

REPORT DOCUMENTATION PAGE			Form Approved OMB NO. 0704-0188		
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1. REPORT DATE (DD-MM-YYYY) 22-04-2020		2. REPORT TYPE Final Report		3. DATES COVERED (From - To) 5-Jun-2015 - 31-Dec-2019	
4. TITLE AND SUBTITLE Final Report: L1 - Based Major Component Detection and Analysis (L1 MCDA) for n-Dimensional Data Clouds Based on Linear Conic Programming			5a. CONTRACT NUMBER W911NF-15-1-0223		
			5b. GRANT NUMBER		
			5c. PROGRAM ELEMENT NUMBER 611102		
6. AUTHORS			5d. PROJECT NUMBER		
			5e. TASK NUMBER		
			5f. WORK UNIT NUMBER		
7. PERFORMING ORGANIZATION NAMES AND ADDRESSES North Carolina State University 2701 Sullivan Drive Admin Srvcs III, Box 7514 Raleigh, NC 27695 -7514			8. PERFORMING ORGANIZATION REPORT NUMBER		
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS (ES) U.S. Army Research Office P.O. Box 12211 Research Triangle Park, NC 27709-2211			10. SPONSOR/MONITOR'S ACRONYM(S) ARO		
			11. SPONSOR/MONITOR'S REPORT NUMBER(S) 67395-MA.66		
12. DISTRIBUTION AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.					
13. SUPPLEMENTARY NOTES The views, opinions and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy or decision, unless so designated by other documentation.					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:		17. LIMITATION OF ABSTRACT		15. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT UU	b. ABSTRACT UU	c. THIS PAGE UU	UU		Shu-Cherng Fang
					19b. TELEPHONE NUMBER 919-515-2192

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as of 24-Apr-2020

Agency Code:

Proposal Number: 67395MA

Agreement Number: W911NF-15-1-0223

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DUNS Number: 042092122

EIN: 566000756

Report Date: 31-Mar-2020

Date Received: 22-Apr-2020

Final Report for Period Beginning 05-Jun-2015 and Ending 31-Dec-2019

Title: L1 - Based Major Component Detection and Analysis (L1 MCDA) for n-Dimensional Data Clouds Based on Linear Conic Programming

Begin Performance Period: 05-Jun-2015

End Performance Period: 31-Dec-2019

Report Term: 0-Other

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Distribution Statement: 1-Approved for public release; distribution is unlimited.

STEM Degrees: 4

STEM Participants: 4

Major Goals: The objective of this research is to establish new theory and efficient algorithms for identifying the major component(s) of statistically distributed data clouds in n-dimensional Euclidean space. Principal Component Analysis (PCA) is a method widely used for identifying the spread of data in mutually orthogonal directions. Conventional PCA is based on the l_2 norm and Gaussian statistics and has excellent performance as long as there are no or extremely few outliers in the data. However, data clouds obtained under any conditions other than benign laboratory conditions often contain significant numbers of outliers (i.e., the error is mostly from a heavy-tailed distribution) which strongly limits the accuracy of PCA. To remedy this situation, "robust PCAs" that involve the l_1 norm have been proposed over the past few years. In most of the l_1 reformulations of PCA that have been proposed, l_2 -based steps (inner products, averages, singular values) and Gaussian-based concepts (averages, variances and covariances) are retained and use of the l_1 norm is limited. A 2D/3D l_1 -based Major Component Detection and Analysis (l_1 MCDA) method that does not use any of the conventional l_2 or Gaussian steps or concepts has recently been developed and tested by the PI and his research group. The computational experiments support the superiority of l_1 MCDA in detecting and analyzing the major components embedded in statistically distributed data clouds. The effectiveness of l_1 MCDA for handling higher dimensional data clouds hinges upon the computation speed of solving some l_1 norm constrained nonlinear optimization problems. It has recently been shown that a nonlinear l_1 -norm constrained optimization problem can be converted into a linear optimization problem over an l_1 -norm based first-order cone, but, the resulting problem may become intractable (NP-hard) in theory. The proposed research intends to uncover new theory and solution/approximation methods of linear conic programming to develop l_1 MCDA for higher dimensional data clouds that has all key operations in l_1 and direct connection with heavy-tailed statistics.

Based on the 2D/3D l_1 MCDA that has been developed, we propose to develop a computationally efficient n-dimensional l_1 MCDA by incorporating linear conic programming theory and methods. The n-D l_1 MCDA that we propose will come, just as was the case for the 2D/3D l_1 MCDA, exclusively from a unified theoretical framework based on heavy-tailed distributions and the l_1 norm. Preliminary work that has already been carried out indicates that the overall framework for the 3D case can be extended to n-D. In addition, while our treatment of 2D/3D l_1 MCDA assumed symmetry of the distribution around the central point, we wish to create an n-D l_1 MCDA that does not assume such symmetry. Here we describe the overall approach for the n-D work and provide information about potential changes. As that in the 2D/3D l_1 MCDA, the n-D l_1 MCDA will include the following three major steps:

1. Calculate the central point of data cloud and subtract it out of the data.
2. Calculate the major directions of density and/or radial extension of the point cloud that results from Step 1.

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3. Calculate the radial spread of the point cloud in various directions where the radial spread is maximal. However, new methods of calculating the central point and identifying the major directions of density, radial extension and spread of the point cloud will differ from the 2D/3D I1 MCDA in the following four ways:
 1. Symmetry of the distribution around a point will not be assumed. This requires revision of the procedure for calculating the central point.
 2. The local-quadratic-fit procedure used for calculating the local maximum of the median radius in the 2D case will be changed to a local-median-fit procedure for the n-D case.
 3. The procedure for calculating the local maxima of a quantity will be extended to calculate not only the local maxima but also the local minima and saddle points.
 4. New optimization models and solution techniques of linear conic programming will be developed for handling I1-based problems occurring in the project.

The proposed research is divided into four major tasks:

Task 1 – efficient calculation of central point in Step 1 of the n-D I1 MCDA,

Task 2 – fast calculation of characteristics of radial extension in Step 2 of the n-D I1 MCDA,

Task 3 - conduction of computational experiments of the n-D I1 MCDA for higher dimensional data clouds,

Task 4 - exploration of the theory and methods of linear conic programming for developing computationally efficient n-D I1 MCDA.

An add-on project was awarded in June 2017 for two years. The goal is to explore new metrics for measuring commonly faced social and political phenomena.

Add-on Task - investigation of sub-one norm metrics for studying social and political phenomena in social networks.

This research will be carried out at North Carolina State University (NCSU). Related computing hardware and software at PI's laboratories will be available to support the proposed research. The detailed schedule for conducting this research is shown below:

Task 1: (n-D I1 MCDA Step 1) Computation of Central Point, 3rd Quarter of 2015 to 2nd Quarter of 2016.

Task 2: (n-D I1 MCDA Step 2) Calculation of Characteristics of Radial Extension, 2nd Quarter of 2016 to 1st Quarter of 2017.2

Task 3: (n-D I1 MCDA) Computational Experiments in Higher Dimensions, 1st Quarter of 2017 to 4th Quarter of 2017.

Task 4: (n-D I1 MCDA) Linear conic programming based models and computational methods, 2nd Quarter of 2017 to 2nd Quarter of 2018.

Add-on Task: (sub-one norm metrics) Investigation of sub-one norm metrics for social and political phenomena, 3rd Quarter of 2017 to 3rd Quarter of 2019.

The whole project ends by December 31, 2019.

Accomplishments: The objective of this research is to establish new theory and efficient algorithms for identifying the major component(s) of statistically distributed data clouds in the n-dimensional Euclidean space.

The proposed research is originally divided into four major tasks:

Task 1 – Efficient calculation of the “central point” of any given data cloud for the design and development of the proposed n-D I1 MCDA technology,

Task 2 – Fast calculation of the characteristics of radial extensions of the proposed n-D I1 MCDA,

Task 3 - Conduction of computational experiments of the proposed n-D I1 MCDA for higher dimensional data clouds, and

Task 4 - Exploration of the theory and methods of linear conic programming for developing computationally efficient methods for n-D I1 MCDA.

One additional add-on research was granted as below.

Add-on Task - Investigation of the sub-one l_p “norm metrics” for studying social and political phenomena in social networks.

In the period of May 1, 2015 – December 31, 2019, PI and his team have successfully completed all tasks with concrete research results reported. We highlight some major accomplishments of each task below.

(Task #1)

This task is to find an effective and efficient calculation of the “central point” of a given data cloud in order to design the proposed n-dimensional I1 MCDA.

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A brand new idea of defining and finding the “central point” of a given data cloud from a heavy-tailed distribution, without assuming that the data points are symmetrically positioned around the origin, has been successfully developed. The results have been documented and published as a journal article entitled “l1-norm Based Central Point Analysis for Asymmetric Radial Data,” which appeared in *Annals of Data Science*, 5(2018), 469-486 <doi.org/10.1007/s40745-018-0147-2>. (Uploaded to System as Manuscript #1)

(Tasks #2 and #3)

Task 2 is to study and develop fast computations of the data spread information along radial extensions. Task 3 is to integrate the findings of Tasks 1 and 2 to build the proposed n-D l1 MCDA and to conduct computational experiments for higher dimensional data clouds

1. To find the radial extension and spread along a principal direction, we have investigated and designed algorithms for solving a quadratic function subject to l1-norm based constraints with discrete variables. Generalized results have been documented and published as a journal article entitled “Enhanced Linear Reformulation for Engineering Optimization Models with Discrete and Bounded Continuous Variables,” which appeared in the *Journal of Applied Mathematical Modeling*, 58(2018), 140-157 <doi: 10.1016/j.apm.2017.09.047>. (Uploaded to System as Manuscript #2)

2. A new “n-D algorithm for calculating local maximum of the median radius” has been integrated with the previously developed “Algorithm for calculating central point” to form the main body of the proposed “n-D l1 MCDA.” Computational experiments have been conducted to examine and characterize the performance of the proposed l1MCDA. Research results have been documented and published as a journal article entitled “L1-norm based Major Component Detection and Analysis for Asymmetric Radial Data,” which appeared in the *International Journal of Operations Research*, 15(2018), 89-100. (Uploaded to System as Manuscript #3)

(Task #4)

Task 4 is to investigate new models and solution technologies for conic optimization with discrete variables in support of Tasks 1, 2 and 3 for fast computations.

1. PI and his research team have developed a new structural linear reformulation for binary quadratically constrained quadratic programs. Compared to state-of-the-art methods, the proposed linear reformulation supports much more efficient computations. Research results have been documented and published as a journal article entitled “Structured Linear Reformulation of Binary Quadratically Constrained Quadratic Programs,” which appeared in *Optimization Letter*, 14 (2020), 611-636 <doi.org/10.1007/s11590-018-1361-8>. (Uploaded to System as Manuscript #4)

2. In addition, a commonly faced challenge for effectively solving a quadratically constrained quadratic programming problem occurred in Tasks 1, 2, and 3 is to adopt a conic relaxation of a trust-region subproblem. However, how to recover a solution to the original problem from an SOC-SDP conic relaxation remains to be an open problem. Team members have seriously studied this problem. Some research results have been documented and published as a journal article entitled “Recovering Optimal Solutions via SOC-SDP Relaxation of Trust Region Sub-problem with Non-intersecting Linear Constraints,” which appeared in the *Journal of Industrial and Management Optimization*, 15(2019), 1677-1699. <doi: 10.3934/jimo.2018117>. (Uploaded to System as Manuscript #5)

(Add-on Task)

The add-on research task has two subtasks: (1) extension of current project to a thorough investigation of various properties of L1 and l1 metrics for measuring social or political phenomena; and (2) study of Lp and lp “metrics”, $0 < p < 1$, for measuring social or political phenomena of a social network.

1. For this task, mathematical analysis shows that losing convexity is the vital difficulty involved in sub-one “norm metrics” based optimization models. In this period, our team began with the study of “sub-one quasi-norm” optimization problem with linear constraints. A new concept of “Scaled K. K. T. Conditions” has been proposed by the team for designing efficient solution methods. A brand new algorithm that outperforms all known methods in the literature for solving linearly constrained lp minimization problem have been documented in the manuscript titled “A Gradient Descent Based Algorithm for lp Minimization,” which appeared in the *European Journal of Operational Research*, Vol 283(2020), pp 47-56. (Uploaded to System as Manuscript #6)

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2. Team members have also investigated the prevailing business practice of using “recommender systems” to promote potential Internet on-line sales. We have successfully developed a “sub-one similarity measure” for the mechanism of “collaborative filtering” used in current recommender systems for recommending new products to potential new customers. This could be the first study that links “sub-one norm metrics” to a social network application. Results have been documented in a manuscript titled “A Sub-one Similarity Measure for Collaborative Filtering Recommendation,” which appeared in the Journal of Information Sciences, Vol 487(2019), pp142-155, <doi.org/10.1016/j.ejor.2019.11.051>. (Uploaded to System as Manuscript #7)

3. We have also investigated the potential of using the proposed “sub-one quasi-norm” for sparse signal recovering in data reconstruction and major factor identification in cancer analysis. Results are very encouraging - the “sub-one quasi-norm model” pretty much outperforms all known methods for identifying sparse solutions. Results have been documented in a manuscript titled “Sparse Solutions by a Quadratically Constrained l_p Minimization Model.” This work has been submitted to INFORMS Journal of Computing. Its second revision is now under review. (Uploaded to System as Manuscript #8)
(Other research and publications)

The PI and STEM students have also worked with non-project collaborators on the research front to publish additional journal articles relating l_1 splines, linear conical optimization, machine learning and social behavioral operations management. All of joint works have Project W911NF-15-1-0223 acknowledged.

A total of thirty three (33) publications have been uploaded onto the system.

In addition, a total of 4 female STEM PhD students have been working on the project. Among them, 3 have received PhD degrees in Industrial and Systems Engineering and 1 passed her PhD Preliminary Exam as of December 31, 2019. PI and students have delivered 9 public speeches in domestic and international conferences.

Training Opportunities: Although this project is not set up for general training, the new theory and solution methods investigated in this project have been nicely incorporated to classroom teaching of several graduate level courses taught by the PI at NC State University.

The project has also provided an opportunity to motivate and recruit young researchers engaging research in the field. A total of 4 female STEM graduate students have gone through the doctoral training process:

1. Ms. Tiantian Nie received her PhD degree in Industrial and Systems Engineering in December 2016. She then became Assistant Professor of Systems Engineering in the University of North Carolina at Charlotte.
2. Ms. Qi An received her Master degree in December 2015, PhD degree in Industrial and Systems Engineering in May 2019. Then she joined American Express in NYC.
3. Ms. Shan Jiang received her Master degree in December 2016, PhD degree in Industrial and Systems Engineering in December 2019. Then she became Assistant Professor of Management in Xiamen University, China.
4. Ms. Chi-Yi Chen received her Master degree in May 2017 and passed her PhD Preliminary Exam in Industrial and Systems Engineering in December 2019. She expects to receive her PhD degree in December 2020.

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Results Dissemination: A total of 33 peer reviewed journal articles have been published. Additional 3 journal articles are under current review.

A. Published Journal Articles (Project W911NF-15-1-0223 acknowledged) (sequenced by the year of publication, *marked authors worked on the project)

1. Z. Wang, S.-C. Fang*, J. E. Lavery*: On shape-preserving capability of cubic \mathbb{P}^1 spline fits, *Computer Aided Geometric Design*, 40 (2015), 59-75, doi: 10.1016/j.cagd.2015.09.004.
2. Z. Deng, S.-C. Fang*, Q. Jin, C. Lu: Conic approximation to nonconvex quadratic programming with convex quadratic constraints, *Journal of Global Optimization*, 61 (2015), 459-478, doi: 10.1007/S10898-014-0195-x.
3. T. Nie*, S.-C. Fang*, Z. Deng, J. E. Lavery*: On linear conic relaxation of discrete quadratic programs, *Optimization Methods and Software*, 31 (2016), 737-754, doi: 10.1080/10556788.2015.1134528.
4. Y. Tian, S.-C. Fang*, Z. Deng, Q. Jin: Cardinality constrained portfolio selection problem: a completely positive programming approach, *Journal of Industrial and Management Optimization*, 12(2016), 1041-1056, doi: 10.3934/jimo.2016.12.1041.
5. H.-L. Li, S.-C. Fang*, Y.-H. Huang and T. Nie, An Enhanced Logarithmic Method for Solving Signomial Programming Problems with Discrete Variables, *European Journal of Operational Research*, 255(2016), 922-934, doi: 10.1016/j.ejor.2016.05.063.
6. J. Luo, S.-C. Fang*, Z. Deng and X. Guo, Soft Quadratic Surface Vector Machine for Binary Classification, *Asia Pacific Journal of Operations Research*, 33(2016), 22-, doi: 10.1142/S0217595916500469.
7. T. Nie*, Z. Wang, S.-C. Fang* and J. E. Lavery*, Convex Shape Preservation of Cubic L1 Spline Fits, *Annals of Data Science*, 4 (2017), 123-147, doi: 10.1007/s40745-016-0099-3.
8. L. Gajny*, O. Gibaru, E. Nyiri and S.-C. Fang*, Best L1 Approximation of Heaviside- type functions in Chebyshev and Weak-Chebyshev Spaces, *Numerical Algorithms*, 75(2017), 827-843, doi: 10.1007/s11075-016-0222-8.
9. H.-L. Li, S.-C. Fang* and Y.-H. Huang, Linear Reformulation of Polynomial Discrete Programming for Fast Computation, *INFORMS Journal of Computing*, 29(2017), 108-122, doi: 10.1287/ijoc.2016.0716.
10. J. Zhou, S.-C. Fang* and W. Xing, Conic Approximation to Quadratic Optimization with Linear Complementarity Constraints, *Computational Optimization and Applications*, 66 (2017), 97-122. doi:10.1007/s10589-016-9855-8.
11. J. Zhang, S.-C. Fang*, Y. Xu and Z. Wang, A Cooperative Game with Envy, *Journal of Industrial and Management Optimization*, 13(2017), 2049-2066. doi: 10.3934/jimo.2017031.
12. Q. An*, S.-C. Fang*, T. Nie* and S. Jiang*, l_1 -norm Based Central Point Analysis for Asymmetric Radial Data, *Annals of Data Science*, 5(2018), 469-486. doi.org/10.1007/s40745-018-0147-2.
13. Q. An*, S.-C. Fang*, H.-L. Li, and T. Nie*, Enhanced Linear Reformulation for Engineering Optimization Models with Discrete and Bounded Continuous Variables, *Journal of Applied Mathematical Modeling*, 58(2018), 140-157. doi: 10.1016/j.apm.2017.09.047.
14. X. Qian, S.-C. Fang*, M. Huang, Q. An* and X. Wang, Reverse Auctions with Regret-anticipated Bidders, *Annals of Operations Research*, 268(2018), 293-313. doi: 10.1007/s10479-017-2475-6.
15. J. Luo, T. Hong and S.-C. Fang*, Benchmarking Robustness of Load Forecasting Models under Data Integrity Attacks, *International Journal of Forecasting*, 34(2018), 89-104. doi: 10.1016/j.ijforecast.2017.08.004.
16. C. Lu, Z. Deng, W. Zhang and S.-C. Fang*, Argument Division Based Branch-and-Bound Algorithm for Unimodulus Constrained Complex Quadratic Programming, *Journal of Global Optimization*, 70(2018), 171-187. doi: 10.1007/s10898-017-0551-8.

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17. Z. Deng, S.-C. Fang*, C. Lu and X. Guo, A Branch-and-Cut Algorithm Using Polar Cuts for Solving Nonconvex Quadratic Programming Problems, *Optimization*, 67(2018), 359-375. doi: 10.1080/02331934.2017.1391253.
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21. M. Adivar and S.-C. Fang*, Convex Analysis and Duality over Discrete Domains, *Journal of Operations Research Society of China*, 6(2018), 189-247. doi: 10.1007/s40305-017-0158-2.
22. X. Yan, Y. Bai, S.-C. Fang* and J. Luo, A Proximal Quadratic Surface Support Vector Machine for Semi-supervised Binary Classification, *Soft Computing*, 22(2018), 6905-6919. doi:10.1007/s00500-017-2751-z.
23. Q. An*, S.-C. Fang*, S. Jiang* and J.E. Lavery*, L1-norm based Major Component Detection and Analysis for Asymmetric Radial Data, *International Journal of Operations Research*, 15(2018), 89-100.
24. S. Jiang*, S.-C. Fang*, Q. An* and J.E. Lavery*, A Sub-one Quasi-norm-based Similarity Measure for Collaborative Filtering in Recommendation Systems, *Information Sciences*, 487(2019), 142-155. doi: 10.1016/j.ins.2019.03.011.
25. J. Dai, S.-C. Fang* and W. Xing, Recovering Optimal Solutions via SOC-SDP Relaxation of Trust Region Subproblem with Nonintersecting Linear Constraints, *Journal of Industrial and Management Optimization*, 15 (2019), 1677-1699. doi: 10.3934/jimo.2018117.
26. X. Qian, S.-C. Fang*, M. Huang and X. Wang, Winner Determination of Loss-averse Buyers with Incomplete Information in Multi-attribute Reverse Auctions for Clean Energy Device Procurement, *Energy*, 177(2019), 276-292. doi.org/10.1016/j.energy.2019.04.072.
27. X. Qian, S.-C. Fang, M. Huang, T. Nie and X. Wang, Bidding Decisions with None-equilibrium Strategic Thinking in Reverse Auctions, *Group Decision and Negotiation*, 28(2019), 757-786, doi.org/10.1007/s10726-019-09624-7.
28. C. Lu, Z. Deng, S.-C. Fang*, Q. Jin and W. Xing, Fast Computation of Global Solutions to the Single-Period Unit Commitment Problem, *Journal of Combinatorial Optimization*, Nov. 2019. doi.org/10.1007/s10878-019-00489-9.
29. J. Luo, T. Hong and S.-C. Fang*, Robust Regression Models for Load Forecasting, *IEEE Transactions on Smart Grid*, 5(2019), 5397-5404. doi.org/10.1109/TSG.2018.2881562.
30. S. Jiang*, S.-C. Fang*, T. Nie* and Q. An*, Structured Linear Reformulation of Binary Quadratically Constrained Quadratic Programs, *Optimization Letter*, 14 (2020), 611-636. doi.org/10.1007/s11590-018-1361-8.
31. S. Jiang*, S.-C. Fang*, T. Nie* and W. Xing, A Gradient Decent Based Algorithm for lp Minimization, *European Journal of Operational Research*, 283 (2020), 47-56. doi.org/10.1016/j.ejor.2019.11.051.
32. X. Li, S.-C. Fang*, Y. H. Huang and Y. Zhang, An Alternative Effective Representation for the Project Portfolio Selection Problem, *European Journal of Operational Research*, 281(2020), 100-113. doi.org/10.1016/j.ejor.2019.08.022.
33. J. Liu, S.-C*. Fang and H. Chen, Multiplicative Data Envelopment Analysis Cross-Efficiency and Stochastic Weight Space Acceptability Analysis for Group Decision Making with Interval Multiplicative Preference Relations, *Information Sciences*, 514(2020), 319-332. doi.org/10.1016/j.ins.2019.11.032.

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B. Under Review Journal Articles (Project W911NF-15-1-0223 acknowledged).

1. S. Jiang*, S.-C. Fang* and Q. Jin, Sparse Solutions by a Quadratically Constrained Ip Minimization Model, submitted to INFORMS Journal of Computing (2nd revision).
2. L. Zhao, J. You and S.-C. Fang*, A dual-channel Supply Chain Problem with Resource-Utilization Penalty, submitted to Journal of Industrial and Management Optimization.
3. Y.-L. Lin, M.-J. Yao, S.-C. Fang* and J.-Y. Lin, An Integrated Algorithm for Solving Multi-Customer Joint Replenishment Problem with Districting Consideration, Transportation Research – Part B.

Honors and Awards: In the period of project duration, the PI has received several honors and awards:

1. Shu-Cherng Fang received the Fellow Award of the Chinese Institute of Industrial Engineers in Taiwan in December, 2015.
2. Shu-Cherng Fang was appointed Academic Adviser for University Strategic Development of the National Chiao Tung University in Taiwan in April, 2017.
3. Shu-Cherng Fang received the Siwei Cheng Award in Quantitative Management by the International Academy of Information Technology and Quantitative Management (IAITQM) on November 5, 2019 in Granada, Spain.
4. Shu-Cherng Fang was selected to join the Academy of Excellence in Global Engagement, North Carolina State University in Fall 2019.

Protocol Activity Status:

Technology Transfer: Nothing to Report

PARTICIPANTS:

Participant Type: PD/PI

Participant: Shu-Cherng Fang

Person Months Worked: 9.00

Project Contribution:

International Collaboration:

International Travel:

National Academy Member: N

Other Collaborators:

Funding Support:

Participant Type: Faculty

Participant: John E Lavery

Person Months Worked: 9.00

Project Contribution:

International Collaboration:

International Travel:

National Academy Member: N

Other Collaborators:

Funding Support:

Participant Type: Graduate Student (research assistant)

Participant: Tiantian Nie

Person Months Worked: 12.00

Project Contribution:

International Collaboration:

International Travel:

Funding Support:

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as of 24-Apr-2020

National Academy Member: N
Other Collaborators:

Participant Type: Graduate Student (research assistant)

Participant: Qi An

Person Months Worked: 12.00

Funding Support:

Project Contribution:

International Collaboration:

International Travel:

National Academy Member: N

Other Collaborators:

Participant Type: Graduate Student (research assistant)

Participant: Shan Jiang

Person Months Worked: 12.00

Funding Support:

Project Contribution:

International Collaboration:

International Travel:

National Academy Member: N

Other Collaborators:

Participant Type: Graduate Student (research assistant)

Participant: Chi-Yi Chen

Person Months Worked: 2.00

Funding Support:

Project Contribution:

International Collaboration:

International Travel:

National Academy Member: N

Other Collaborators:

ARTICLES:

Publication Type: Journal Article

Peer Reviewed: Y

Publication Status: 1-Published

Journal: Optimization Methods and Software

Publication Identifier Type: DOI

Publication Identifier: 10.1080/10556788.2015.1134528

Volume: 31

Issue: 4

First Page #: 737

Date Submitted: 8/18/16 12:00AM

Date Published: 1/1/16 10:00AM

Publication Location:

Article Title: On linear conic relaxation of discrete quadratic programs

Authors: Tiantian Nie, Shu-Cherng Fang, Zhibin Deng, John E. Lavery

Keywords: discrete quadratic program, linear conic relaxation, RLT method,

Abstract: A special reformulation-linearization technique based linear conic relaxation is proposed for discrete quadratic programming (DQP). We show that the proposed relaxation is tighter than the traditional positive semidefinite programming relaxation. More importantly, when the proposed relaxation problem has an optimal solution with rank one or two, optimal solutions to the original DQP problem can be explicitly generated. This rank-two property is further extended to binary quadratic optimization problems and linearly constrained DQP problems. Numerical results indicate that the proposed relaxation is capable of providing high quality and robust lower bounds for DQP.

Distribution Statement: 3-Distribution authorized to U.S. Government Agencies and their contractors

Acknowledged Federal Support: Y

RPPR Final Report as of 24-Apr-2020

Publication Type: Journal Article Peer Reviewed: Y **Publication Status:** 1-Published

Journal: Journal of Global Optimization

Publication Identifier Type: DOI

Publication Identifier: 10.1007/s10898-014-0195-x

Volume: 61

Issue: 3

First Page #: 459

Date Submitted: 8/18/16 12:00AM

Date Published: 5/1/14 8:00AM

Publication Location:

Article Title: Conic approximation to nonconvex quadratic programming with convex quadratic constraints

Authors: Zhibin Deng, Shu-Cherng Fang, Qingwei Jin, Cheng Lu

Keywords: Nonconvex quadratic programming, Adaptive scheme, Cone of nonnegative quadratic functions

Abstract: In this paper, a conic reformulation and approximation is proposed for solving a nonconvex quadratic programming problem subject to several convex quadratic constraints. The original problem is transformed into a linear conic programming problem, which can be approximated by a sequence of linear conic programming problems over the dual cone of the cone of nonnegative quadratic functions. Since the dual cone of the cone of nonnegative quadratic functions has a linear matrix inequality representation, each linear conic programming problem in the sequence can be solved efficiently using the semidefinite programming techniques. In order to speed up the convergence of the approximation sequence and relieve the computational effort in solving the linear conic programming problems, an adaptive scheme is adopted in the proposed algorithm.

Distribution Statement: 3-Distribution authorized to U.S. Government Agencies and their contractors

Acknowledged Federal Support: Y

Publication Type: Journal Article Peer Reviewed: Y **Publication Status:** 1-Published

Journal: Computer Aided Geometric Design

Publication Identifier Type: DOI

Publication Identifier: 10.1016/j.cagd.2015.09.004

Volume: 40

Issue:

First Page #: 59

Date Submitted: 8/17/16 12:00AM

Date Published: 12/1/15 12:00AM

Publication Location:

Article Title: On shape-preserving capability of cubic L1 spline fits

Authors: Ziteng Wang, Shu-Cherng Fang, John E. Lavery

Keywords: L1 spline; Shape preservation; Approximation; Spline fit; Univariate

Abstract: Cubic L1 spline fits have shown some favorable shape-preserving property for geometric data. To quantify the shape-preserving capability, we consider the basic shape of two parallel line segments in a given window. When one line segment is sufficiently longer than the other, the spline fit can preserve its linear shape in at least half of the window. We propose to use the minimum of such length difference as a shape-preserving metric because it represents the extra information that the spline fits need to preserve the shape. We analytically calculate this metric in a 3-node window for second-derivative-based, first-derivative-based and function-value-based spline fits. In a 5-node window, we compute this metric numerically. In both cases, the shape-preserving metric is rather small, which explains the observed strong shape-preserving capability of spline fits. Moreover, the function-value-based spline fits are indicated to preserve shape better than the other two types of spline fits.

Distribution Statement: 3-Distribution authorized to U.S. Government Agencies and their contractors

Acknowledged Federal Support: Y

RPPR Final Report as of 24-Apr-2020

Publication Type: Journal Article Peer Reviewed: Y **Publication Status:** 1-Published

Journal: Journal of Industrial and Management Optimization

Publication Identifier Type: DOI

Publication Identifier: 10.3934/jimo.2016.12.1041

Volume: 12

Issue: 3

First Page #: 1041

Date Submitted: 8/18/16 12:00AM

Date Published: 9/1/15 8:00AM

Publication Location:

Article Title: Cardinality constrained portfolio selection problem: A completely positive programming approach

Authors: Ye Tian, Shucherng Fang, Zhibin Deng, Qingwei Jin

Keywords: . Cardinality constrained portfolio selection problem, completely positive programming, second-order cone, adaptive approximation

Abstract: In this paper, we propose a completely positive programming reformulation of the cardinality constrained portfolio selection problem. By constructing a sequence of computable cones of nonnegative quadratic forms over a union of second-order cones, an ϵ -optimal solution of the original problem can be found in finite iterations using semidefinite programming techniques. In order to obtain a good lower bound efficiently, an adaptive scheme is adopted in our approximation algorithm. The numerical results show that the proposed algorithm can find better approximate and feasible solutions than other known methods in the literature.

Distribution Statement: 3-Distribution authorized to U.S. Government Agencies and their contractors

Acknowledged Federal Support: Y

Publication Type: Journal Article Peer Reviewed: Y **Publication Status:** 1-Published

Journal: INFORMS Journal of Computing

Publication Identifier Type:

Publication Identifier:

Volume:

Issue:

First Page #:

Date Submitted: 8/21/16 12:00AM

Date Published: 8/19/16 2:49AM

Publication Location:

Article Title: Linear reformulation of polynomial discrete programming for fast computation

Authors: Han-Lin Li, Yao-Huei Huang, Shu-Cherng Fang

Keywords: polynomial discrete program, mixed-integer linear program, linearization equation, branch-and-bound

Abstract: Polynomial discrete programming problems are commonly faced, but hard to solve. Treating the non-convex cross-product terms is the key. State-of-the-art methods usually convert such a problem into a 0-1 mixed-integer linear programming problem, and, then, adopt the branch-and-bound scheme to find an optimal solution. Much effort has been spent on reducing the required numbers of variables and linear constraints as well as on avoiding unbalanced branch-and-bound trees. This study presents a set of equations that linearize the discrete cross-product terms in an extremely effective manner. It is shown that embedding the proposed "Equations for Linearizing Discrete Products" (ELDP) into those state-of-the-art methods in the literature not only significantly reduces the required number of linear constraints for a cubic polynomial discrete program with n variables in h possible values, but also tighten these methods with much more balanced branch-and-bound trees.

Distribution Statement: 3-Distribution authorized to U.S. Government Agencies and their contractors

Acknowledged Federal Support: Y

RPPR Final Report
as of 24-Apr-2020

Publication Type: Journal Article Peer Reviewed: Y **Publication Status:** 1-Published
Journal: European Journal of Operational Research
Publication Identifier Type: DOI Publication Identifier: 10.1016/j.ejor.2016.05.063
Volume: Issue: First Page #:
Date Submitted: 8/18/16 12:00AM Date Published: 8/18/16 6:55PM
Publication Location:

Article Title: An enhanced logarithmic method for signomial programming problems with discrete variables

Authors: Han-Lin Li, Shu-Cherng Fang, Yao-Huei Huang, Tiantian Nie

Keywords: signomial programming; mixed 0-1 linear programming; linearization technique

Abstract: Signomial programming problems with discrete variables (SPD) appear widely in real-life applications, but they are hard to solve. This paper proposes an enhanced logarithmic method to reformulate the SPD problem as a mixed integer 0-1 linear program (MILP) with a minimum number of binary variables and inequality constraints. Both of the theoretical analysis and numerical results strongly support its superior performance to other state-of-the-art linearization methods. We also extend the proposed method to linearize some more complicated problems involving product and fractional terms in discrete and continuous variables.

Distribution Statement: 3-Distribution authorized to U.S. Government Agencies and their contractors

Acknowledged Federal Support: Y

Publication Type: Journal Article Peer Reviewed: Y **Publication Status:** 1-Published
Journal: Computational Optimization and Applications
Publication Identifier Type: DOI Publication Identifier: 10.1007/s10589-016-9855-8
Volume: Issue: First Page #:
Date Submitted: 8/18/16 12:00AM Date Published: 6/1/16 4:00AM
Publication Location:

Article Title: Conic approximation to quadratic optimization with linear complementarity constraints

Authors: Jing Zhou, Shu-Cherng Fang, Wenxun Xing

Keywords: Cone of nonnegative quadratic functions, Conic approximation, Linear complementarity constraints

Abstract: This paper proposes a conic approximation algorithm for solving quadratic optimization problems with linear complementarity constraints. We provide a conic reformulation and its dual for the original problem such that these three problems share the same optimal objective value. Moreover, we show that the conic reformulation problem is attainable when the original problem has a nonempty and bounded feasible domain. Since the conic reformulation is in general a hard problem, some conic relaxations are further considered. We offer a condition under which both the semidefinite relaxation and its dual problem become strictly feasible for finding a lower bound in polynomial time. For more general cases, by adaptively refining the outer approximation of the feasible set, we propose a conic approximation algorithm to identify an optimal solution or an ϵ -optimal solution of the original problem. A convergence proof is given under simple assumptions. Some computational results are included to

Distribution Statement: 3-Distribution authorized to U.S. Government Agencies and their contractors

Acknowledged Federal Support: Y

Publication Type: Journal Article Peer Reviewed: N **Publication Status:** 0-Other
Journal: Project report 1
Publication Identifier Type: Other Publication Identifier:
Volume: Issue: First Page #:
Date Submitted: 8/31/16 12:00AM Date Published: 8/23/16 10:43AM
Publication Location:

Article Title: Task 1 calculation of central point

Authors: Shu-Cherng Fang

Keywords: Calculation of central point

Abstract: This is a proposed procedure for calculating the central point of a data cloud as required by Task 1 of the ARO Project # W911NF-15-1-0223.

Distribution Statement: 3-Distribution authorized to U.S. Government Agencies and their contractors

Acknowledged Federal Support: Y

RPPR Final Report
as of 24-Apr-2020

Publication Type: Journal Article Peer Reviewed: Y **Publication Status:** 1-Published

Journal: Journal of the Operations Research Society of China

Publication Identifier Type: DOI

Publication Identifier: 10.1007/s40305-017-0158-2

Volume:

Issue:

First Page #: 1

Date Submitted: 8/18/17 12:00AM

Date Published: 3/23/17 8:00AM

Publication Location: Shanghai

Article Title: Convex analysis and duality over discrete domains

Authors: Murat Adivar, Shu-Cherng Fang

Keywords: Discrete convex analysis; Discrete Lagrangian duality; Discrete Slater's condition; Discrete strong duality; Integer programming; Integrality

Abstract: The aim of this paper is to establish a fundamental theory of convex analysis for the sets and functions over a discrete domain. By introducing conjugate/biconjugate functions and a discrete duality notion for the cones over discrete domains, we study duals of optimization problems whose decision parameters are integers. In particular, we construct duality theory for integer linear programming, provide a discrete version of Slater's condition that implies the strong duality and discuss the relationship between integrality and discrete convexity.

Distribution Statement: 3-Distribution authorized to U.S. Government Agencies and their contractors

Acknowledged Federal Support: Y

Publication Type: Journal Article Peer Reviewed: Y **Publication Status:** 1-Published

Journal: INFORMS Journal on Computing

Publication Identifier Type: DOI

Publication Identifier: 10.1287/ijoc.2016.0716

Volume: 29

Issue: 1

First Page #: 108

Date Submitted: 8/18/17 12:00AM

Date Published: 12/21/16 10:00AM

Publication Location: Maryland

Article Title: Linear Reformulation of Polynomial Discrete Programming for Fast Computation

Authors: Han-Lin Li, Yao-Huei Huang, Shu-Cherng Fang

Keywords: polynomial discrete program; mixed-integer linear program; linearization equation; branch and bound

Abstract: Polynomial discrete programming problems are commonly faced but hard to solve. Treating the nonconvex cross-product terms is the key. State-of-the-art methods usually convert such a problem into a 0-1 mixed-integer linear programming problem and then adopt the branch-and-bound scheme to find an optimal solution. Much effort has been spent on reducing the required numbers of variables and linear constraints as well as on avoiding unbalanced branch-and-bound trees. This study presents a set of equations that linearize the discrete cross-product terms in an extremely effective manner. It is shown that embedding the proposed "equations for linearizing discrete products" into those state-of-the-art methods in the literature not only significantly reduces the required number of linear constraints from $O(h^3n^3)$ to $O(hn)$ for a cubic polynomial discrete program with n variables in h possible values but also tighten these methods with much more balanced branch-and-bound trees.

Distribution Statement: 3-Distribution authorized to U.S. Government Agencies and their contractors

Acknowledged Federal Support: Y

RPPR Final Report as of 24-Apr-2020

Publication Type: Journal Article Peer Reviewed: Y **Publication Status:** 1-Published

Journal: Annals of Data Science

Publication Identifier Type:

Publication Identifier:

Volume: Issue:

First Page #:

Date Submitted: 8/18/17 12:00AM

Date Published: 1/3/17 10:00AM

Publication Location:

Article Title: Convex shape preservation of cubic L1 spline fits

Authors: Tiantian Nie, Ziteng Wang, Shu-Cherng Fang, John E. Lavery

Keywords: Cubic L1 Spline Fits

Abstract: Cubic L1 spline fits have been developed for geometric data approximation and shown excellent performances in shape preservation. To quantify the convex-shape-preserving capability of spline fits, we consider a basic shape of convex corner with two line segments in a given window. Given the horizontal length difference and slope change of convex corner, we conduct an analytical approach and a numerical procedure to calculate the second-derivative-based spline fit in 3-node and 5-node windows, respectively. Results in both cases show that the convex shape can be well preserved when the horizontal length difference is within the middle third of window's length. In addition, numerical results in the 5-node window indicate that the second-derivative based and first-derivative based spline fits outperform function-value based spline fits for preserving this convex shape.

Distribution Statement: 3-Distribution authorized to U.S. Government Agencies and their contractors

Acknowledged Federal Support: Y

Publication Type: Journal Article Peer Reviewed: Y **Publication Status:** 1-Published

Journal: Project report 1

Publication Identifier Type:

Publication Identifier:

Volume: Issue:

First Page #:

Date Submitted: 8/21/17 12:00AM

Date Published:

Publication Location:

Article Title: Task 1 Final report

Authors: Qi An, Shu-Cherng Fang

Keywords: I1 central point

Abstract: Abstract not available.

Distribution Statement: 3-Distribution authorized to U.S. Government Agencies and their contractors

Acknowledged Federal Support: Y

Publication Type: Journal Article Peer Reviewed: Y **Publication Status:** 1-Published

Journal: Annals of Operations Research

Publication Identifier Type:

Publication Identifier:

Volume: Issue:

First Page #:

Date Submitted: 8/18/17 12:00AM

Date Published: 4/11/16 4:00AM

Publication Location:

Article Title: Reverse auctions with regret-anticipated bidders

Authors: Xiaohu Qian, Shu-Cherng Fang, Min Huang, Qi An, Xingwei Wang

Keywords: Reverse auction, Anticipated regrets, Mitigation strategy, Reserve price

Abstract: Suppliers may experience emotional/behavioral consequences of anticipated regrets that consist of winner and loser regrets in first- and second-price sealed-bid reverse auctions. Constructing mathematical models that incorporate regret theory to derive closed-form solutions of regret-anticipated suppliers' bid decisions, this paper theoretically examines the effects of anticipated regrets on suppliers' bid prices, buyer's expected procurement cost and auction format decision. Comparing with the no regret scenario, we find that winner regret has adverse effects on the buyer's expected procurement cost in first-price sealed-bid reverse auctions with regret-anticipated suppliers. To mitigate the adverse effects, we propose using the reserve price strategy for the buyer with theoretical analysis and numerical supports.

Distribution Statement: 3-Distribution authorized to U.S. Government Agencies and their contractors

Acknowledged Federal Support: Y

RPPR Final Report as of 24-Apr-2020

Publication Type: Journal Article Peer Reviewed: Y **Publication Status:** 1-Published

Journal: Journal of Industrial and Management Optimization

Publication Identifier Type: Publication Identifier:

Volume: Issue: First Page #:

Date Submitted: 8/26/18 12:00AM Date Published: 3/1/17 5:00AM

Publication Location:

Article Title: A Cooperative Game with Envy

Authors: J. Zhang, S.-C. Fang, Y. Xu, Z. Wang,

Keywords: Cooperative game

Abstract: This paper proposes an envy-incorporated cooperative game model and investigates the envy effects on players' coalition-forming and payoff-allocating decisions. A player's utility depends on her/his own payoff and the envy toward other players, inside and outside the same coalition, with higher payoffs. Envy core is defined to characterize stable coalition structures and payoff allocations of this new game. Conditions for the envy core to be nonempty are provided. The relative significance of in-coalition envy and out-coalition envy is shown to be a key factor to the form of the envy core. Application to a simple game shows that envy may significantly change players' decisions.

Distribution Statement: 3-Distribution authorized to U.S. Government Agencies and their contractors

Acknowledged Federal Support: Y

Publication Type: Journal Article Peer Reviewed: Y **Publication Status:** 1-Published

Journal: Soft Computing

Publication Identifier Type: Publication Identifier:

Volume: Issue: First Page #:

Date Submitted: 8/26/18 12:00AM Date Published:

Publication Location:

Article Title: A proximal quadratic surface support vector machine for semi-supervised binary classification

Authors: Xin Yan, Yanqin Bai, Jian Luo, Shu-Cherng Fang

Keywords: Semi-supervised classification, Proximal support vector machine, Kernel-free, Quadratic surface, Alternating direction method

Abstract: Semi-supervised support vector machine is a popular method in the research area of machine learning. Considering a large amount of unlabeled data points in real-life world, the semi-supervised support machine has the ability of good generalization for dealing with nonlinear classification problems. In this paper, a proximal quadratic surface support vector machine model is proposed for semi-supervised binary classification. The main advantage of our new model is that the proximal quadratic surfaces are constructed directly for nonlinear classification instead of using the kernel function, which avoids the tasks of choosing kernels and tuning their parameters. We reformulate this proposed model as an unconstrained mixed-integer quadratic programming problem. Semi-definite relaxation is then adopted, and a primal alternating direction method is further proposed for fast computation. We test the proposed method on some artificial and public benchmark data sets.

Distribution Statement: 3-Distribution authorized to U.S. Government Agencies and their contractors

Acknowledged Federal Support: Y

RPPR Final Report as of 24-Apr-2020

Publication Type: Journal Article Peer Reviewed: Y **Publication Status:** 1-Published
Journal: Annals of Operations Research
Publication Identifier Type: **Publication Identifier:**
Volume: **Issue:** **First Page #:**
Date Submitted: 8/26/18 12:00AM **Date Published:**
Publication Location:
Article Title: Inventory centralization with risk-averse newsvendors
Authors: J. Zhang, S.-C. Fang, Y. Xu
Keywords: Inventory centralization·Risk-averse·Risk sharing·Pareto-optimality·Core
Abstract: In the paper, we study the inventory centralization problem with risk-averse newsvendors using cooperative game theory. Pareto-optimality and collective rationality conditions are adopted to characterize the stable profit allocations among coalition members. Pareto-optimal profit allocation rules are derived for exponential and power utilities while the necessary and sufficient conditions are shown for stable profit allocations. We also show that the game model has a nonempty core when the exponential and power utilities are adopted to describe the risk-averse behavior.
Distribution Statement: 3-Distribution authorized to U.S. Government Agencies and their contractors
Acknowledged Federal Support: Y

Publication Type: Journal Article Peer Reviewed: Y **Publication Status:** 1-Published
Journal: International Journal of Forecasting
Publication Identifier Type: **Publication Identifier:**
Volume: **Issue:** **First Page #:**
Date Submitted: 8/26/18 12:00AM **Date Published:** 1/9/18 10:00AM
Publication Location:
Article Title: Benchmarking robustness of load forecasting models under data integrity attacks
Authors: Jian Luo, Tao Hong, Shu-Cherng Fang,
Keywords: Cybersecurity, Data integrity attack, Electric load forecasting, Linear regression, Neural network, Support vector regression
Abstract: As the internet's footprint continues to expand, cybersecurity is becoming a major concern for both governments and the private sector. One such cybersecurity issue relates to data integrity attacks. This paper focuses on the power industry, where the forecasting processes rely heavily on the quality of the data. Data integrity attacks are expected to harm the performances of forecasting systems, which will have a major impact on both the financial bottom line of power companies and the resilience of power grids. This paper reveals the effect of data integrity attacks on the accuracy of four representative load forecasting models (multiple linear regression, support vector regression, artificial neural networks, and fuzzy interaction regression).
Distribution Statement: 3-Distribution authorized to U.S. Government Agencies and their contractors
Acknowledged Federal Support: Y

Publication Type: Journal Article Peer Reviewed: Y **Publication Status:** 1-Published
Journal: Journal of the Operations Research Society of China
Publication Identifier Type: **Publication Identifier:**
Volume: **Issue:** **First Page #:**
Date Submitted: 8/26/18 12:00AM **Date Published:** 8/23/18 4:00AM
Publication Location:
Article Title: Core of the Reinsurance Market with Dependent Risks
Authors: Jia-Hua Zhang, Shu-Cherng Fang, Yi-Fan Xu
Keywords: Core, Risk premium, Reinsurance market, Exponential utility, Cooperative game
Abstract: Baton and Lemaire (Astin Bull 12:57–71, 1981) proved the nonemptiness of the core of a reinsurance market in which the risks of companies are independent. However, cases involving dependent risks have received increasing concerns in modern actuarial science. In this paper, we investigate the nonemptiness of the core of a reinsurance market where the risks of different companies may be dependent. When the exponential utility function is employed, we find an important property on risk premium and show that the core of the market is always nonempty.
Distribution Statement: 3-Distribution authorized to U.S. Government Agencies and their contractors
Acknowledged Federal Support: Y

RPPR Final Report as of 24-Apr-2020

Publication Type: Journal Article Peer Reviewed: Y **Publication Status:** 1-Published
Journal: International Journal of Operations Research
Publication Identifier Type: Publication Identifier:
Volume: Issue: First Page #:
Date Submitted: 8/18/19 12:00AM Date Published:
Publication Location:

Article Title: l1-norm based major component detection and analysis for asymmetric radial data

Authors: Qi An · Shu-Cherng Fang · Shan Jiang · John E. Lavery

Keywords: Principal component analysis · l1-norm · multivariate statistics

Abstract: l1-norm based major component detection and analysis (l1 MCDA) is a state-of-the-art tool based exclusively on l1-norm to identify the major components of a multivariate data set with irregularly positioned “spokes” and “clutters”. In this paper, we develop an algorithmic framework of l1 MCDA for treating radial data clouds without the assumption of symmetry. This two-phase algorithm first locates the central point of the data by a pre-selection procedure to screen out candidate points with sufficient data points in the vicinity followed by solving an l1-norm discrete minimization problem. It then calculates the major directions and median radii in those directions via a two-level median fitting process. Extensive computational experiments have been conducted on n-dimensional data sets of various configurations randomly generated from light-tailed and heavy-tailed distributions with possibly artificial outliers to support the accuracy and robustness of the proposed method.

Distribution Statement: 3-Distribution authorized to U.S. Government Agencies and their contractors

Acknowledged Federal Support: Y

Publication Type: Journal Article Peer Reviewed: Y **Publication Status:** 1-Published
Journal: International Journal of Operations Research
Publication Identifier Type: Publication Identifier:
Volume: Issue: First Page #:
Date Submitted: 8/18/19 12:00AM Date Published:
Publication Location:

Article Title: Project Report # 4_Tasks 2&3 (Journal Submission)

Authors: Qi An, Shu-Cherng Fang, Shan Jiang, John E. Lavery

Keywords: Principal component analysis, l1-norm, multivariate statistics

Abstract: l1-norm based major component detection and analysis (l1 MCDA) is a state-of-the-art tool based exclusively on l1-norm to identify the major components of a multivariate data set with irregularly positioned “spokes” and “clutters”. In this paper, we develop an algorithmic framework of l1 MCDA for treating radial data clouds without the assumption of symmetry. This two-phase algorithm first locates the central point of the data by a pre-selection procedure to screen out candidate points with sufficient data points in the vicinity followed by solving an l1-norm discrete minimization problem. It then calculates the major directions and median radii in those directions via a two-level median fitting process. Extensive computational experiments have been conducted on n-dimensional data sets of various configurations randomly generated from light-tailed and heavy-tailed distributions with possibly artificial outliers to support the accuracy and robustness of the proposed method.

Distribution Statement: 3-Distribution authorized to U.S. Government Agencies and their contractors

Acknowledged Federal Support: Y

RPPR Final Report as of 24-Apr-2020

Publication Type: Journal Article Peer Reviewed: Y **Publication Status:** 1-Published

Journal: Group Decision and Negotiation

Publication Identifier Type:

Publication Identifier:

Volume:

Issue:

First Page #:

Date Submitted: 8/18/19 12:00AM

Date Published:

Publication Location:

Article Title: Bidding Decisions with None-equilibrium Strategic Thinking in Reverse Auctions

Authors: Xiaohu Qian, Shu-Cherng Fang, Min Huang, Tiantian Nie, Xingwei Wang

Keywords: Reverse auction, Bounded rationality, Nonequilibrium strategic thinking, Level-k model

Abstract: This paper considers decisions of bidders with bounded rationality in different thinking levels for a first-price sealed-bid reverse auction. To characterize the nonequilibrium strategic thinking, we construct a mathematical model that incorporates the "level-k decision rule" to iteratively derive closed-form solutions. Then the effects of bidders' heterogeneous beliefs of thinking levels on their bid prices and expected payoffs are investigated. We find that under some assumptions, bidders will exhibit oscillating behavior in their bid prices and expected profits in terms of thinking levels. When the thinking level tends to infinity, the bid prices and expected profits converge to those in the conventional analysis with perfectly rational bidders. An interesting finding from theoretical analysis verified by numerical experiments is that any bidder with a thinking level above two should bid according to level-2 bidder's strategy to achieve the highest expected profit.

Distribution Statement: 3-Distribution authorized to U.S. Government Agencies and their contractors

Acknowledged Federal Support: Y

Publication Type: Journal Article Peer Reviewed: Y **Publication Status:** 1-Published

Journal: Energy

Publication Identifier Type:

Publication Identifier:

Volume:

Issue:

First Page #:

Date Submitted: 8/18/19 12:00AM

Date Published:

Publication Location:

Article Title: Winner Determination of Loss-averse Buyers with Incomplete Information in Multi-attribute Reverse Auctions for Clean Energy Device Procurement

Authors: Xiaohu Qian, Shu-Cherng Fang, Min Huang, Xingwei Wang

Keywords: Clean energy market Reverse auction Multi-attribute decision making Incomplete information Winner determination Loss aversion

Abstract: Clean energy is an important source to mitigate the pressure of resources shortage and environmental effects. While multiattribute reverse auction is frequently adopted for the procurement efficiency of clean energy devices, the associated winner determination problem is explicitly studied for a utility company/buyer to select the most appropriate supplier in the clean energy market. Considering the buyer's loss-averse behavior with incomplete information and suppliers' conflicting attributes in different types evaluated by multiple experts, we incorporate an IULOWAf (induced uncertain linguistic ordered weighted averaging) operator and a revised TODIM (an acronym in Portuguese of Interactive and Multi-attribute Decision Making) measure that is consistent with prospect theory into the "benefits, opportunities, costs and risks" (BOCR) framework to develop a novel BOCR-uRTODIM solution method for multi-attribute decision making.

Distribution Statement: 3-Distribution authorized to U.S. Government Agencies and their contractors

Acknowledged Federal Support: Y

RPPR Final Report as of 24-Apr-2020

Publication Type: Journal Article Peer Reviewed: Y **Publication Status:** 1-Published

Journal: Journal of Industrial and Management Optimization

Publication Identifier Type: Publication Identifier:

Volume: Issue: First Page #:

Date Submitted: 8/18/19 12:00AM Date Published:

Publication Location:

Article Title: Recovering Optimal Solutions via SOC-SDP Relaxation of Trust Region Subproblem with Nonintersecting Linear Constraints

Authors: Jinyu Dai, Shu-Cherng Fang, Wenxun Xing

Keywords: Trust region subproblem, SOC-SDP relaxation, Slater condition, matrix decomposition, recovering algorithm.

Abstract: In this paper, we study an extended trust region subproblem (eTRS) in which the unit ball intersects with m linear inequality constraints. In the literature, Burer et al. proved that an SOC-SDP relaxation (SOCSDPr) of eTRS is exact, under the condition that the nonredundant constraints do not intersect each other in the unit ball. Furthermore, Yuan et al. gave a necessary and sufficient condition for the corresponding SOCSDPr to be a tight relaxation when $m = 2$. However, there lacks a recovering algorithm to generate an optimal solution of eTRS from an optimal solution X^L of SOCSDPr when $\text{rank}(X^L) \geq 2$ and $m \geq 3$. This paper provides such a recovering algorithm to complement those known works.

Distribution Statement: 3-Distribution authorized to U.S. Government Agencies and their contractors

Acknowledged Federal Support: Y

Publication Type: Journal Article Peer Reviewed: Y **Publication Status:** 1-Published

Journal: Information Sciences

Publication Identifier Type: Publication Identifier:

Volume: Issue: First Page #:

Date Submitted: 8/18/19 12:00AM Date Published:

Publication Location:

Article Title: A Sub-one Quasi-norm-based Similarity Measure for Collaborative Filtering in Recommendation Systems

Authors: Shan Jiang, Shu-Cherng Fang, Qi An, John E. Lavery

Keywords: Recommender system Collaborative filtering Neighborhood-based CF Similarity measure l_p quasi-norm

Abstract: Collaborative filtering (CF) is one of the most successful approaches for an online store to make personalized recommendations through its recommender systems. A neighborhood-based CF method makes recommendations to a target customer based on the similar preference of the target customer and those in the database. Similarity measuring between users directly contributes to an effective recommendation. In this paper, we propose a sub-one quasi-norm-based similarity measure for collaborative filtering in a recommender system. The proposed similarity measure shows its advantages over those commonly used similarity measures in the literature by making better use of rating values and deemphasizing the dissimilarity between users.

Computational experiments using various real-life datasets clearly indicate the superiority of the proposed similarity measure, no matter in fully co-rated, sparsely co-rated or cold-start scenarios.

Distribution Statement: 3-Distribution authorized to U.S. Government Agencies and their contractors

Acknowledged Federal Support: Y

DISSERTATIONS:

Publication Type: Thesis or Dissertation

Institution: North Carolina State University

Date Received: 26-Aug-2018 Completion Date: 12/7/16 2:25AM

Title: Quadratic Programming with Discrete Variables.

Authors: Tiantian Nie

Acknowledged Federal Support: N

RPPR Final Report
as of 24-Apr-2020

Scientific research is documented by publications.