Determining Critical Infrastructure Using Social Network Analysis

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Outline

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Introduction

- Urban critical infrastructure (CI) forms the backbone of our community well-being.

- Understanding the possible risks to CI is paramount to strengthening our CI to improve quality of life.

- Risks are not often contained to just one sector and often have interconnected repercussions (cascade).

Motivation

- The understanding of how these cascades occur are not fully understood, or even well researched in risk analysis.
- Current models also don’t account for stakeholder perceptions of the weight of the threat (leading to inaccuracy).
- Network science isn’t being used at the forefront of risk analysis, despite clear analogues.

Related Works

- Disruption in infrastructure serviceability negatively impacts community wellbeing (Correa-Henao et al.)
- Risks are dynamic and risk impact analysis has been modeled in the literature before (Fang et al.)
- Risk assessments must not only consider introverted risks, but to the impact of risks outside the immediate network (Theoharidou et al.)
- There are multiple stakeholders and considering all their perceptions in the decision making process is noted to be challenging (Cholda et al.)

Handy Definitions

- Stakeholder: Person, group, or organization with a degree of responsibility or authority over the CI
- Risk: a possible hazard to the CI.
- RPV: The Risk Priority Value, unique to each risk, which is a function of the severity, likelihood, and detection of the risk.

Methodology: Proposal & First Step

- Paper introduces fuzzy critical risk analysis (FCRA) as a means to assess risk.
  - Basis rests on existing risk assessment strategies.
  - Simulates and integrates perceptions form different stakeholders.

- The first step is to identify the stakeholders and risk(s) in the context of the infrastructure.

- Each risk is analyzed to determine to focus and limit the analysis boundary.

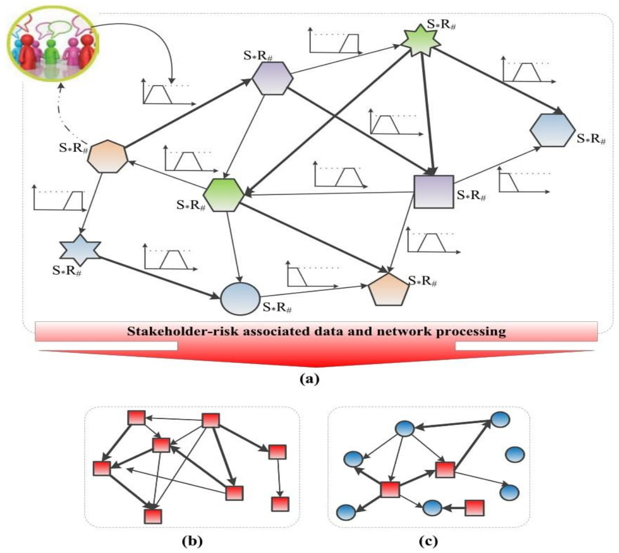
Methodology: Perception

- Each stakeholder participates in the assessment of the risks.
- Fuzzy-based risk structure matrices are used to accommodate the stakeholder's opinions of perceived risks.
  - The process by which this is done is omitted and reference (Lie et al.)
- A matrix is constructed to assign each stakeholder a "hazard value" based on the total perception of each phenomena's impact across the entire system.

Methodology: Network Construction

- A network is created using the risk structure matrix method (not detailed in the paper).
- This matrix represents the relationships and dependencies of the stakeholders, factoring in likelihood and severity.
- The matrix created by this (the S.R.-S.R. network) is deconstructed to the Risk-Risk network and the Stakeholder-Risk matrix.

Methodology: Network Construction (con't)



Notes: (a) Fuzzy-based Stakeholder-Risk Associated Network; (b) Risk-Risk Network; (c) Stakeholder-Risk Network

Methodology: Network Metrics

- Density
- Degree Centrality
- Betweenness Centrality
- Status Centrality - Like degree centrality but considering all nodes two hops away
- Eigenvector Centrality
- Closeness Centrality

Risk Criticality Analysis

- A combination of the normalized value of all the centrality metrics in the S-R and R-R networks.

$$\mathrm{Crit}_{R_n} = \left[\begin{array}{l} \left\{ \mathrm{RPV}_{R_n} \times \left(\sum \underset{\max}{\mathrm{Norm}}(\mathrm{OutCloseC}_{R_n}), \underset{\max}{\mathrm{Norm}}(\mathrm{BetC}_{R_n}), \underset{\max}{\mathrm{Norm}}(\mathrm{OutStaC}_{R_n}), \underset{\max}{\mathrm{Norm}}(\mathrm{EignvC}_{R_n}) \right)_{\text{R-R}} \right\} + \\ \left\{ \mathrm{RPV}_{R_n} \times \left(\sum \underset{\max}{\mathrm{Norm}}(\mathrm{DegC}_{R_n}), \underset{\max}{\mathrm{Norm}}(\mathrm{CloseC}_{R_n}), \underset{\max}{\mathrm{Norm}}(\mathrm{BetC}_{R_n}), \underset{\max}{\mathrm{Norm}}(\mathrm{EignvC}_{R_n}) \right)_{\text{S-R}} \right\} \end{array} \right]$$

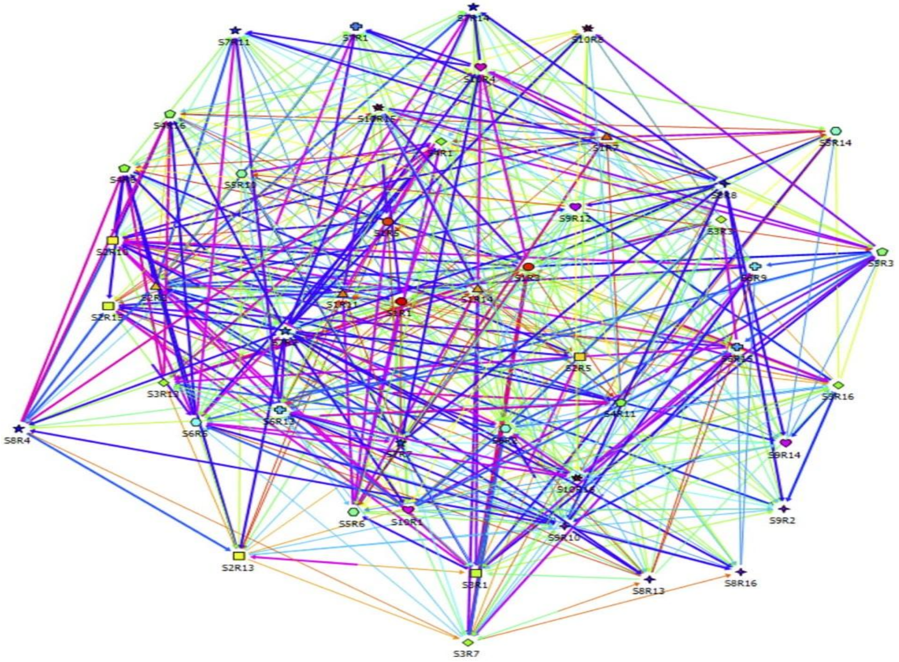
$$= \left[\begin{array}{l} \left\{ \mathrm{RPV}_{R_n} \times \left(\sum \phi_{\mathrm{OutCloseC}_{R_n}}, \phi_{\mathrm{BetC}_{R_n}}, \phi_{\mathrm{OutStaC}_{R_n}}, \phi_{\mathrm{OutStaC}_{R_n}} \right)_{\text{R-R}} \right\} + \\ \left\{ \mathrm{RPV}_{R_n} \times \left(\sum \phi_{\mathrm{DegC}_{R_n}}, \phi_{\mathrm{CloseC}_{R_n}}, \phi_{\mathrm{BetC}_{R_n}}, \phi_{\mathrm{EigenvC}_{R_n}} \right)_{\text{S-R}} \right\} \end{array} \right]$$

Methodology Verification

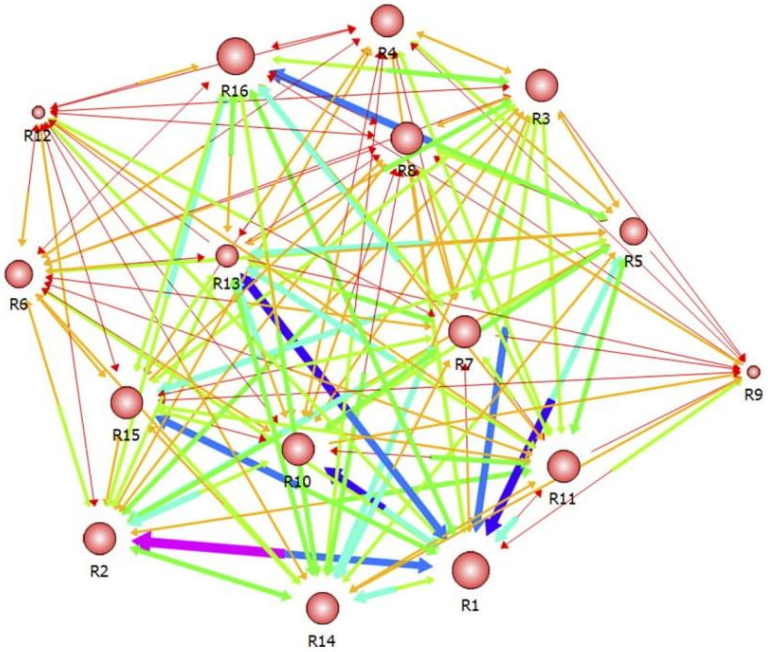
- A toy example was created with 10 stakeholders in differing groups and 16 risk hazards.

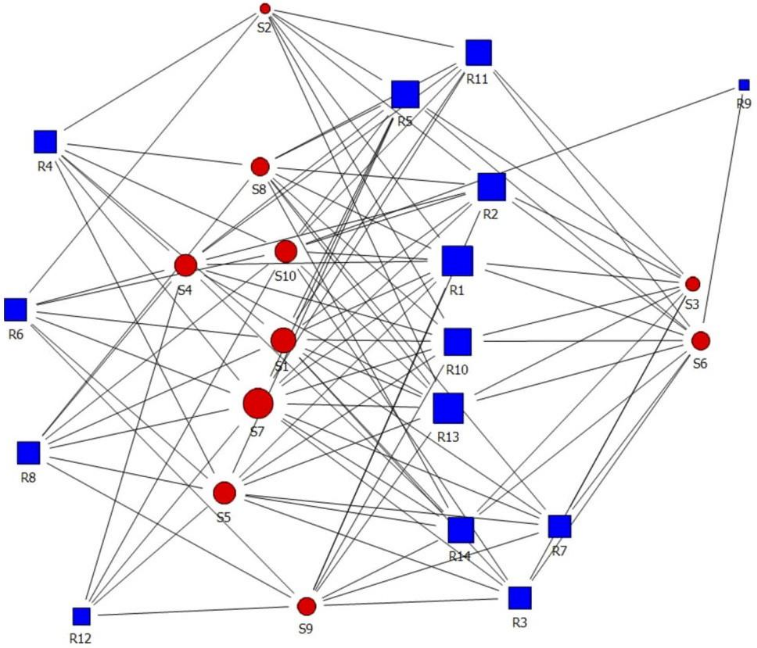
- The risk hazards are based on UWS infrastructure from mainstream research and resilience literatures.
    - Range from exchange rate instability to drought.
- The risk ordering was compared between the proposed FCRA and the field-standard FMECA.

SR-SR Network



R-R Network and S-R Network





Results: Centralities

Hazard ID (node)	Degree centrality	Closeness centrality	Betweenness centrality	EigenV centrality
R_1	1.000	1.000	0.035	0.439
R_2	0.900	0.952	0.028	0.328
R_3	0.700	0.869	0.015	0.287
R_4	0.700	0.869	0.015	0.232
R_5	0.900	0.952	0.028	0.238
R_6	0.700	0.869	0.015	0.169
R_7	0.700	0.869	0.014	0.167
R_8	0.700	0.869	0.013	0.132
R_9	0.200	0.714	0.000	0.055
R_{10}	0.900	0.952	0.027	0.309
R_{11}	0.800	0.909	0.021	0.213
R_{12}	0.500	0.800	0.006	0.034
R_{13}	1.000	1.000	0.035	0.289
R_{14}	0.800	0.909	0.019	0.258
R_{15}	0.700	0.869	0.016	0.256
R_{16}	0.800	0.909	0.020	0.260
Node		Normalized values		
R_1	1.000	1.000	1.000	1.000
R_2	0.900	0.952	0.797	0.747
R_3	0.700	0.869	0.446	0.654
R_4	0.700	0.869	0.436	0.528
R_5	0.900	0.952	0.800	0.543
R_6	0.700	0.869	0.449	0.384
R_7	0.700	0.869	0.405	0.379
R_8	0.700	0.869	0.398	0.300
R_9	0.200	0.714	0.023	0.126
R_{10}	0.900	0.952	0.769	0.704
R_{11}	0.800	0.909	0.614	0.485
R_{12}	0.500	0.800	0.197	0.077
R_{13}	1.000	1.000	1.000	0.659
R_{14}	0.800	0.909	0.548	0.588
R_{15}	0.700	0.869	0.477	0.584
R_{16}	0.800	0.909	0.597	0.592

Table VI.
The one-mode "R" topology decipherment data from "S-R" two-mode network analysis

Results: Risk Comparison

Risk ID	Fuzzy-based FMECA RPV (Norm)	Risk rank	Risk criticality	FCRA Risk criticality (Norm)	Risk criticality rank	Sum
R_1	0.945	4	8.505	1.000	1	▲
R_2	0.928	7	6.553	0.770	2	▲
R_3	0.882	11	5.701	0.670	10	▼
R_4	1.000	1	5.590	0.657	11	▼
R_5	0.932	6	6.531	0.768	3	▲
R_6	0.986	2	5.333	0.627	13	▼
R_7	0.901	8	5.393	0.634	12	▼
R_8	0.785	16	4.127	0.485	14	▲
R_9	0.834	14	1.954	0.230	16	▼
R_{10}	0.888	10	6.207	0.730	6	▲
R_{11}	0.938	5	6.015	0.707	7	▼
R_{12}	0.873	13	3.416	0.402	15	▼
R_{13}	0.818	15	6.010	0.707	8	▲
R_{14}	0.978	3	6.405	0.753	5	▼
R_{15}	0.876	12	5.701	0.670	9	▲
R_{16}	0.895	9	6.490	0.763	4	▲

Note: ▲,▼ means the ranking order changes (increasing or decreasing)

Table VII. The summary of risk ranking based on fuzzy-based FMECA and FCRA

Reflection

- No comparative analysis is done to determine “goodness” of new model.
- Setup feels incomplete:
  - Stakeholder parameters aren’t clear
  - Fuzzy-set logic to stand in for stakeholder perceptions isn’t explicitly defined
- The stakeholders aren’t given a centrality value
- Glaring flaws that shouldn’t have made it through edits