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Final Report: Data-driven Risk-aware Adversarial Analysis under Uncertainty

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7. PERFORMING ORGANIZATION NAMES AND ADDRESSES

University of Michigan - Ann Arbor
3003 South State Street

Ann Arbor, MI 48109 -1274

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Approved for public release; distribution is unlimited.

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The views, opinions and/or findings contained in this report are those of the author(s) and should not contrued as an official Department of the Army position, policy or decision, unless so designated by other documentation.

14. ABSTRACT

15. SUBJECT TERMS

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a. REPORT	b. ABSTRACT	c. THIS PAGE			Siqian Shen
UU	UU	UU	UU		19b. TELEPHONE NUMBER 734-764-5126

RPPR Final Report
as of 03-Apr-2018

Agency Code:

Proposal Number: 68655NSII **Agreement Number: W911NF-17-1-0102**
INVESTIGATOR(S):

Name: Siqian May Shen
Email: siqian@umich.edu
Phone Number: 7347645126
Principal: Y

Organization: **University of Michigan - Ann Arbor**
Address: 3003 South State Street, Ann Arbor, MI 481091274
Country: USA
DUNS Number: 073133571 EIN: 386006309
Report Date: 07-Feb-2018 Date Received: 02-Feb-2018
Final Report for Period Beginning 08-Feb-2017 and Ending 07-Nov-2017
Title: Data-driven Risk-aware Adversarial Analysis under Uncertainty
Begin Performance Period: 08-Feb-2017 **End Performance Period:** 07-Nov-2017
Report Term: 0-Other
Submitted By: Siqian Shen Email: siqian@umich.edu
Phone: (734) 764-5126
Distribution Statement: 1-Approved for public release; distribution is unlimited.

STEM Degrees: 0 **STEM Participants:** 3

Major Goals: MAJOR GOALS:
Goal 1. Model sequential two-person games for specific network interdiction problems with risk-averse objectives. (Months 1-3)
Goal 2. Extend the models and solution algorithms developed for the network interdiction problems in (1) to stochastic network design problems, formulated also in two stages: The first-stage problem designs a network (arcs and intersection nodes) and the second-stage problem optimizes flow operations on the network. (Months 4-6)
Goal 3. Analyze (distributionally) robust variants of the two-stage models developed in (1) and (2) in which decisions are made under uncertainty or under ambiguously known distribution of uncertain parameters. (Months 1-6)
Goal 4. Develop multi-stage interdiction models and solution approaches following linear decision rules. Apply the models and algorithms to multi-stage power flow optimization under adversarial attacks to demonstrate the results. (Months 7-9)

The actual completion percentages of each activity (goal) are the following:
Goal 1. 100%
Goal 2. 100%.
Goal 3. 100%.
Goal 4. 100%

Accomplishments: 1) Major activities:
We formulate and solve (i) chance-constrained shortest path interdiction problem in which the leader ensures the maximum probability that the follower can travel within a certain time limit from source to destination is minimized; (ii) chance-constrained maximum flow interdiction with a similar probabilistic setting as in (i); (iii) distributionally robust network design problem under random capacities, arc cost, or arc availability; (iv) distributionally robust chance-constrained optimal power flow problem with multiple stages of decisions and uncertainties.

2) Specific objectives:
We compare results of the shortest path interdiction and maximum flow interdiction models with the ones obtained by using standard stochastic programs to show solution sensitivity to different risk preferences of players. We compare the results of standard stochastic programming approaches with the ones of distributionally robust models to show the importance of considering ill data and unknown distributions in network optimization context. We also compare two-stage and multi-stage robust power flow solutions under uncertain generation and loads.

3) Significant results: Solutions given by standard stochastic programming approaches could perform badly when following mistaken risk preferences of players. When we assume unknown preferences and use distributionally robust approaches, the solutions are more robust. The computation of multi-stage distributionally robust optimization models is highly complex and has the curse-of-dimensionality issue. We develop adaptive linear models to approximate the results and overcome computational barriers in network flow problems in power grids.

4) Key outcomes and other achievements.
We have published in the following journal papers:
1. Hideaki Nakao, Siqian Shen, Zhihao Chen, "Network design in scarce data environments using moment-based distributionally robust optimization," Computers & Operations Research, 88(1), 44-57, 2017.
2. Siqian Shen, Mingdi You, Yintai Ma, "Single-commodity stochastic network design under demand and topological uncertainties with insufficient data," Naval Research Logistics, 64(2), 154-173, 2017.
3. Xiao Lei, Siqian Shen, Yongjia Song, “Stochastic maximum flow interdiction problems under heterogeneous risk references,” Computers & Operations Research, 90(1), 97-109, 2018.

We have also published the following conference proceeding papers:
1. Yu, M., Nagarajan, V., Shen, S., “Minimum Makespan Vehicle Routing Problem with Compatibility Constraints.” In International Conference on AI and OR Techniques in Constraint Programming for Combinatorial Optimization Problems (CPAIOR), pages 244-253. Springer, Cham, 2017.

Training Opportunities: We have trained one PhD student as a Graduate Student Research Assistant (GSRA) from March to July. Two more PhD students work on the project in Summer 2017. The students have attended the 2017 Mixed-Integer Programming (MIP) workshop and the 2017 INFORMS Transportation Science Conference to disseminate their work. The students also published two papers in top Computer Science and Energy Optimization conferences, i.e., CPAIOR and PowerTech, respectively and disseminated our results there. In Fall 2017, the funded students attended INFORMS Annual Meeting in Houston to further present our work and discussed them with other researchers.

Results Dissemination: We have published or submitted three journal papers listed as follows.
1. Hideaki Nakao, Siqian Shen, Zhihao Chen, "Network design in scarce data environments using moment-based distributionally robust optimization," Computers & Operations Research, 88(1), 44-57, 2017.
2. Siqian Shen, Mingdi You, Yintai Ma, "Single-commodity stochastic network design under demand and topological uncertainties with insufficient data," Naval Research Logistics, 64(2), 154-173, 2017.
3. Xiao Lei, Siqian Shen, Yongjia Song, “Stochastic maximum flow interdiction problems under heterogeneous risk references,” Computers & Operations Research, 90(1), 97-109, 2018.

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Outreach activities: We are currently designing an Excel macro-based multiplayer-game designed for high school age students (Grades 9-12) to learn network design and interdiction problems in power system optimization. The PI also incorporates models and algorithms for risk-averse network interdiction and network design problems into courses she teaches at UM at all undergraduate (IOE 310), master (IOE 510), and PhD (IOE 612) levels.

Honors and Awards: PI Siqian Shen:
2017 Department of Energy Early Career Award.

Protocol Activity Status:

Technology Transfer: Nothing to Report

PARTICIPANTS:

Participant Type: PD/PI
Participant: Siqian Shen
Person Months Worked: 1.00 **Funding Support:**

Project Contribution:
International Collaboration:
International Travel:
National Academy Member: N
Other Collaborators:

Participant Type: Graduate Student (research assistant)
Participant: Miao Yu
Person Months Worked: 5.00 **Funding Support:**
Project Contribution:
International Collaboration:
International Travel:
National Academy Member: N
Other Collaborators:

Participant Type: Graduate Student (research assistant)
Participant: Hideaki Nakao
Person Months Worked: 3.00 **Funding Support:**
Project Contribution:
International Collaboration:
International Travel:
National Academy Member: N
Other Collaborators:

Participant Type: Graduate Student (research assistant)
Participant: Yiling Zhang
Person Months Worked: 1.00 **Funding Support:**
Project Contribution:
International Collaboration:
International Travel:
National Academy Member: N
Other Collaborators:

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Publication Identifier Type: DOI Publication Identifier: 10.1016/j.cor.2017.07.002
Volume: 88 Issue: First Page #: 44
Date Submitted: 8/12/17 12:00AM Date Published: 12/1/17 10:00AM
Publication Location:
Article Title: Network design in scarce data environment using moment-based distributionally robust optimization
Authors: Hideaki Nakao, Siqian Shen, Zhihao Chen
Keywords: Stochastic/robust network design; Distributionally robust optimization; Mixed-integer linear programming; Polynomial linearization; Cutting-plane algorithm
Abstract: We consider a network design problem (NDP) under random demand with unknown distribution for which only a small number of observations are known. We design arc capacities in the first stage and optimize single-commodity network flows after realizing the demand in the second stage. The objective is to minimize the total cost of allocating arc capacities, flowing commodities, and penalty for unmet demand. We formulate a distributionally robust NDP (DR-NDP) by constructing an ambiguity set of the unknown demand distribution based on marginal moment information, to minimize the worst-case total cost over all possible distributions. Approximating polynomials with piecewise-linear functions, we reformulate DR-NDP as a mixed-integer linear program optimized via a cutting-plane algorithm. We test diverse network instances to compare DR-NDP with a stochastic programming approach, a deterministic benchmark model, and a robust NDP formulation.
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Acknowledged Federal Support: **Y**

Publication Type: Journal Article Peer Reviewed: Y **Publication Status:** 1-Published
Journal: Naval Research Logistics (NRL)
Publication Identifier Type: DOI Publication Identifier: 10.1002/nav.21739
Volume: 64 Issue: 2 First Page #: 154
Date Submitted: 8/12/17 12:00AM Date Published: 3/1/17 10:00AM
Publication Location:
Article Title: Single-commodity stochastic network design under demand and topological uncertainties with insufficient data
Authors: Siqian Shen, Mingdi You, Yintai Ma
Keywords: two-stage stochastic optimization; robust optimization; mixed-integer linear programming (MILP); linearization techniques; cutting-plane algorithms; valid inequalities
Abstract: In this article, we design arcs in a network to optimize the cost of single-commodity flows under random demand and arc disruptions. We minimize the network design cost plus cost associated with network performance under uncertainty evaluated by two schemes. The first scheme restricts demand and arc capacities in budgeted uncertainty sets and minimizes the worst-case cost of supply generation and network flows for any possible realizations. The second scheme generates a finite set of samples from statistical information (e.g., moments) of data and minimizes the expected cost of supplies and flows, for which we bound the worst-case cost using budgeted uncertainty sets. We develop cutting-plane algorithms for solving the mixed-integer nonlinear programming reformulations of the problem under the two schemes. We compare the computational efficacy of different approaches and analyze the results by testing diverse instances of random and real-world networks.
Distribution Statement: 1-Approved for public release; distribution is unlimited.
Acknowledged Federal Support: **Y**

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Publication Type: Journal Article Peer Reviewed: Y **Publication Status:** 1-Published
Journal: Computers & Operations Research
Publication Identifier Type: DOI Publication Identifier: 10.1016/j.cor.2017.09.004
Volume: 90 Issue: First Page #: 97
Date Submitted: 2/2/18 12:00AM Date Published:
Publication Location:
Article Title: Stochastic Maximum Flow Interdiction Problems under Heterogeneous Risk Preferences
Authors: Xiao Lei, Siqian Shen, Yongjia Song
Keywords: maximum flow interdiction; stochastic programming; Conditional Value-at-Risk (CVaR); risk-averse optimization; mixed-integer linear programming
Abstract: We consider a generic maximum flow interdiction problem that involves a leader and a follower who take actions in sequence. Given an interdiction budget, the leader destroys a subset of arcs to minimize the follower's maximum flows from a source to a sink node. The effect from an interdiction action taken on each arc is random, following a given success rate of decreasing the arc's capacity to zero. The follower can add additional arc capacities for mitigating flow losses, after knowing the leader's interdiction plan but before realizing the uncertainty. We consider risk-neutral and risk-averse behaviors of the two players and investigate five bi-level/tri-level programming models for different risk-preference combinations. The models incorporate the expectation, left-tail, and right-tail Conditional Value-at-Risk (CVaR) as commonly used convex risk measures for evaluating random maximum flows in the leader's and follower's objectives.
Distribution Statement: 1-Approved for public release; distribution is unlimited.
Acknowledged Federal Support: **Y**

CONFERENCE PAPERS:

Publication Type: Conference Paper or Presentation **Publication Status:** 1-Published
Conference Name: International Conference on AI and OR Techniques in Constraint Programming for Combinatorial Optimization Problems (CPAIOR)
Date Received: 02-Feb-2018 Conference Date: 28-Jun-2017 Date Published:
Conference Location: Padova, Italy
Paper Title: Minimum Makespan Vehicle Routing Problem with Compatibility Constraints
Authors: Miao Yu, Viswanath Nagarajan, Siqian Shen
Acknowledged Federal Support: **Y**

Nothing to report in the uploaded pdf (see accomplishments).