System-Level Approaches for Landslide Risk Management and Assessing Economic Impacts

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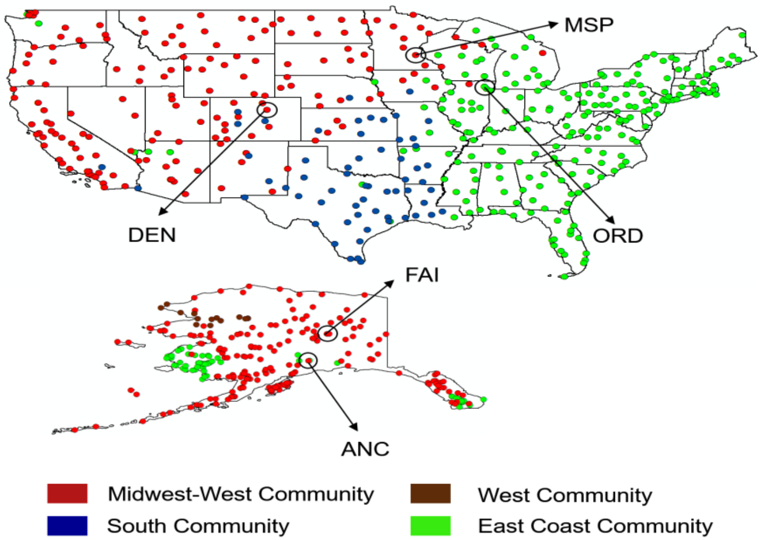
Landslides

- One of the most widespread natural hazards
- Economic damages and loss of life (especially in mountainous regions)
- 17% of the fatalities from natural hazard attributable to landslides (Source: Centre for Research on the Epidemiology of Disasters, CRED, http://www/cred/be/)
- Need to move from reactive to proactive. Need for data-informed risk management and decision-making
- Economic losses underestimated- Often attributed to other natural hazards (floods, earthquakes)

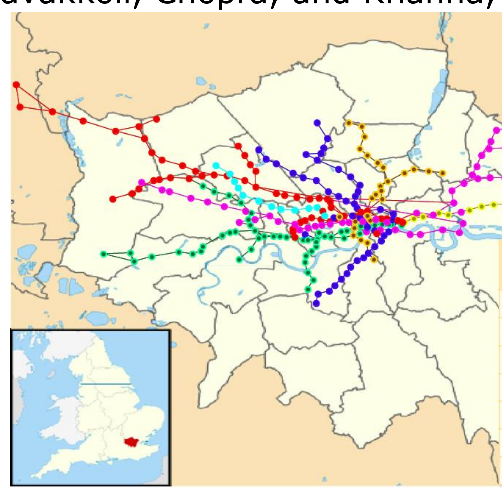
Infrastructure Interdependencies

- Interdependencies and interconnectedness amongst infrastructure systems establish *high vulnerabilities*
- "System of systems" make the system more *vulnerable to abrupt failures*
- Patterns of interdependencies *cause cascading impacts by amplifying the effects of disruptions*

Infrastructure Resilience: Network perspective

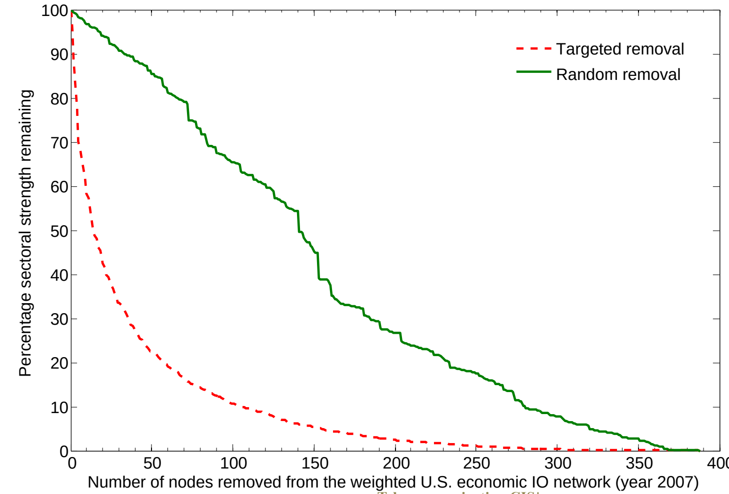


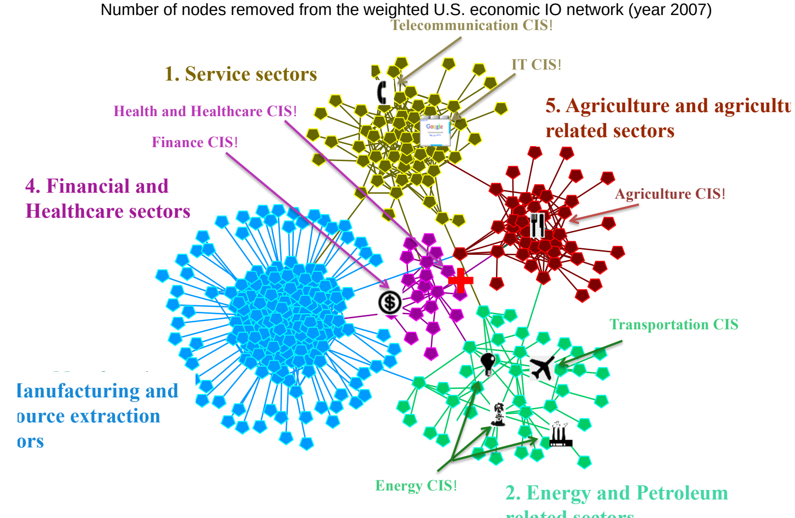
Tavakkoli, Chopra, and Khanna, SRA, under review



AM sub-communities	no. stations
red	56
pink	54
green	53
blue	48
orange	28
yellow	17
aqua	12

Chopra, Bilec, & Khanna, *J. Royal Society Interface*, 2016





Chopra and Khanna, *Physica A: Statistical Mechanics and its Applications*, 2015

Landslides: Direct vs Indirect Costs

- Direct:
  - Repair, replacement, or maintenance

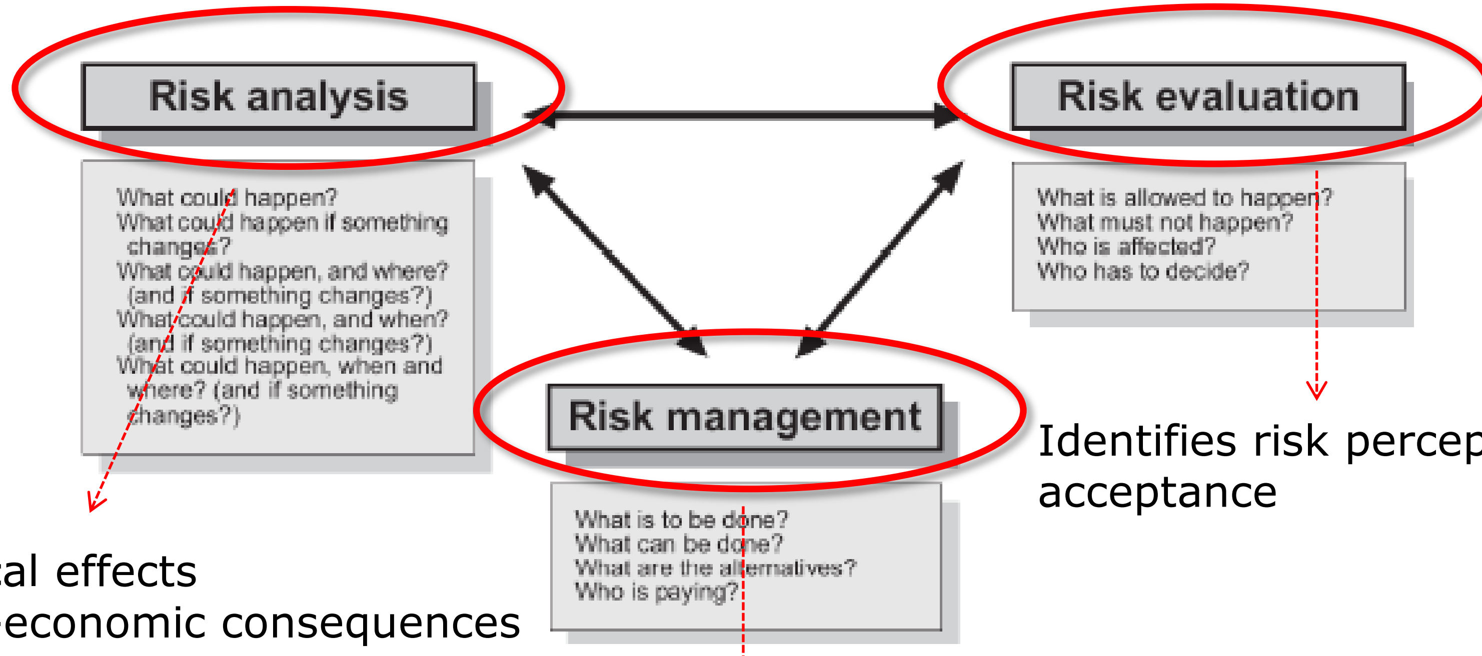
- Indirect costs (several of these often ignored):
  - Loss of productivity because of injury, death
  - Loss of industrial, agricultural, and forest productivity and tourist revenues or interruption of transportation systems
  - Reduced real estate values; Loss of tax revenues
  - Measures that are required to be taken, to prevent or mitigate additional landslide damage
  - Adverse effects on water quality in streams and irrigation facilities

  - Indirect losses could be as significant or higher than the direct damages (Sterlacchini et al., *Nat. Hazards Earth Syst. Sci.*)

Landslides- Economic Impacts

- Losses exceeding $3.5 billion- avoidable by effective planning and management (*Schuster and Highland, 2001*)
- Reality- constrained budgets and competing priorities
- Need for data-driven decisions to guide prioritization efforts and resource allocation
- Risk Analysis- Systems-level approach

Landslide Risk Analysis: State-of-the-art



Physical effects
Socio-economic consequences

Identifies risk perception and acceptance

Combines analysis & evaluation
Best solution

Truly requires a multi-disciplinary and multi-stakeholder methodological approach (scenario mapping, cause-effect correlation, and concepts from environmental economics)

Australian Geomechanics Society (AGS, Sub- Committee on Landslide Risk Management, 2000)

Landslide Risk Analysis

- Chemical risk assessment vs landslide risk assessment

Risk= Hazard (toxicity) * Exposure (environmental concentration)

Landslide risk assessment (integration of frequency analysis and consequence analysis)

Risk= consequence* Frequency

Hazard Identification (Domain Experts)

Requires an understanding of the slope processes and the relationship of those processes to geomorphology, geology, hydrogeology, climate and vegetation

- Compiling an inventory of possible hazards
- Classify the types of potential landsliding
- Physical extent of each potential landslide
- Assess the likely initiating event(s), the physical characteristics of the materials involved, and the slide mechanics
- Estimating anticipated travel distance and velocity of movement

Australian Geomechanics Society (AGS, Sub- Committee on Landslide Risk Management, 2000)

Frequency Analysis

The frequency of landslides can be expressed as:

- Annual frequency of occurrence of landslides in an area based on previous rates of occurrence (historical data)
- The probability of an existing landslide moving or a particular slope failing in a given period
- The driving forces exceeding the resisting forces in probability or reliability terms, expressing it as an annual frequency

- Again a combination of domain expertise, expert judgment, and historical data

Consequence Analysis

- Net present value
- Property damage
- Injury/loss of life
- Travel times
- Loss to businesses
- Effect on reputation
- Others- Public outrage, consequential costs (e.g. litigation)

- Many of these may not be readily quantifiable and will require considerable judgement if they are to be included in the assessment
- Consideration of such consequences may form part of the risk evaluation process by the client/owner/regulator

Quantitative Risk Analysis

Risk= Hazard (consequence)* Exposure (Frequency)

$$R(Prop) = P(H) \times P(S|H) \times V(Prop|S) \times E$$

- R(Prop) is the risk (annual loss of property value)
- P(H) is the annual probability of the hazardous event (the landslide)
- P(S|H) is the probability of spatial impact by the hazard (i.e. of the landslide impacting the property, taking into account the travel distance)
- V(Prop|S) is the vulnerability of the property to the spatial impact (proportion of property value lost)
- E is the element at risk (e.g. the value or net present value of the property)

- Extensions to quantify loss of life

A full risk analysis involves consideration of all landslide hazards for the site and all the elements at risk

Australian Geomechanics Society (AGS, Sub- Committee on Landslide Risk Management, 2000)

Risk Evaluation and Risk Treatment/Management

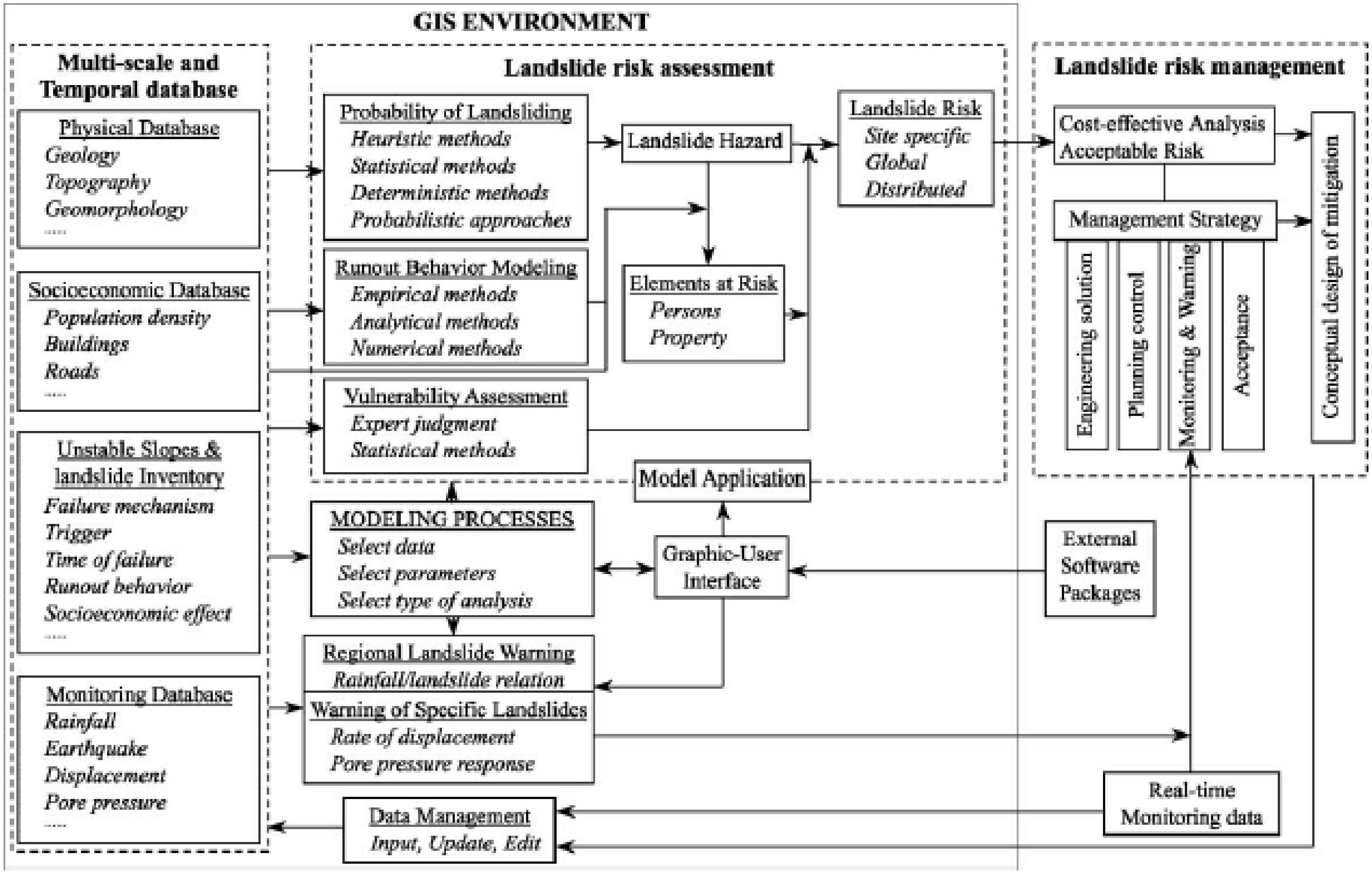
- Risk Evaluation
  - Judgment about the significance and acceptability of the estimated risk
  - Comparison of the assessed risks with risk acceptance criteria related to financial, loss of life or other values
  - consideration of public reaction, politics, public confidence and fear of litigation

- Risk Management
  - Accept the risk
  - Reduce the likelihood; proactive measures
  - Reduce the consequences; Monitoring and warning systems
  - Transfer the risk; compensate for the risk such as by insurance
  - Postpone the decision;
  - Cost to benefit tradeoffs

Outlook and Data Needs

- Increasing propensity of landslides:
  - Increased urbanization and development in landslide-prone areas;
  - Continued deforestation of landslide-prone areas;
  - increased regional precipitation (changing climatic patterns)
- Quality of landslide risk assessment dependent on length, quality, and nature of available information

GIS Framework



Proposed GIS-based conceptual integrated system for landslide risk assessment and management (Dai et al., *Eng. Geology*, 64, 65-87

Data Needs

- Landslide database for landslide risk assessment and management (e.g., Allegheny County Landslide Portal)
- Landslide records (geotechnical information, date and extent of failure, and consequence from individual landslide sites)
- Physical and social data (assets/other infrastructures) are critical for all subsequent probability, vulnerability and risk assessment and management
- Regional scale landslide risk studies could result in the identification of areas with different levels of hazard and risk
- Hazard and risk zoning- could inform land-use planning, guidelines for engineering practice