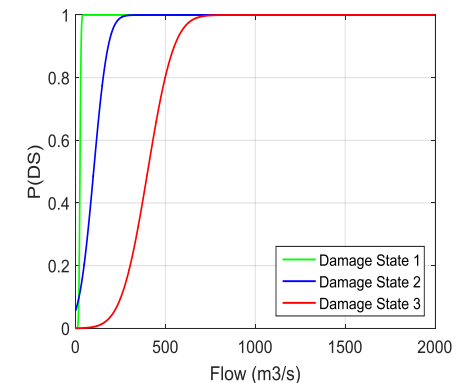
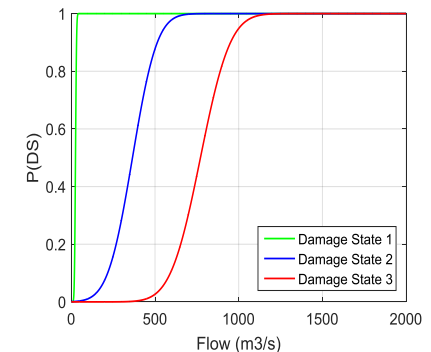
Network Vulnerability – Karlovac Bridge

- **Development of fragility functions**

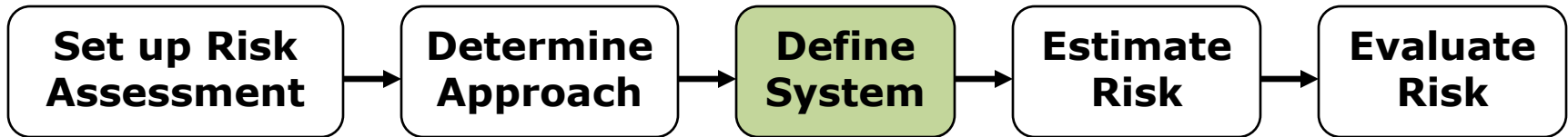
- Three damage states defined

1. Limit train speed during repair works
2. Total traffic interruption during repair works
3. Total collapse

- Defined for bridges piers and abutments



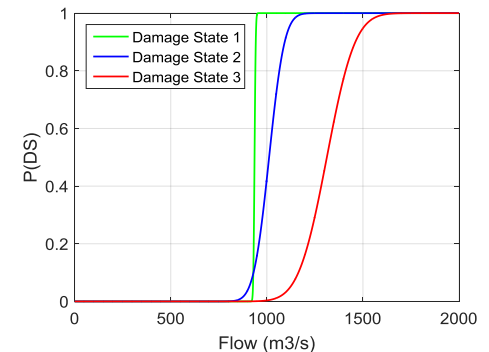
Italian Case Study



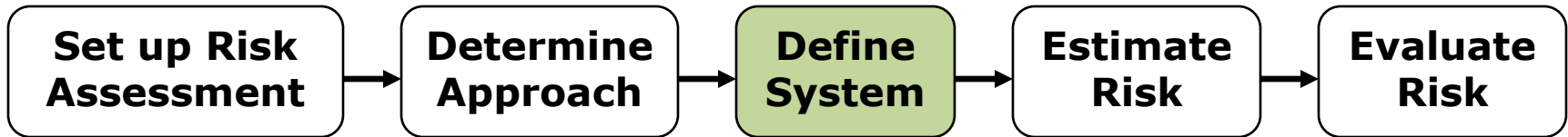
Network Vulnerability – Karlovac Bridge

- **Development of fragility functions**

- Three damage states defined
 1. Limit train speed during repair works
 2. Total traffic interruption during repair works
 3. Total collapse
- Defined for bridges piers and abutments
- Consideration of scour protection measures

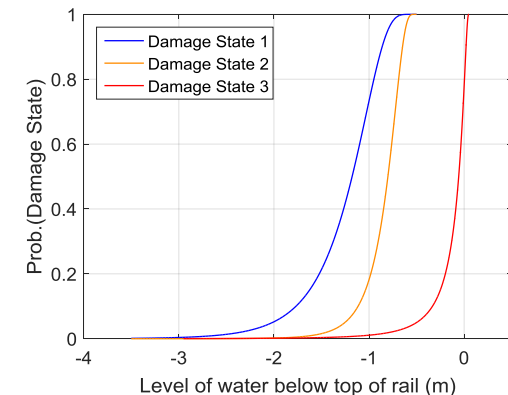
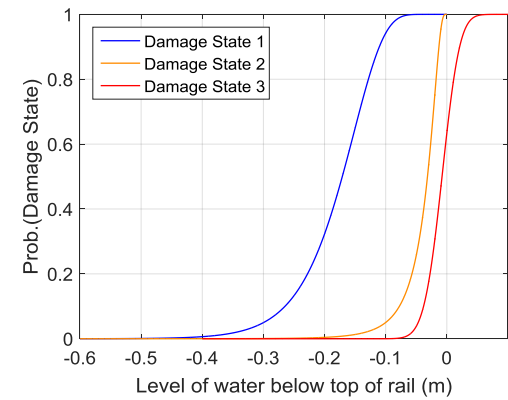


Italian Case Study

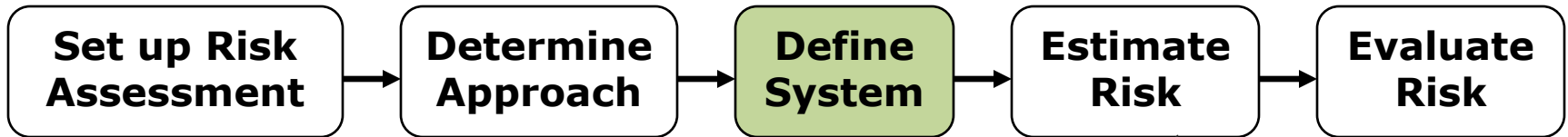


Network Vulnerability – Track Inundation

- Visual inspection of flood hazard maps
- Susceptible rail segments identified
- Three damage states defined
 - Slight
 - Moderate
 - Extensive/Complete
- Fragility functions developed for:
 - Rails on grade or in cut
 - Rails on embankments

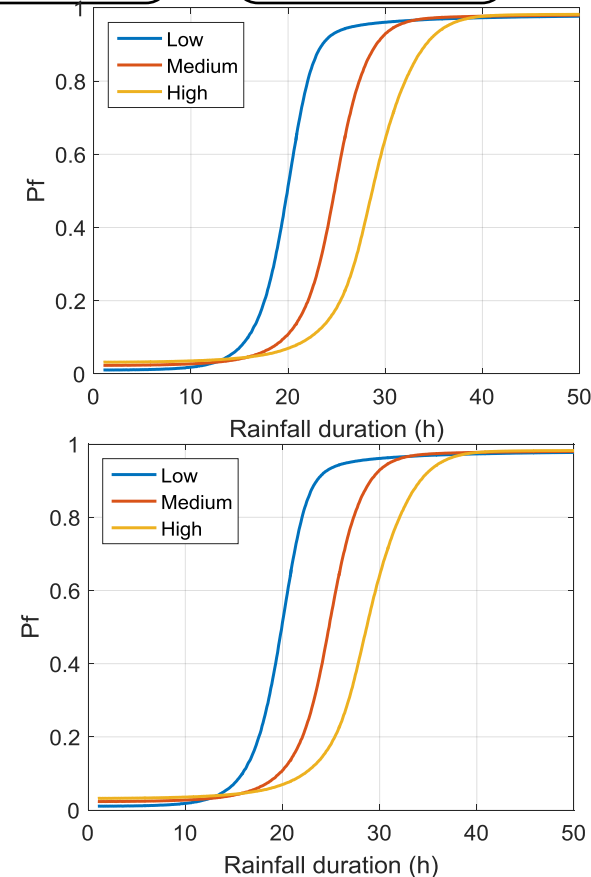


Italian Case Study

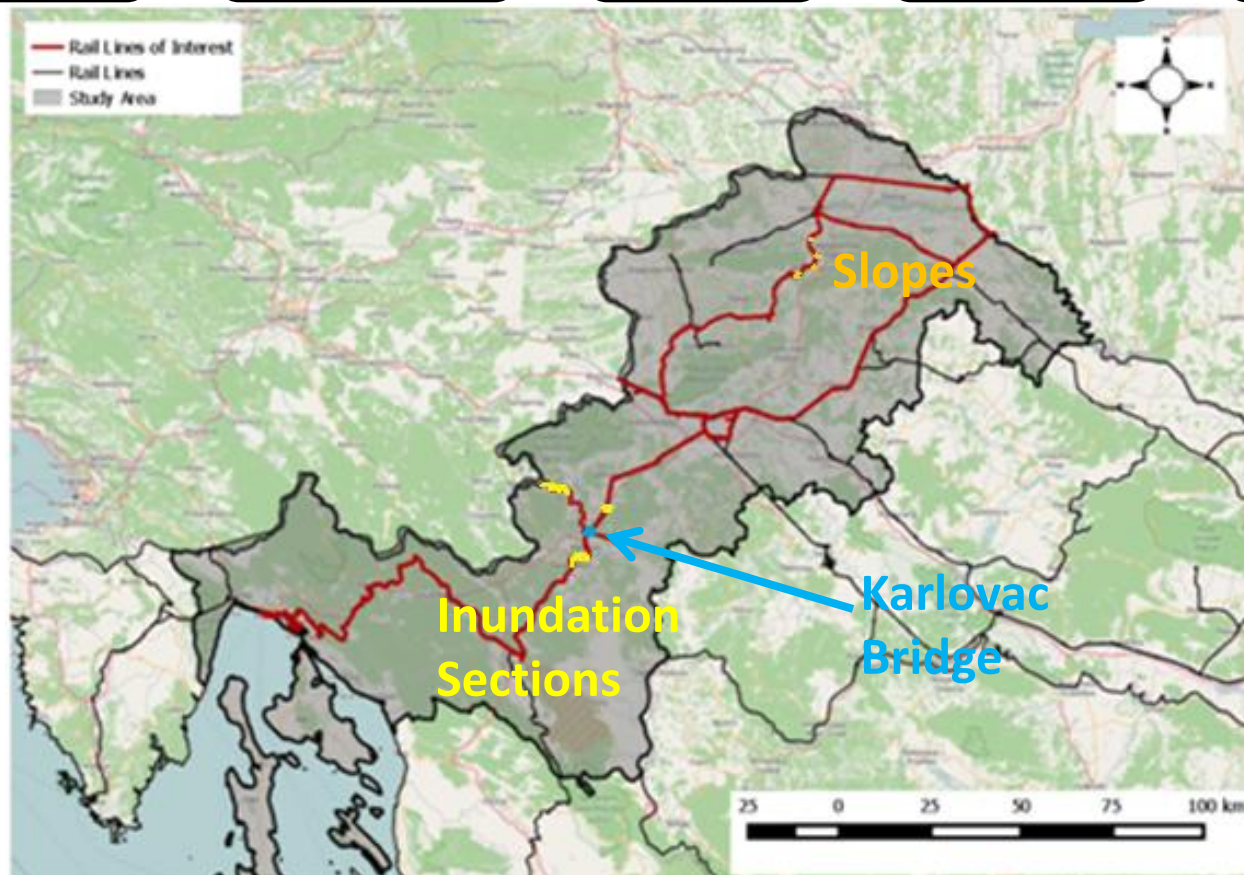
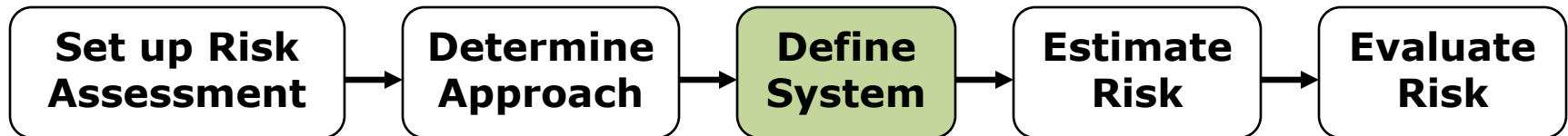


Network Vulnerability – Landslides

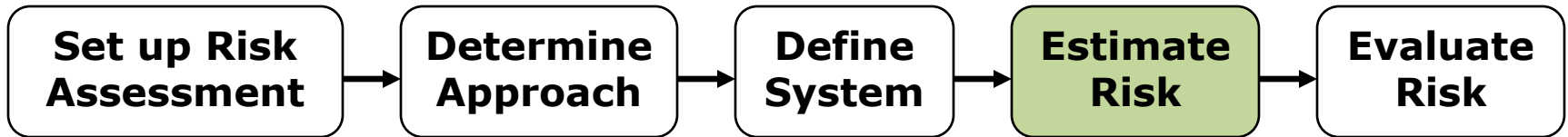
- Visual inspection of Google Maps
- Susceptible slopes identified
- Three damage states defined
 - Low
 - Medium
 - High
- Fragility functions developed for:
 - Different rainfall intensities



Croatian Case Study

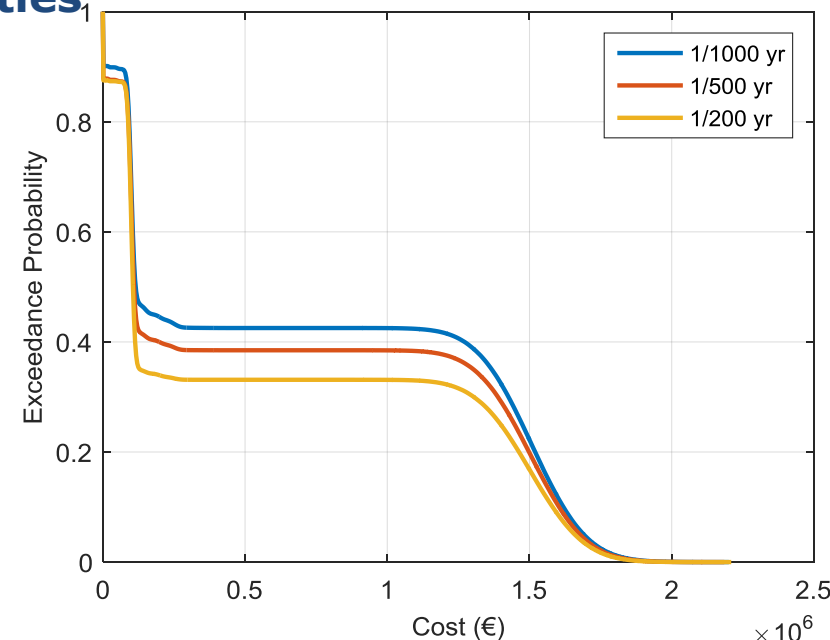


Croatian Case Study

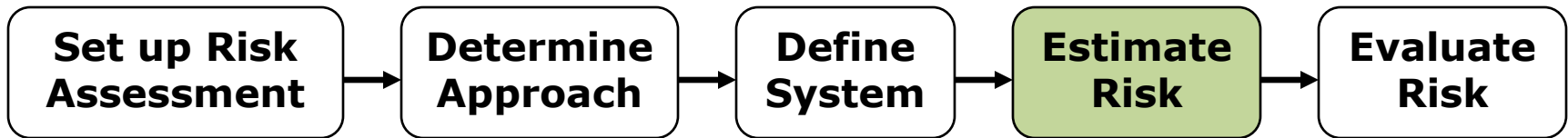


- Monte Carlo sampling method
 - Aleatoric and epistemic uncertainties
- Direct consequences
 - Total network repair cost

Scour + Inundation

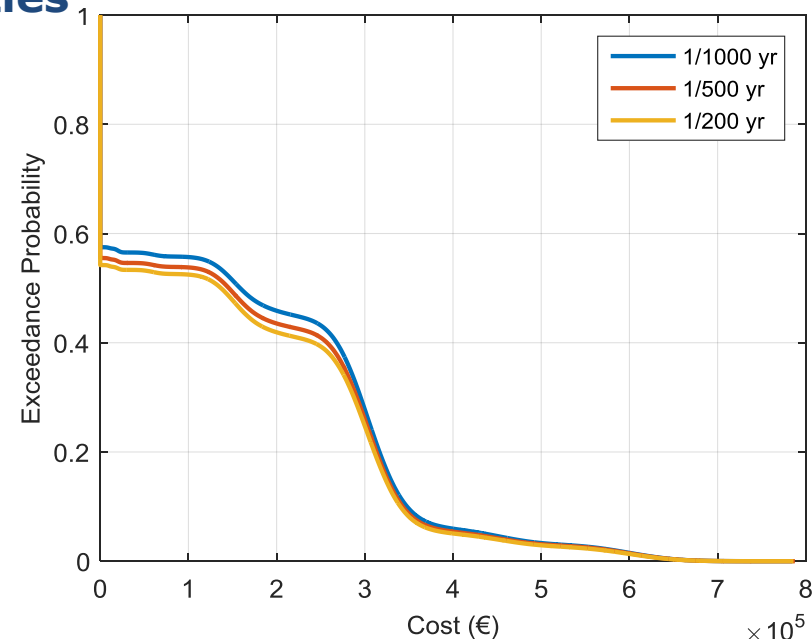


Croatian Case Study

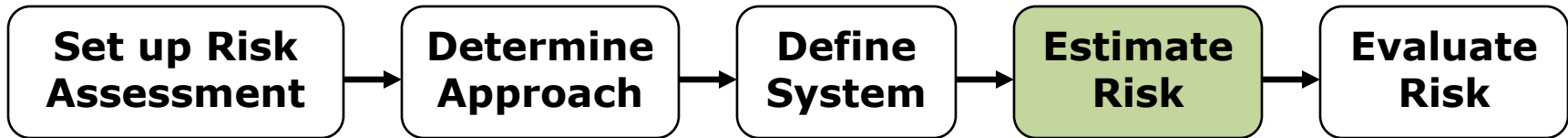


- Monte Carlo sampling method
 - Aleatoric and epistemic uncertainties
- Direct consequences
 - Total network repair cost

Rainfall Induced Landslides

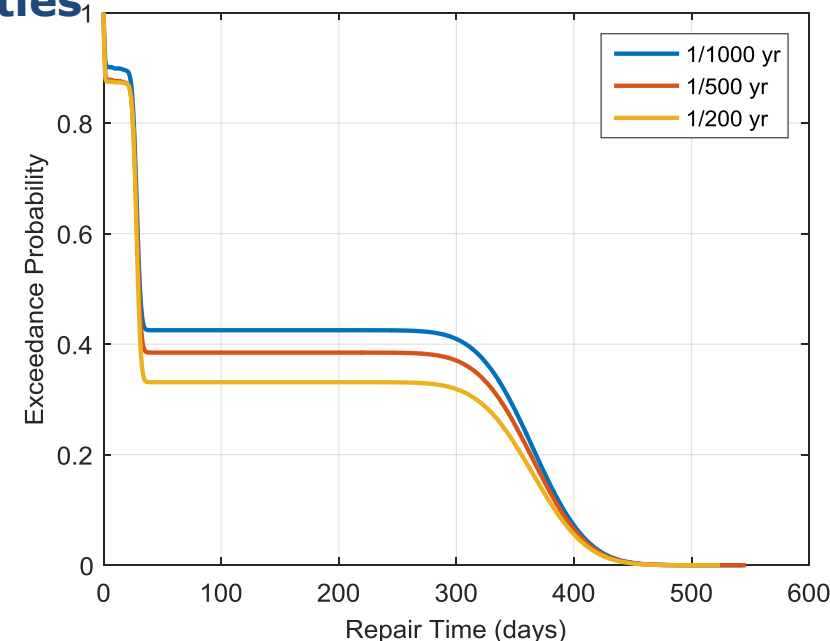


Croatian Case Study

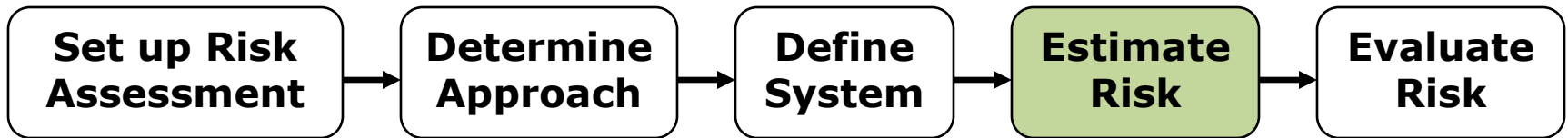


- **Monte Carlo sampling method**
 - Aleatoric and epistemic uncertainties
- **Direct consequences**
 - Total network repair cost
- **Indirect consequences**
 - Time to repair network

Scour + Inundation

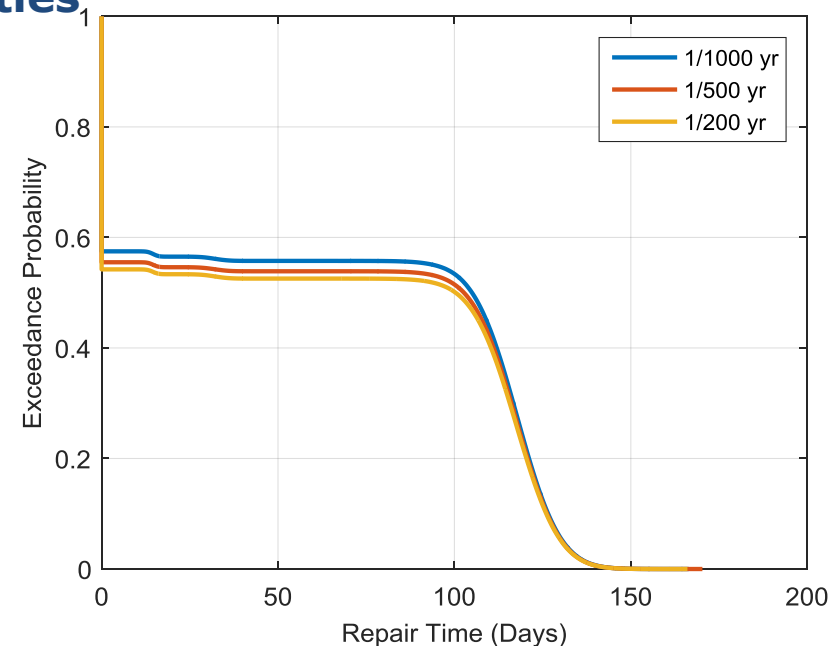


Croatian Case Study

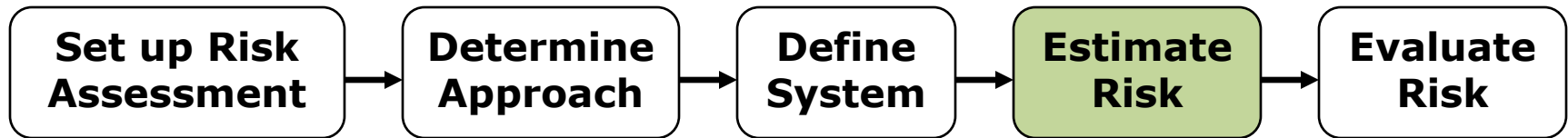


- **Monte Carlo sampling method**
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Rainfall Induced Landslides

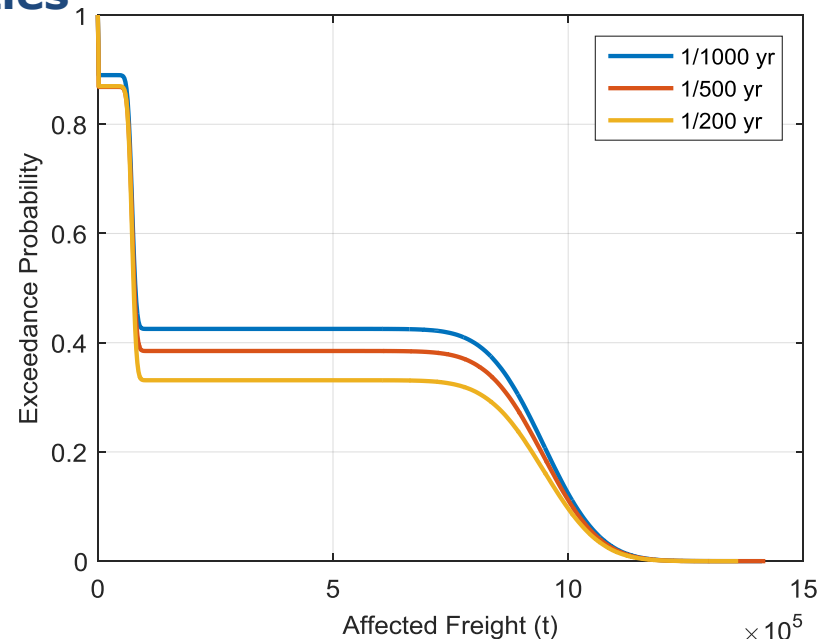


Croatian Case Study

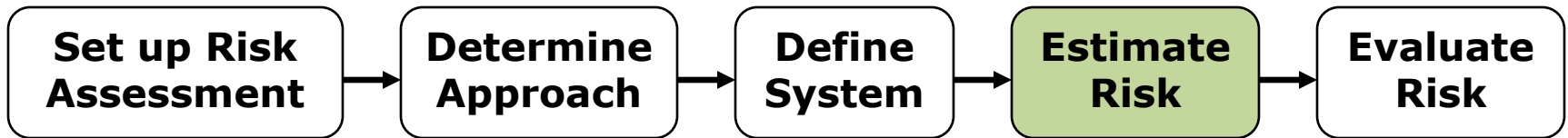


- **Monte Carlo sampling method**
 - Aleatoric and epistemic uncertainties
- **Direct consequences**
 - Total network repair cost
- **Indirect consequences**
 - Time to repair network
 - Level of affected freight

Scour + Inundation

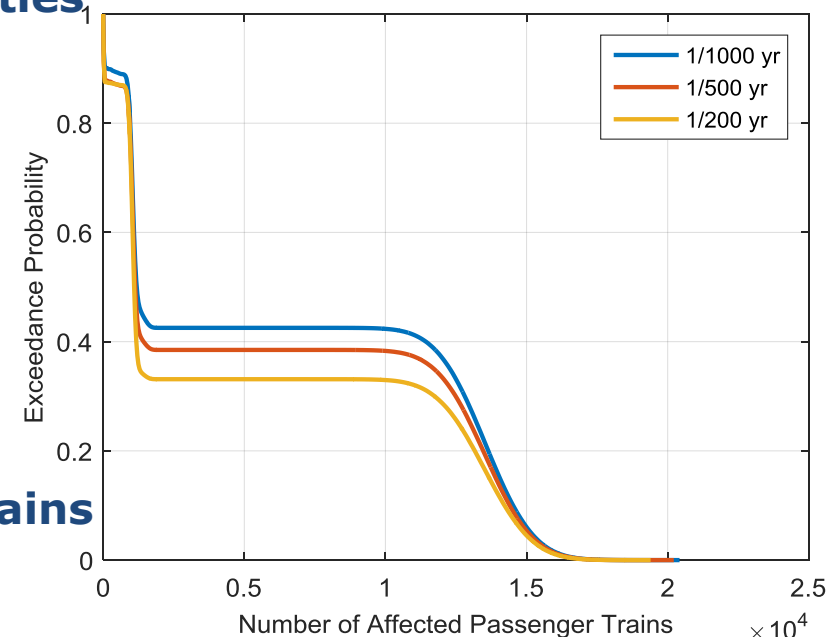


Croatian Case Study

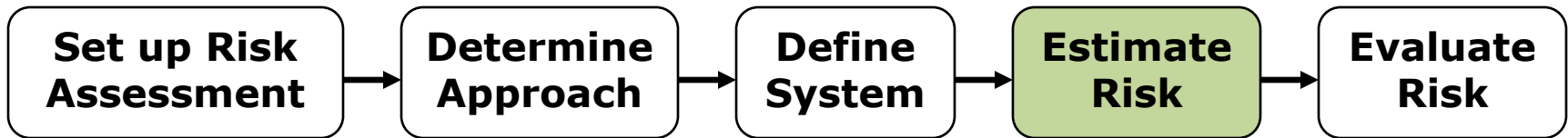


- **Monte Carlo sampling method**
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- **Indirect consequences**
 - Time to repair network
 - Level of affected freight
 - Number of impacted passenger trains

Scour + Inundation

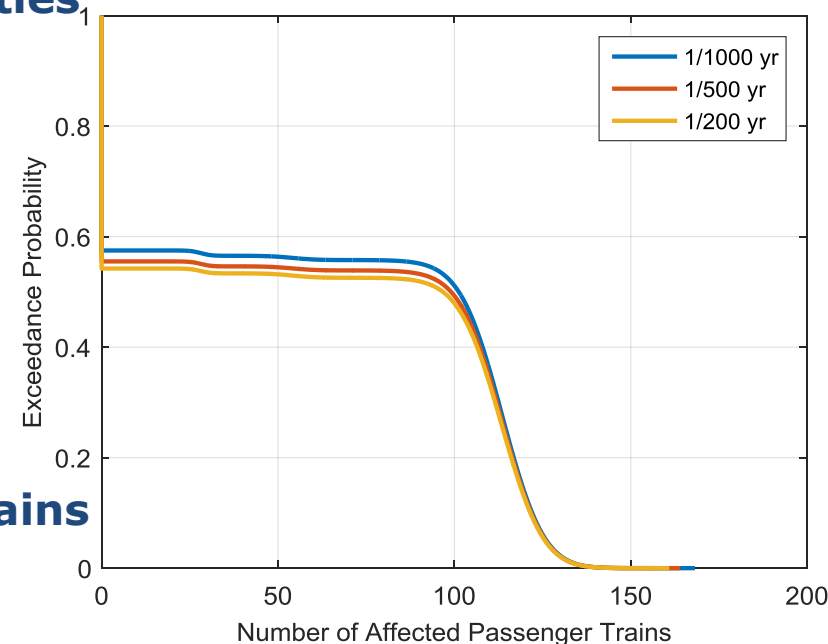


Croatian Case Study



- **Monte Carlo sampling method**
 - Aleatoric and epistemic uncertainties
- **Direct consequences**
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Rainfall Induced Landslides



Further Information

Deliverable 8.2 Case Study Results



Novel Indicators for identifying critical **INFRA**structure at **RISK** from Natural Hazards

Website

www.infrarisk-fp7.eu

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