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Risk, Resilience, and Decision Analytics for Infrastructure Defense

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CREATE 20th Anniversary Symposium

Los Angeles, CA

April 19, 2024

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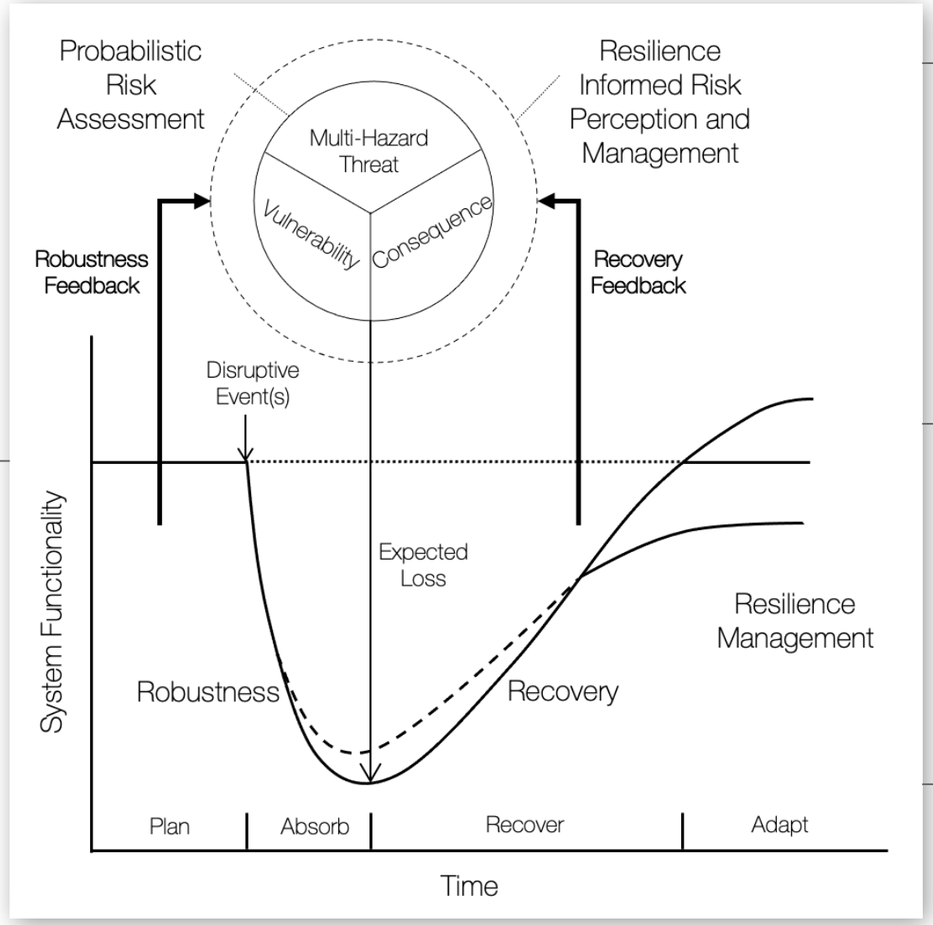
Research Overview



Infrastructure Network Resilience Modeling

Interdependent network failure and recovery modeling and simulation

Security Risk and Decision Analytics

Multi-hazard risk analysis and resource allocation under uncertainty

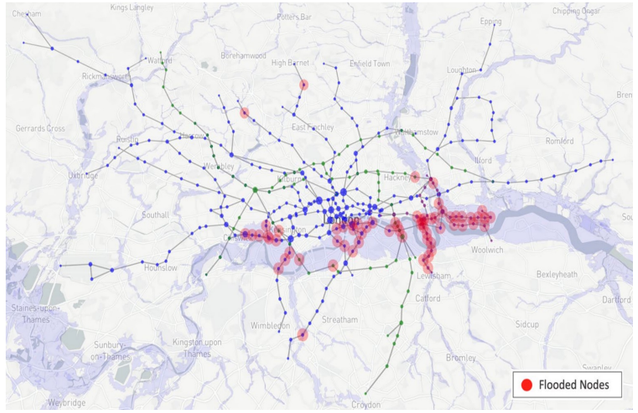
Multi-Agent Learning and Optimization

Multi-level optimization, game theory, and deep reinforcement learning

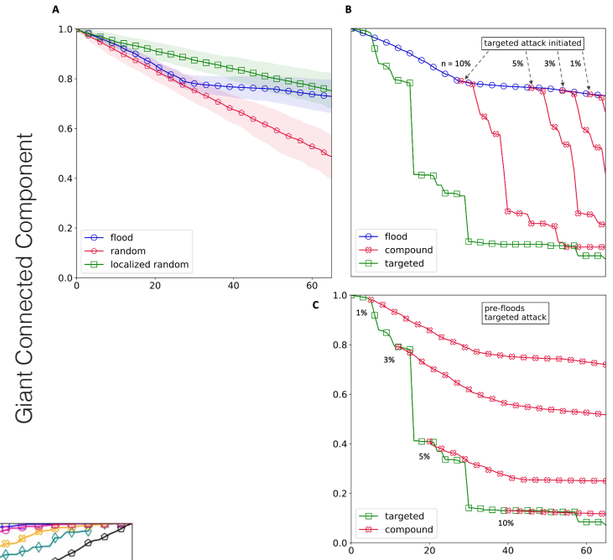
Focus on Cyber and Cyber-Physical Infrastructure Systems

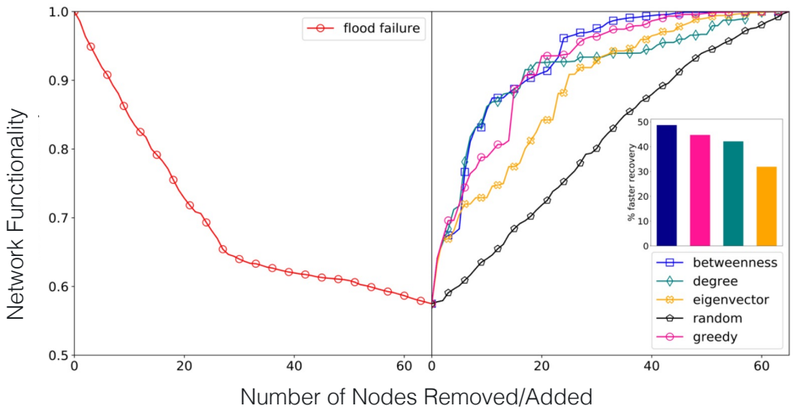
Infrastructure Network Resilience Modeling

Urban Rail Network Resilience under Compound Failures



London Rail Network





Simulated Resilience Curves

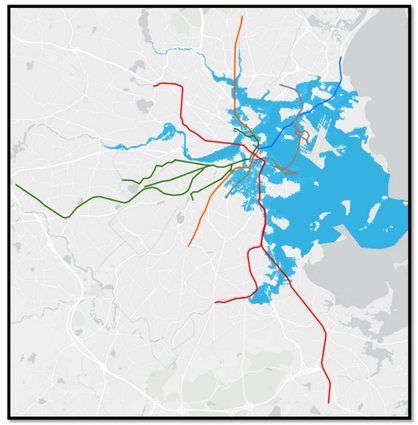
www.nature.com/scientificreports

SCIENTIFIC REPORTS

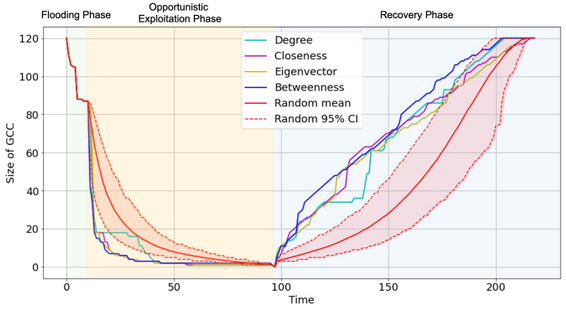
nature research

Resilience of Urban Transport Network-of-Networks under Intense Flood Hazards Exacerbated by Targeted Attacks

Nishant Yadav[1], Samrat Chatterjee[2✉] & Auroop R. Ganguly[1✉]



Boston Rail Network



Simulated Resilience Curves

Resilience of Urban Rail Transit Networks under Compound Natural and Opportunistic Failures

Jack R. Watson[1,2], Samrat Chatterjee[1,2], *SM-IEEE*, Auroop Ganguly[2,1], *SM-IEEE*
[1]Pacific Northwest National Laboratory, Richland WA 99352 USA
[2]Northeastern University, Boston MA 02115 USA

SRA 2022
Global Risks @ the Tipping Point
Risk Analysis & Policy Driving Systemic Change
December 4-8 • Tampa, Florida

SRA 2022 and 2021 Student Merit Awards from Resilience Analysis Specialty Group

IEEE Advancing Technology for Humanity

2022 Virtual IEEE International Symposium on Technologies for Homeland Security

IEEE-HST 2022 Best Paper Award in Climate and Homeland Resilience Track

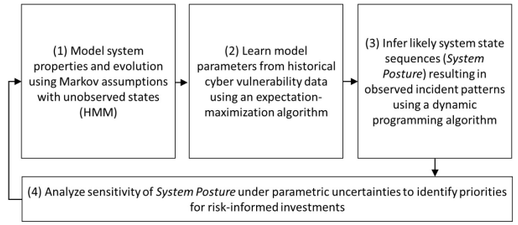
Based on work as CREATE postdoc

Security Risk and Decision Analytics

Multi-Hazard Risk Analysis and Resource Allocation under Uncertainty

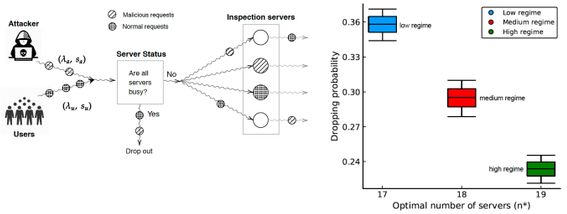
An iterative learning and inference approach to managing dynamic cyber vulnerabilities of complex systems

Samrat Chatterjee[a], Shital Thekdi[b,*]



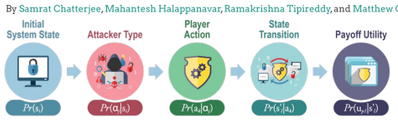
Cyber Threat Screening Using a Queuing-Based Game-Theoretic Approach

Arnab Bhattacharya[1], Shaunak D. Bopardikar [2], Samrat Chatterjee[1], Draguna Vrabie[1]



Game Theory and Uncertainty Quantification for Cyber Defense Applications

By Samrat Chatterjee, Mahantesh Halappanavar, Ramakrishna Tipireddy, and Matthew Oster



Dynamic Network Analysis of Nuclear Science Literature for Research Influence Assessment

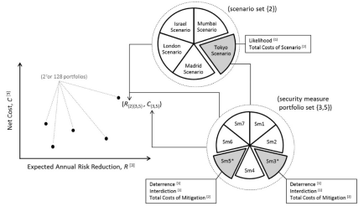
Samrat Chatterjee, Dennis Thomas, Daniel Fortin, Karl Pazdernik, Benjamin Wilson, and Lisa Newburn

A Methodology for Modeling Regional Terrorism Risk

Samrat Chatterjee[1,*] and Mark D. Abkowitz[2]

Portfolio Analysis of Layered Security Measures

Samrat Chatterjee,[1] Stephen C. Hora,[2,*] and Heather Rosoff[2]

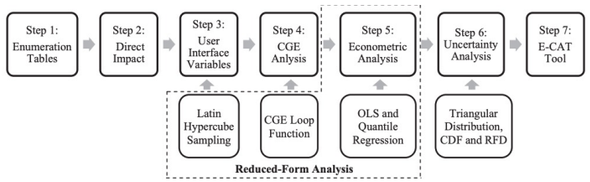


A Framework for Analyzing the Economic Tradeoffs Between Urban Commerce and Security Against Terrorism

Adam Rose,[1,*] Misak Avetisyan,[1,2] and Samrat Chatterjee[1]

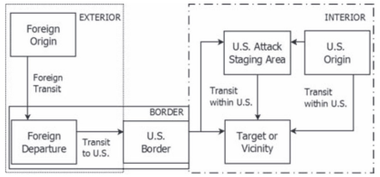
Economic consequences of aviation system disruptions: A reduced-form computable general equilibrium analysis

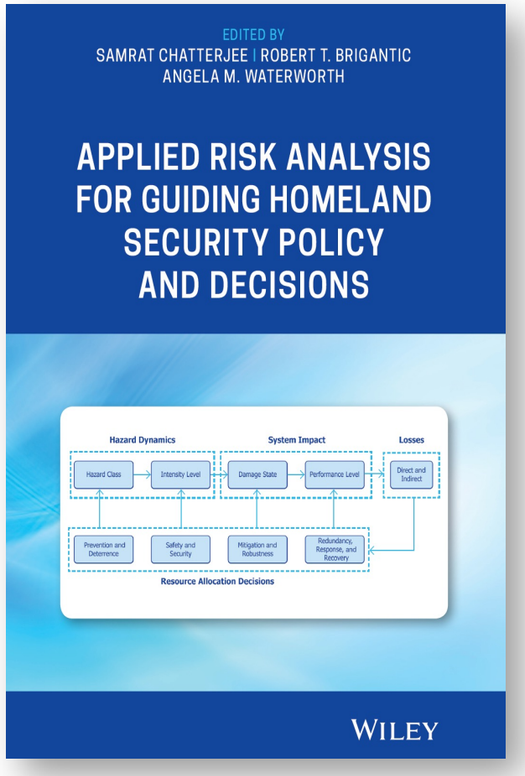
Zhenhua Chen [a,*], Adam Z. Rose [b], Fynnwin Prager [c], Samrat Chatterjee [d]



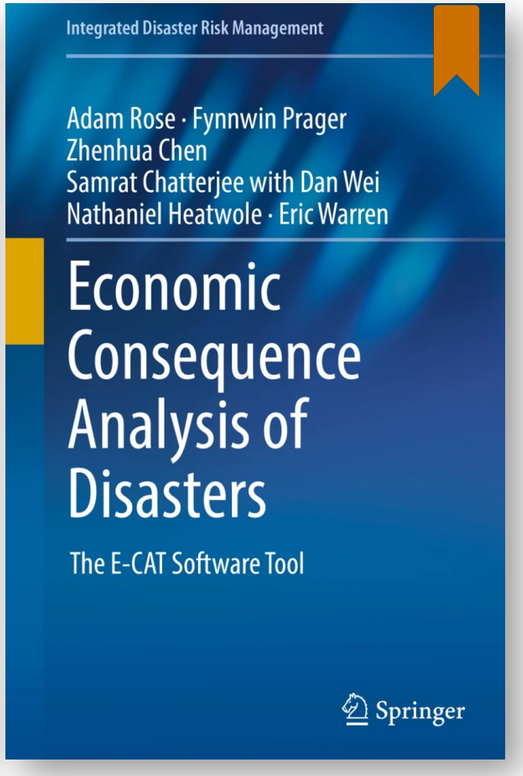
A Systems Approach for Evaluating the Effectiveness of Radiological and Nuclear Detection Architectures in Urban Areas

Samrat Chatterjee,* Daniel E. Salazar, and Isaac Maya





Chatterjee et al., 2021



Rose et al., 2017

SRA 2019 Best Poster Award for Interdependent Infrastructure Network Resilience Analysis

IEEE-HST 2017 and 2015 Best Paper Awards in Attack/Disasters and Cyber Security Tracks

Multi-Agent Learning and Optimization

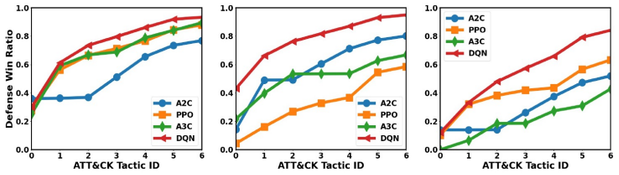
Deep Reinforcement Learning for Cyber and Cyber-Physical Infrastructure Defense

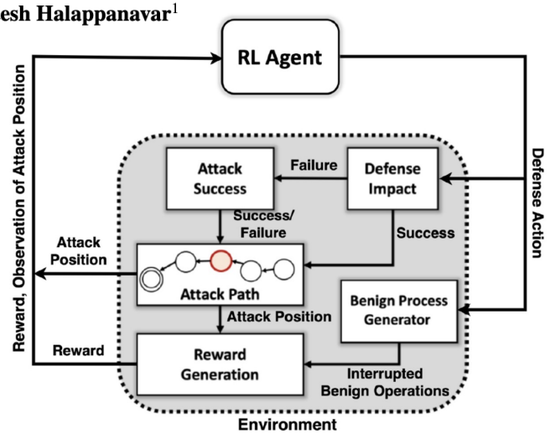
Deep Reinforcement Learning for Cyber System Defense under Dynamic Adversarial Uncertainties

Ashutosh Dutta[1], **Samrat Chatterjee**[1], **Arnab Bhattacharya**[1], **Mahantesh Halappanavar**[1]

The AAAI-23 Workshop on
Artificial Intelligence for Cyber Security (AICS)
Feb 14, 2023, Washington, DC, USA

Attacker Type 1 | Attacker Type 2 | Attacker Type 3



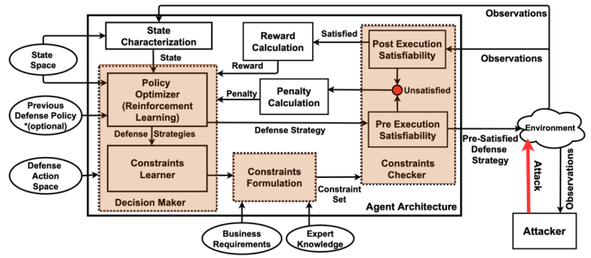


Autonomous Cyber Defense Framework

Constraints Satisfiability Driven Reinforcement Learning for Autonomous Cyber Defense*

Ashutosh Dutta[1], Ehab Al-Shaer[2], and Samrat Chatterjee[3]

2023 Conference on Neural Information Processing Systems



Autonomous cyber defense agent architecture

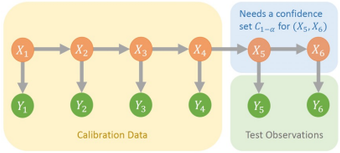
Assessing the Impact of Distribution Shift on Reinforcement Learning Performance

Ted Fujimoto[1] **Joshua Suetterlein**[1] **Samrat Chatterjee**[1,2] **Auroop Ganguly**[2,1]
[1]Pacific Northwest National Laboratory [2]Northeastern University

ICML | 2023
Fortieth International Conference on Machine Learning

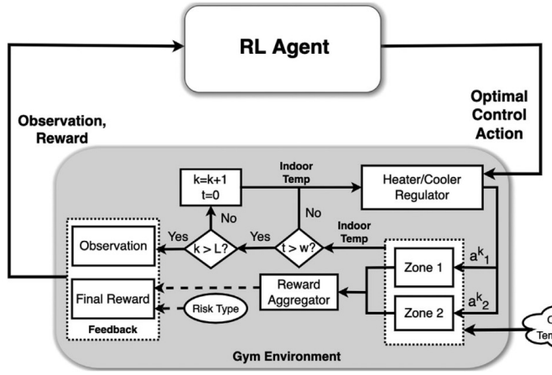
Extending Conformal Prediction to Hidden Markov Models with Exact Validity via de Finetti's Theorem for Markov Chains

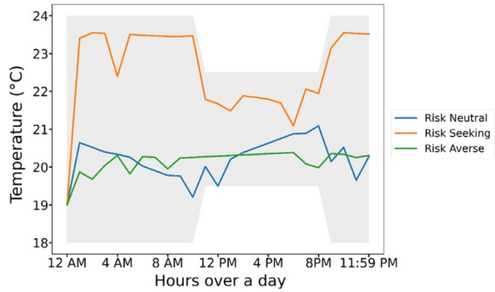
Buddhika Nettasinghe[1] **Samrat Chatterjee**[2] **Ramakrishna Tipireddy**[3] **Mahantesh Halappanavar**[2]



Role of reinforcement learning for risk-based robust control of cyber-physical energy systems

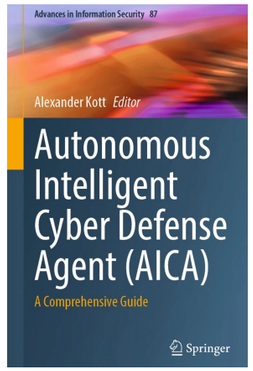
Yan Du[1] | **Samrat Chatterjee**[2] | **Arnab Bhattacharya**[1] | **Ashutosh Dutta**[3] | **Mahantesh Halappanavar**[4]



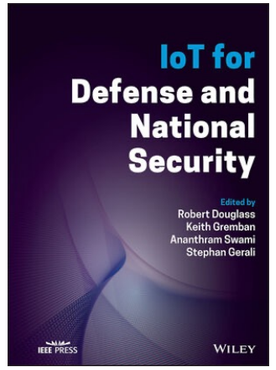


RL-based building temperature control actions by risk posture

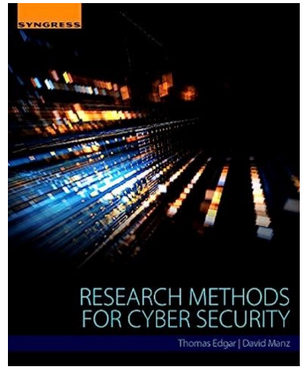
Invited Book Chapters: Multi-agent systems, CPS resilience, ML for cyber



Kott, 2023



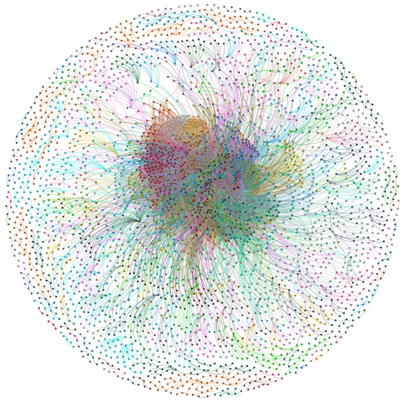
Douglass et al., 2023



Edgar & Manz, 2017

Ongoing Research

National Critical Functions Network Risk and Resilience Analysis

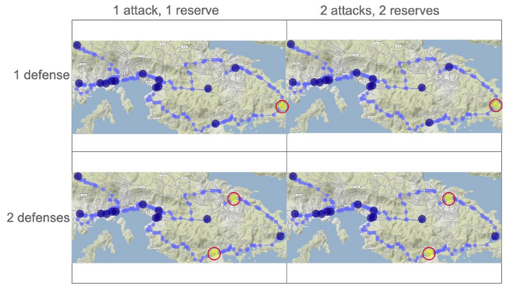


Interdependent Fuel and Transportation Network Resilience

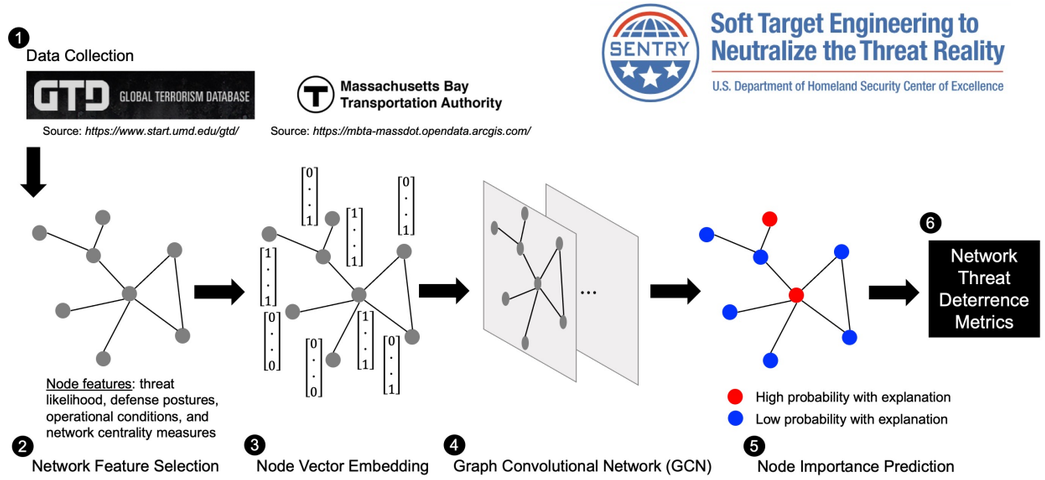
Defender prepares — Operator manages

$$\min_{w \in W} \left\{ \max_{x \in X} \left\{ \min_{y \in Y(w,x)} f(w,x,y) \right\} \right\}$$

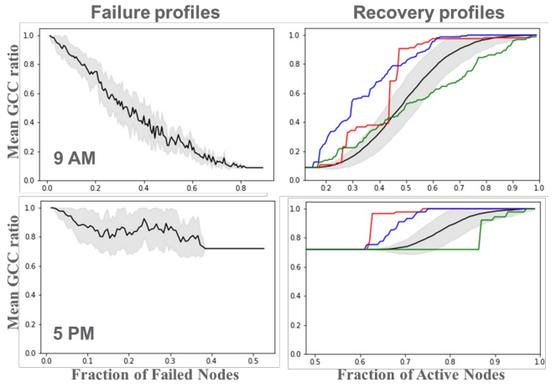
Attacker acts



Urban Rail Network Threat Deterrence with Graph Convolutional Networks

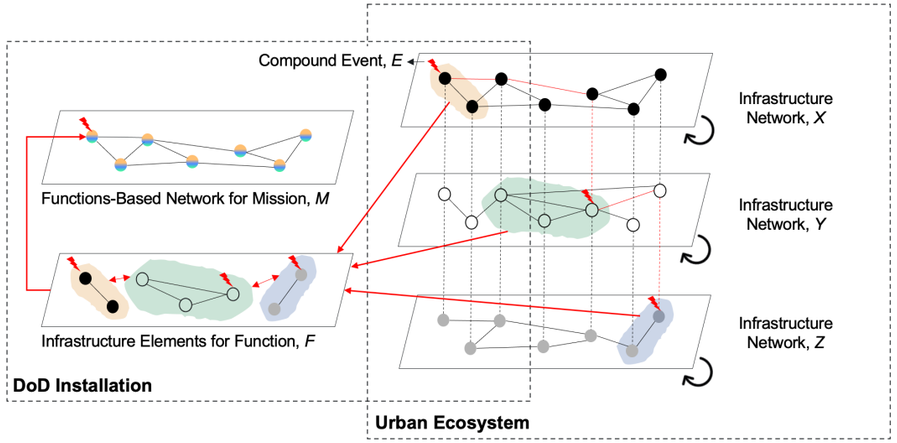


Dynamic Aircraft-to-Aircraft Communication Network Resilience



Recovery strategies: **random**, **degree**, **betweenness**, **eigenvector**

Multiplex Network Science and Multiscale System Dynamics for DoD Installation Resilience



Selected References

1. Du, Y., S. Chatterjee, A. Bhattacharya, A. Dutta, and M. Halappanavar. (2023) Role of reinforcement learning for risk-based robust control of cyber-physical energy systems. *Risk Analysis*, 43(11), 2280-2297. PNNL-SA-163685.
2. Fujimoto, T., J. Suetterlein, S. Chatterjee, and A. Ganguly. (2023) "Assessing the impact of distribution shift on reinforcement learning performance." In Regulatable Machine Learning Workshop at the 37th Conference on Neural Information Processing Systems (NeurIPS), New Orleans, LA. PNNL-SA-192422.
3. Nettasinghe, B., S. Chatterjee, R. Tipireddy, and M. Halappanavar. (2023) "Extending conformal prediction to hidden Markov models with exact validity via de Finetti's theorem for Markov chains." In Proceedings of 40th International Conference on Machine Learning (ICML), PMLR 202:25890-25903, Honolulu, HI. PNNL-SA-178224.
4. Dutta, A., S. Chatterjee, A. Bhattacharya, and M. Halappanavar. (2023) "Deep reinforcement learning for cyber system defense under dynamic adversarial uncertainties." In Association for the Advancement of Artificial Intelligence (AAAI)-23 Workshop on Artificial Intelligence for Cyber Security (AICS), Washington D.C. PNNL-SA-181841.
5. Watson, J., S. Chatterjee, and A. Ganguly. (2022) "Resilience of urban rail transit networks under compound natural and opportunistic failures." In Proceedings of IEEE Homeland Security Technologies (HST) International Virtual Symposium. *Best Paper Award (Climate and Homeland Resilience Track)*. PNNL-SA-174329.
6. Chatterjee, S., R.T. Brigantic, and A.M. Waterworth (editors). (2021) Applied risk analysis for guiding homeland security policy and decisions, Wiley Series in Operations Research and Management Science, 528 pp. PNNL-SA-139656.
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8. Chatterjee, S., and S. Thekdi. (2020) An iterative learning and inference approach to managing dynamic cyber vulnerabilities of complex systems. *Reliability Engineering and System Safety*,193, 1-14. PNNL-SA-140369.
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10. Rose, A., F. Prager, Z. Chen, S. Chatterjee, D. Wei, N. Heatwole, and E. Warren.(2017) Economic consequence analysis of disasters: The E-CAT software tool, Springer:Singapore, 137 pp. PNNL-SA-126764.
11. Chen, Z., A. Rose, F. Prager, and S. Chatterjee. (2017) Economic consequences of aviation system disruptions: a reduced-form computable general equilibrium analysis. *Transportation Research Part A: Policy and Practice*, 95, 207-226. PNNL-SA-115526.
12. Chatterjee, S., S.C. Hora, and H. Rosoff. (2015) Portfolio analysis of layered security measures. *Risk Analysis*, 35(3), 459-475.
13. Rose, A., M. Avetisyan, and S. Chatterjee. (2014) A framework for analyzing the economic tradeoffs between urban commerce and security against terrorism. *Risk Analysis*, 34(8), 1554-1579.
14. Chatterjee, S., D.E. Salazar, and I. Maya. (2014) A systems approach for evaluating the effectiveness of radiological and nuclear detection architectures in urban areas. *Systems Engineering*, 17(2), 157-165.
15. Chatterjee, S. and M.D. Abkowitz. (2011) A methodology for modeling regional terrorism risk. *Risk Analysis*, 31(7), 1133-1140.

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