SAND2017-8658PE

Stochastic Optimization to Enhance Resiliency and Response Strategies in Critical Infrastructure

Sandia National Laboratories
J.P. Watson, C.D. Laird, A. Castillo, J.D. Siirola and M.L. Bynum
Sandia National Laboratories, Albuquerque 87185

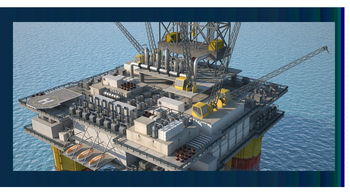
Problem

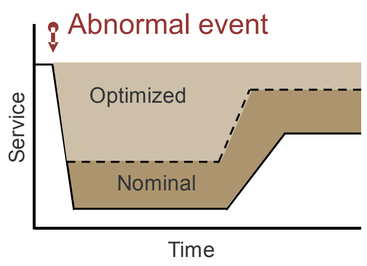
Critical infrastructure must be operated robustly and safely under abnormal conditions

Power systems vulnerable to extreme weather and adversaries

Water systems vulnerable to contamination and loss of service

Petroleum and chemical facilities vulnerable to flammable and toxic gas release





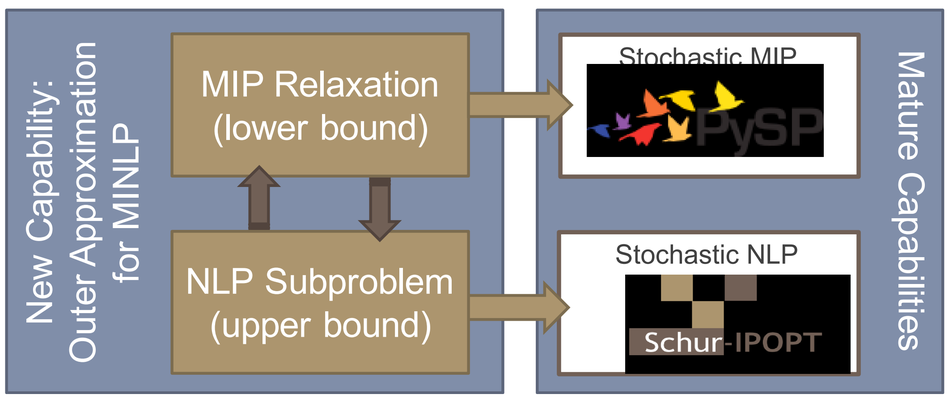
Optimal strategies for hardening and design of monitoring and mitigation systems

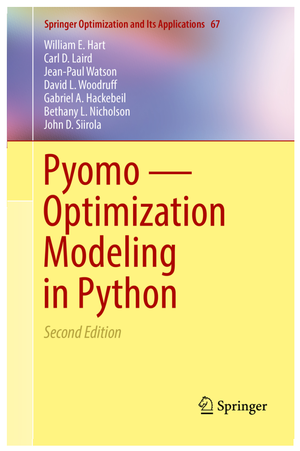
Real-time tools for optimal pre-positioning, response, and recovery

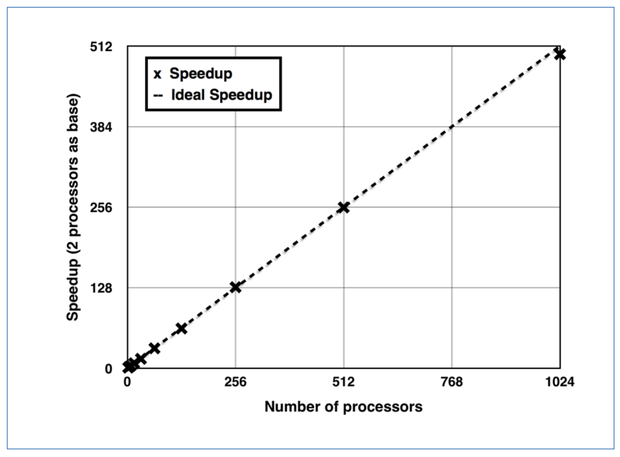
Approach

Characteristics: large-scale, uncertain, **discrete & nonlinear**
Existing Capabilities [1-3]:
- stochastic mixed-integer linear programming (MIP)
- stochastic nonlinear programming (NLP)
- parallel decomposition strategies

New Capabilities:
MINLP-CRIT: mixed-integer nonlinear programming (MINLP)
EGRET: Electrical Grid Research and Engineering Tool

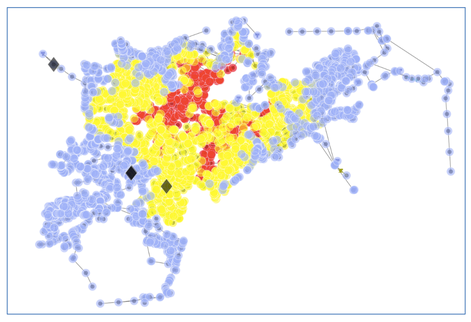


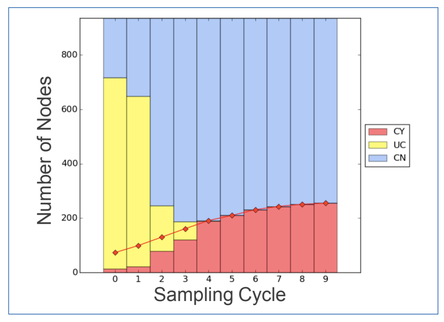




Results

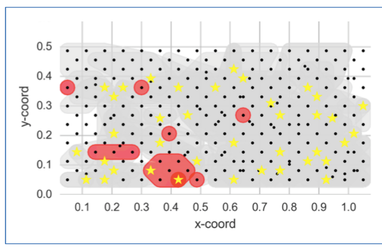
Optimal real-time sampling for plume identification





MINLP strategies to determine optimal sampling locations can be coupled with Bayesian statistics to rapidly resolve plume extent with few sampling cycles [4]

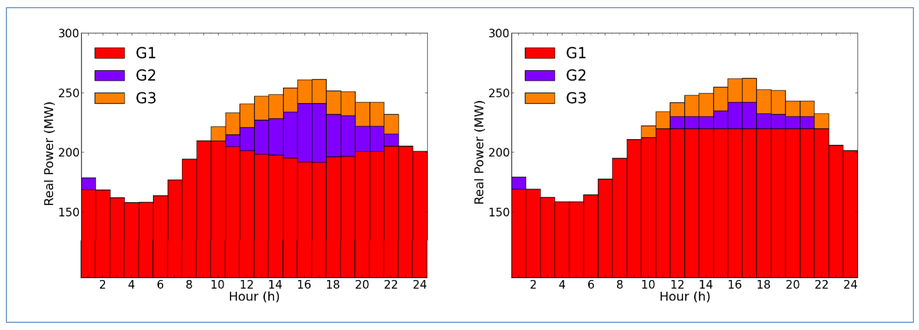
Optimal gas detector placement in offshore facilities



# Sensors	Best Solution	Lower Bound	Gap (%)	CPU Time	Iterations
1	8622.88	8622.88	0	69	1
5	5954.81	5981.49	0	1003	2
10	4354.6	4357.52	0	2306	2
15	3302.06	3303.6	0	2484	2
20	2553.53	2554.22	0	1911	2
25	1894.25	1894.76	0	4128	3
30	1426.55	1426.57	0	4213	3
35	1068.67	1068.12	0.0005	9032	7
40	779.09	778.43	0.0008	7929	4

Tractable solution of detector placement under non-uniform uncertainty outperforms current industrial practice based on standards recommendations

Optimal Unit Commitment with Nonlinear Physics



Optimal unit commitment with rigorous nonlinear physics yields different generator commitment than linearized model (with significant savings)

Significance

Rigorous discrete optimization with high-fidelity physics
- Nonlinear unit commitment problem (IEEE case 118)
  - **Linearized solution infeasible**
  - **Global solution $3.6 M/yr better than local**
- Scalable N-1 Contingency-constrained ACOPF
  - **Optimal solution with reliability guarantee**

Optimal sensor placement and sampling strategies
- Contaminant sampling in water distribution systems
  - **Planned application with US EPA for Flint, MI**
- Optimal gas detector placement in process facilities
  - **Approach outperforms existing practice**
  - **Non-uniform sensor failure probability**

[1[Hart, W.E., Laird, C.D., Watson, J.P., Woodruff, D.L, Hackebeil, G.A., Nicholson, B.L., Siirola, J.D. “Pyomo — Optimization Modeling in Python, 2nd. Ed.”, Springer Optimization and Its Applications, Springer International Publishing AG,

[2] Kang, Jia, Yankai Cao, Daniel P. Word, and Carl D. Laird. "An interior-point method for efficient solution of block-structured NLP problems using an implicit Schur-complement decomposition." Computers & Chemical Engineering 71 (2014): 563-573.

[3] Gade, D., Hackebeil, G., Ryan, S. M., Watson, J. P., Wets, R. J. B., & Woodruff, D. L. (2016). Obtaining lower bounds from the progressive hedging algorithm for stochastic mixed-integer programs. Mathematical Programming, 157(1), 47-67.

[4] Rodriguez, J.S., Bynum, M., Hart, D., Laird, C., Klise, K., and Haxton, T., “Optimal sampling locations to reduce uncertainty in contamination extent in water distribution systems”, Submitted to EPA

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC., a wholly owned subsidiary of Honeywell International, Inc., for the U.S. Department of Energy’s National Nuclear Security Administration under Contract DE-NA0003525.

SAND 2017-xxxP