International Conference on Operations Research and Game Theory with Economic Applications

January 28-30, 2026

ICORGTE26

Organized by

Centre for Research on Economics and Data Analysis

Indian Statistical Institute Delhi Centre

Contents

Welcome to ICORGTE 2026

On behalf of the organizers of ICORGTE26, I welcome you in the three days International Conference on Operations Research and Game Theory with Economic Applications (ICORGTE) organized by Centre for Research on Economics and Data Analysis (**CREDA**) during 28-30 January 2026 at Indian Statistical Institute, Delhi Centre.

This International conference on Operations Research and Game Theory aims at discussing new developments in the methods of decision making in Economic Applications and promises to build an interaction between the users from industry and the academic model developers by bringing them together. **ICORGTE** intends to present the state-of-the-art results and recent advances in these areas with a view to highlight possible future course of research in economic applications of these models working in the area of Operations Research (OR), Management Science, Data Science.

This conference also intends to bring out a publication of selected and refereed papers in the Special Issues on Computational Operations Research and Algorithmic Game Theory in honor of Prof. T. Parthasarathy and Prof. T. E. S. Raghavan focused on "Operations Research and Algorithmic Game Theory". We invite researchers and scholars from various disciplines to participate/present the paper in this conference and contribute their original research papers to this conference and special issues.

Selected articles will get an opportunity of possible publication in special issues of the following journals.

subject to acceptance after the standard peer review process adopted by the journals.

The aim of these special issues is to explore both theoretical and algorithmic advances in the field of computational operations research and algorithmic game theory. Furthermore, these special issues will focus on game theoretical applications of Operations Research

Also, book chapters/expository articles are invited for the book-volume 'Applied Operations Research, Game theory, and Decision Science' which is intended to be published in some reputed series of SPRINGER**.**

Authors are encouraged to submit papers as a book chapter/ expository articles that contribute to the advancement of knowledge in the field and offer practical insights for policymakers, industry professionals, and researchers. All submissions will undergo a rigorous peer-review process to ensure the highest quality of published articles. Paper presented in the conference may be submitted as a book chapter before June 30, 2026 to the organizing committee chair Prof. S. K Neogy (e.mail: skn@isid.ac.in)

The conference topics include (but not limited to):

- ***Operations Research problems in Statistics and Game Theory***
- ***Application of operations research in Management science and Economics***
- ***Unconstrained and constrained optimization.***
- ***Game Theoretical applications of Operations Research***
- ***Multi-objective and robust optimization***
- ***Integrating Artificial Intelligence, machine learning and operations research methods***
- ***Exact/heuristic hybrid methods, involving natural computing techniques in operations research and game theory***
- ***Optimization in dynamic and/or noisy environments***
- ***Optimization on graphs***
- ***Large-scale optimization, in parallel and distributed computational environments***

- ***Static and Dynamic games***
- ***Complementarity and Variational inequalities model in Game Theory***
- ***Portfolio Optimization***
- ***Stochastic Optimization***
- ***Financial Optimization***

Research articles with novelty presented at the conference shall qualify for the possible publication in any of the above publications, if the article is within the scope of the conference as well as the journal and clears the standard peer review process adopted by the journal. Review articles with contents useful for future research and open problems are also welcome.

You may write to the organizing committee chair (**Prof. S. K. Neogy, e.mail skn@isid.ac.in**) about suitability of your paper and Journal name for submission from the journals listed above after acceptance of the abstract to be presented in the conference.

Information about social events will be available to you at the time of registration.

S. K, Neogy
Organizing Committee Chair

Organizing Committee

S. K. Neogy (Chair), Indian Statistical Institute, Delhi Centre

R.B. Bapat, Indian Statistical Institute, Delhi Centre

Arunava Sen, Indian Statistical Institute, Delhi Centre

Prabal Roy Chowdhury, Indian Statistical Institute, Delhi Centre

Monisankar Bishnu, Indian Statistical Institute, Delhi Centre

K. Manjunatha Prasad, Manipal Academy of Higher Education, Manipal

Deepayan Sarkar, Indian Statistical Institute, Delhi Centre

Programme Co-ordinating Committee

Prabal Roy Chowdhury, R. B. Bapat, K. Manjunatha Prasad, Deepayan Sarkar

Facilities Committee

Samapan Padhi (Chair), Simmi Marwah, S. A. Srinivas, Pankaj Kumar Meena, Parama Gogoi, P. Sreejith, Dinesh Kumar, Rajes, Khusboo Singh, Praveen Pandey -- Convener

International Conference on Operations Research and Game Theory with Economic Applications

January 28-30, 2026

Program Overview

Inaugural Session Details

January 28, 2026 Time: 10:00 -10:30 Venue: Auditorium

Opening Remarks, About the Conference, Welcome address, About CREDA, Vote of Thanks

Group Photograph 10:30-10:45
Tea Break: 10:45 -11:00

Sessions Details

January 28, 2026 Time: 11:00 -13:00 Venue: Auditorium

Invited Session I
Chairman : S K Neogy, Indian Statistical Institute Delhi Centre

1.	**Yasunori Kimura** (Toho University, Funabashi, Japan) Iterative schemes for approximating a solution to a convex minimization problem over fixed point sets
2.	**T. E. S. Raghavan**, (University of Illinois at Chicago, USA) On the applications of scaling the entries of a matrix
3.	**C. S. Lalitha** (Department of Mathematics, University of Delhi South Campus, New Delhi) Essential stability for vector variational inequality problems
4.	**Andreay Garnaev** (Rutgers University, North Brunswick, NJ 08901, USA) Guaranteed Payoffs Resource Allocation Problem with Game-Theoretic Applications

Lunch Break: 13:00 -14:00
Venue: Guest House Lawn

January 28, 2026 Time: 14:00 -15:20 Venue: Auditorium

Invited Session II
Chairman: S K Neogy, Indian Statistical Institute Delhi Centre

1.	**Frank Thuijsman** (Maastricht University, The Netherlands) Industry-Academia Collaboration - A Game Theoretic Approach
2.	**Bo Chen** (The University of Warwick, UK) Sequential Voting and the Reliability of Collective Decisions: Game-Theoretic Insights from Condorcet Juries to Digital Platforms.

January 28, 2026 Time: 14.00 -15:00 Venue: Conference Room
Technical Session-I
Chairman : Aseem Pahuja, University of Manchester

1.	**Aseem Pahuja** a, Zhiling Guo b, Tahir Abbas Syed a**(aUniversity of Manchester,** b University of North Texa**s)** Sweet Little Lies: Strategic Manipulation by AI Shopping Assistants
2.	**Thirumulanathan D** (Indian Institute of Technology Kanpur) On the equivalence of Monge and Kantarovich Problems in Discrete Optimal Transport
3.	**Ram Kumar Phuyal** (Tribhuvan University,Kirtipur,Nepal) Duopoly Competition with Quality-Dependent Fixed Costs in Covered and Uncovered Markets

January 28, 2026 Time: 14.00 -15:20 Venue: Seminar Room 2
Technical Session-II
Chairman : Vivek LAHA Banaras Hindu University, Varanasi, India

1.	**Palanivel K. (**Vellore Institute of Technology (VIT), Vellore) Sustainable optimization of E-waste management through neutrosophic applications: A comprehensive decision-making approach
2	**Amit Kumar Goyal** (Manipal University Jaipur) Two-warehouse inventory model for imperfect production process under the effect of learning
3.	**Sudharsan J R** (Vellore Institue of Technology, Vellore, India) Sustainable Biomedical Waste Optimization through Neutrosophic Decision Making
4.	

January 28, 2026 Time: 15.30 -18:30 Venue: Seminar Room 2
Technical Session-III

Chairman : Anurag Jayswal, Indian Institute of Technology (ISM) Dhanbad

1.	**Vivekananda Rayanki (**VNR Vignana Jyothi Institute of Engineering and Technology affiliated to JNTU hyderabad) Variational Control Problems with Multiobjective Interval-Valued Functions: Optimality and Duality
2.	**Km Raksha** (Department of Economics, University of Allahabad) Optimal Export Allocation and Growth Outcomes: Evidence from India
3	**Akhilesh Kumar** (Arignar Anna Government Arts & Science College, Karaikal) Optimal Replenishment Policy for a Dual-Warehouse Fractional-Order Inventory System with Memory-Dependent Deterioration and Shortages
4	**Prashant Khileri (**Christ (Deemed to be University) A Sustainable Inventory Model for Growing Items Considering Carbon Emission, Trade Credit, and Shortages.
5	**Akanksha Singh** (Chandigarh University, Gharuan, Mohali) Generalized Fuzzy Entropy for Intuitionistic Fuzzy Soft Sets: Theoretical Insights and Decision-Making Applications
6	**Muskaan Saini** (Sardar Vallabhbhai National Institute of Technology, Surat) Application of Double Orbit Retrial Repair Model in Hydraulic Cylinder Repair Workshop
7.	**Arpita Bhattacharyya** (Indian Institute of Social Welfare & Business Management, University of Calcutta, Kolkata) Optimization of the Number of Variables for Model Development
8.	**Ayushi Verma** (Bundelkhand University,Jhansi) A Hybrid WASPAS-CRADIS Decision Analytics Framework for Smart Power Grid Analyst Selection under Multi-Criteria Environments
9.	

January 28, 2026 Time: 17:00- 18:30 Venue: Conference Room

Technical Session-IV

Chairman : Thirumulanathan D (Indian Institute of Technology Kanpur)

1.	**Ayush Gupta (Indian Institute of Management Indore)** Advance Purchasing: Strategic Inventory or Forward Contracts?
2.	**KM Soni** ((MNNIT Allahabad) Ant colony optimization algorithm for solving capacitated vehicle routing problem with neutrosophic fuzzy stochastic demands
3	**Afasar Ali (MNNIT Allahabad)** A hybrid ant colony optimization algorithm based on clark wright saving algorithm for vehicle routing problem with driver fatigue
4	**Sourish Dutta** (VIPS-TC (GGSIPU, Delhi)) The Anatomy of Value Creation: Input-Output Linkages, Policy Shifts, and Economic Impact in India's Mobile Phone GVC

Tea: 15:00-15:30

January 28, 2026 Time: 15:30 -18:45 Venue: Auditorium

Best Paper award Session (Methodology/Application Category

Chairman : K. Manjunatha Prasad, Manipal Academy of Higher Education, Manipal

1.	**Shivani Sain** (IIT Patna) Gap Functions and Existence Results for Approximate Vector Variational Inequality Problems on Hadamard Manifolds **(Mehodology Category)**
2.	**Subham Poddar (IIT Patna)** Inertial proximal point algorithm on Hadamard manifolds: convergence analysis and finite termination **(Mehodology Category)**
3.	**Gaurav Uniyal (IIT (ISM), Dhanbad**) Lagrange duality and saddle point criteria for semi-infinite variational programming problem with Caputo-Fabrizio fractional derivative (**Mehodology category)**
4.	**Prashant Jaiswal (Banaras Hindu University)** On quasidifferentiable interval-valued multiobjective optimization **(Mehodology Category)**
5.	**Pallabi Samal,** IIT (ISM), Dhanbad, Well-posedness of multidimensional semi-infinite variational inequalities with applications **(Mehodology Category)**
6	**Meenakshi**(University of Delhi) Normal Cones in Groups and Optimality Conditions **(Mehodology category)**
7	**Divyanee Garg (IIT Delhi)** Enhanced indexing using cumulative prospect theory utility function with expectile risk **(Application Category)**
8.	**Salini K** (Central University of Kerala) The Price of Anarchy in Queueing-Inventory Systems with Delay-Sensitive Customers **(Application Category)**
9	**Akhil Vijayan R (Central University of Kerala)** Assessing the Impact of Replenishment Policies and Repair Mechanisms on Energy Management System Reliability **(Application Category)**
10	**Rekha** (Shiv Nadar Institution of Eminence) An Optimized Model for Pseudo-Random and Deterministic Construction of Sensing Matrix **(Application Category)**
11.	**Sajal Ghosh** (ISI Delhi Centre) A Note on Some Open Problems on Quitting Games **(Application Category)**
12	**Kamayani Shukla (Netaji Subhas University of Technology, Delhi)** Robust Portfolio Optimization via Linear Deviation Risk Measures **(Application Category)**

Cultural Programme: 7pm-8pm

Venue: Auditorium

Conference Dinner: 8:15 pm onwards

Venue: Guest House Lawn

January 29, 2026 Time: 10:00 -11:45 Venue: Auditorium

Invited Session III

Chairman: Reinoud Joosten (University of Twente)

1.	**Reinoud Joosten** (University of Twente, The Netherlands), The power of weak threats in stochastic games
2.	**Anurag Jayswal** (Indian Institute of Technology (Indian School of Mines), Dhanbad-826004) A neural network approach for mathematical programming problems having vanishing constraints
3.	**J. Dutta (Indian Institute of Technology Kanpur, India)** Second Order Conditions in Convex Multiobjective Opimization

Tea Break: 11:45 -12:00

January 29, 2026 Time: 12:00 -13:00 Venue: Auditorium

Invited Session IV

Chairman: S. Dharmaraja, (Indian Institute of Technology Delhi, India)

1.	**S. Dharmaraja,** (Indian Institute of Technology Delhi, India), Reliability analysis of anti-UAV systems: an analytical approach
2.	**Bart de Keijzer** (King's College London) On the Approximation Ratio of Optimal Fixed-Price Mechanisms for Single and Multi-Unit Bilateral Trade

Tea Break: 11:30 -12:00

January 29, 2026 Time: 12:00 -13:00 Venue: Conference Room

Technical Session V

Chairman: Varun Ramamohan (Indian Institute of Technology Delhi)

1.	**Ram Krishna Vinayak (IIT Delhi)**Farmer's Game: A N-person Stag hunt game model
2.	**Arindam Maity (IIT Guwahati)** Robust mean-variance portfolio selection with intractable claim under probability distortion
3.	**Varun Ramamohan** (Indian Institute of Technology Delhi) A Statistical Assessment of the Impact of Machine Learning Inputs on the Performance of Integer-Valued Markowitz-Type Portfolios

Lunch Break: 13:00 -14:00

January 29, 2026 Time: 14:00 -16:00 Venue: Auditorium

Invited Session V

Chairman: Agnieszka Wiszniewska-Matyszkiel (Institute of Applied Mathematics and Mechanics. University of Warsaw, Poland)

1.	**Gajendra Pratap Singh** (Jawaharlal Nehru University, New Delhi-110067, India) Characterization and Optimality of Boolean and Crisp Boolean Petri Nets
2.	**David Bartl,** (Silesian University in Opava, School of Business Administration in Karvina, Czech Farkas' Lemma), Gale's Theorem of the Alternative, and the Bondareva-Shapley Theorem in the Infinite Case
3.	**Vikas Vikram Singh,** (Indian Institute of Technology Delhi, India) Distributionally Robust Single-Controller Chance-Constrained Stochastic Games
4.	**Dipti Dubey,** (Shiv Nadar University), On the Properties of Solutions of Absolute Value Equations and Related Matrix Classes

January 29, 2026 Time: 14:00 -16:00 Venue: Conference Room

Technical Session VI

Chairman: Abhay G. Bhatt (Indian Statistical Institute Delhi)

1.	**Akriti Dwivedi** (Banaras Hindu University, Varanasi)Stationarity conditions for nonsmooth interval-valued multiobjective semi-infinite programming problems with switching constraints via tangential subdifferentials
2.	**Bhawna Kohli** (Sri Guru Nanak Dev Khalsa College, University of Delhi) A study on solution criteria for bilevel multi-objective optimization problems
3.	**Shweta Yadav** (Shiv Nadar Institution of Eminence) On the Properties of Solution Set of Absolute Value Equations
4.	**Dinesh Kumar** (Indian Institue of Technology Kharagpur, Kharagpur) A Subgradient-Based Approach for Nonsmooth Quasiconvex Multiobjective Optimization
5	**Rashmi Kumari** (Indian Institute of Technology Kharagpur)A Two-Step Smoothing Newton Method for Second-Order Cone Complementarity Problems
6.	**Umashankar Bajpei** (Banaras Hindu University, Varanasi,India)Vector Optimization Problems and Vector Variational Inequalities via Lower Global Subdifferentials

Tea: 16:00-16:30

January 29, 2026 Time: 16:30 -18:50 Venue: Auditoriam

Technical Session VII

Chairman: Reinoud AMG Joosten, University of Twente, The Netherlands.

1.	**Dipanjali Ghosh** (Indian Institute of Technology Bombay) Efficiency is not Stability: An Endogenous Coalition formation game in Last-mile delivery
2.	**Neha Punetha** (IIIT Delhi) Integrating Game Theory and Linguistic Intelligence for Hindi Review Sentiment
3.	**Arpan Dutta** (IIT Kharagpur) A bilevel approach to optimize farm subsidies in India
4.	**Kushal Guha (Amity University Kolkata)** β-Discounted Approximations and Limiting Average Optimality in Zero-Sum Perfect Information Stochastic Games
5	**Karl Darryl Lewis** (Indian Institute of Technology Madras)Replicator Dynamics on Bilinear Games with Exponential Strategies: A Comparison with StaticStability
6	**Paritosh Roy (IIT Delhi)** Discounted Robust stochastic games
7	**Ghurumuruhan Ganesan (**University of Bristol) Redundancy mitigation in big data using graphs and Shapley value

January 29, 2026 Time: 16:30 -18:30

Venue: Conference Room

Technical Session VIII

Chairman: J. Dutta (Indian Institute of Technology Kanpur, India)**/ K.S. Mallikarjuna Rao** (Indian Institute of Technology Bombay, India)

1.	**Priyanka Bharati (**Banaras Hindu University) Stationarity conditions and constraint qualifications for robust nonsmooth optimization problems with switching constraints
2.	**Debasish Ghorui (** Ghani Khan Choudhury Institute of Engineering and Technology, Malda) Solutions of Binary Mean Payoff Games and its Matrix Classes
3.	**Vanshika Datta**(IIT Kharagpur) Robust Optimization Frameworks for 3D Sensor Networks in Uncertain Terrains
4.	**Vandana Singh (**Indian Institute of Technology (BHU)) Duality results for quasidifferentiable mathematical programs with equilibrium constraints
5	**Dhruv Singh** (Institute of Science, Banaras Hindu University, Varanasi) Duality results for E-differentiable multiobjective fractional programming problems under E-B-invexity
6.	**Prasad Kothari** (Editorial Board Member - Blockchain for Healthcare Today), Evolutionary Game Theory for Optimizing LLM Performance, Compute Costs, Hallucinations, and Accuracy

January 30, 2026 Time: 10:00 -11:30 Venue: Auditorium

Invited Session VI

Chairman: Agnieszka Wiszniewska-Matyszkiel, University of Warsaw, Poland

1.	**Agnieszka Wiszniewska-Matyszkiel** (Institute of Applied Mathematics and Mechanics. University of Warsaw, Poland) Partial cooperation in resource extraction on networks: sharing wealth versus sharing extraction rights
	K.S. Mallikarjuna Rao (Indian Institute of Technology Bombay, India) Cooperative Games and Focal Point Inducing Mechanisms
3.	**R K Amit (IIT Madras)** Approximate dynamic programming based thresholds for cargo capacity management considering postponements

Tea Break: 11:30 -12:00

January 30, 2026 Time: 12:00 -13:00 Venue: Auditorium

Invited Session VII

Chairman: Sivaramakrishnan Sivasubramanian (IIT Bombay)

1.	**Sivaramakrishnan Sivasubramanian** (Department of Mathematics IIT Bombay) Unimodality and peak location of the characteristic polynomials of two distance matrices of trees
2.	**K C. Sivakumar** (Department of Mathematics IIT Madras) Q_0-matrices revisited.

January 30, 2026 Time: 12:00 -13:00 Venue: Conference Hall

Technical Session IX

Chairman: Q. M. Danish Lohani (South Asian University)

1.	**Q. M. Danish Lohani** (South Asian University) Intuitionistic Fuzzy Clustering Technique Emphasizing the Fuzzy Variant
2.	**Amita Sharma (**Netaji Subhas University of Technology Delhi)On analysis the different modeling approaches for index tracking problem
3.	**Sumit Maheshwari** (Indian Institute of Management Jammu) A Closed-Loop Supply Chain

	Optimization Framework Incorporating Environmental Investment and Multi-Shipment Logistics

Lunch Break: 13:00 -14:00

January 30, 2026 Time: 14:00 -15:30 Venue: Auditorium

Invited Session VIII

Chairman: S. K. Mishra (Department of Mathematics, Institute of Science, Banaras Hindu University, Varanasi)

1.	**S. K. Mishra** (Department of Mathematics, Institute of Science, Banaras Hindu University, Varanasi) Solving Mathematical Programs with Vanishing Constraints
2.	**N. Hemachandra (Indian Institute of Technology Bombay, India)Would congestion-based service systems** with impatient users be in equilibrium?
3.	**K. Manjunatha Prasad** (Department of Applied Statistics and Data Science, PSPH, Manipal Academy of Higher Education, Manipal, Karnataka, India 576 104) Generalized Inverses associated with Networks

January 30, 2026 Time: 14:00 -15:40 Venue: Conference Hall

Technical Session X

Chairman: Monisankar Bishnu, Indian Statistical Institute, Delhi Centre

1.	**Niher Ranjan Das**(South Asian University) A Bounded Variation–Based Probabilistic Intuitionistic Fuzzy C-Means Clustering Algorithm
2.	**Shikha Tomar** (University of Delhi) Pricing and Coordination in Refurbished Closed-Loop Supply Chain: a game-theoretic analysis
3.	**Shikha Tripathi** (Jawaharlal Nehru University, New Delhi) Applications of Stochastic Game and Graph Theory in Network Security
4.	**Ratan Kumar**(Indian Institute of Technology, Bombay) Standby Optimization for Airline Crew Scheduling: A Prescriptive Approach with Predictive Integration
5	**Oindrila Banerjee** (University of Delhi) Standby Optimization for Airline Crew Scheduling: A Prescriptive Approach with Predictive Integration

January 30, 2026 Time: 14:00 -15:40 Venue: Seminar Room 2

Technical Session XI

Chairman: Vivek LAHA(Banaras Hindu University, Varanasi, India)

1.	**Umashankara Kelathaya** (Manipal Institute of Technology, Manipal Academy of Higher Education, Manipal) Generalized Inverses in Network Flow Optimization
2.	**Vivek LAHA**(Banaras Hindu University, Varanasi, India) First and second order optimality conditions for nonsmooth multiobjective problems with equilibrium constraints
3.	**Manisha Kumari** (Indira gandhi delhi technical university for women) A new decision-making framework using an improved aggregation operator in intuitionistic fuzzy soft sets
4.	**Md Abu Talhamainuddin Ansary** (Indian Institute of Technology Jodhpur, India) A Hybrid Approach for Box Constrained Multi-objective Optimization Problems Combining Quasi-Newton and NSGA-II Methods"
5	**Saloni** (Manipal University Jaipur) Optimization modeling of dea for measuring hospital performance efficiency with python coding

Tea Break: 15:40 -16:00

January 30, 2026 Time: 16:15 -18:30 Venue: Auditorium

Technical Session XII

Chairman: Deepayan Sarkar, Indian Statistical Institute, Delhi Centre

1.	**Anjali Naik (IIT Delhi)** Inverse Data Envelopment Analysis under Non-Homogeneity and Negative Data
2.	**Nauman Ansary** (South Asian University) Entropy based Intuitionistic Fuzzy Weighted Least Square Twin Support Vector Machine
3.	**Rishabh Sahu**(Gati Shakti Vishwavidyalaya, Vadodara) When Priority Fails: A Bilevel Framework for Resolving Passenger-Freight Conflicts in Indian Railways
4.	**Arushi Sahu** (Indraprastha College For Women) Ancient Wisdom to Modern System: An Indian Knowledge System (IKS) Driven Spherical Fuzzy WASPAS Framework for Circular Economy
5.	**Priyal Jain** (IIT Delhi) Neural Approximation of Optimal DDoS Defense Strategies
6.	

January 30, 2026 Time: 16:15 -18:30 Venue: Conference Hall

Technical Session XIII

Chairman: Anurag Jayswal* (Indian Institute of Technology (Indian School of Mines), Dhanbad

1.	**Gambheer** Singh (Indian Statistical Institute, Delhi Center) Additional classes of interval matrices in linear complementarity theory
2.	**Kishan Suthar** (Indian Institute of Management Indore) Cooperative Games With Shared Constraints Under Uncertainty
3.	**Santo Sali** (Central University of Kerala, Kasaragod) Equilibrium and Evolutionary Stability in Multi-Threshold Dynamic Service Control of M/M/1 Queues: A Metaheuristic Optimization Approach
4.	**Meenakshi patil** (Karnatak Art's Science and Commerce Degree College Bidar) Optimal Crop Mix for Wheat, Rice and Vegetables to Maximize Profit Under Resources Constraints
5.	
6	

ABSTRACT OF THE PAPERS

Industry-Academia Collaboration - A Game Theoretic Approach

Frank Thuijsman
Maastricht University, The Netherlands

Based on my background in Game Theory, I initiated an educational program in which university, businesses, and (bachelor) students collaborate in a way that is beneficial to each of the parties involved. Since its launch in 2014, over 250 projects, were started with approximately 100 different businesses. Here, "businesses" should be interpreted broadly to also include industrial and non-profit organizations. These businesses vary from startups and SME's to large national and multinational partners. The educational program actively stimulates talent development and talent retention, as well as contract research. Setup and experiences will be shared with the audience.

Iterative schemes for approximating a solution to a convex minimization problem over fixed point sets

Yasunori Kimura
Toho University, Japan

The convex minimization problem over fixed point sets of non-expansive mappings provides a unified framework for connecting convex analysis and fixed point theory in geodesic spaces. In our previous work, we proposed an iterative scheme inspired by the cutting-plane method to approximate a minimizer of a convex function constrained to such a fixed point set.

In this work, we present a further development of that study and establish a strong convergence theorem for the proposed iterative process. The result ensures that the generated sequence converges strongly to a minimizer under suitable assumptions on the coefficient sequence. The proof combines techniques from convex and nonlinear analysis with the use of resolvent operators. This provides deeper insight into how curvature and nonlinearity influence convergence behavior and extends existing results from weak to strong convergence.

Guaranteed Payoffs Resource Allocation Problem with Game-Theoretic Applications

Andreay Garnaev,
Rutgers University, North Brunswick, NJ 08901, USA,

In this presentation, we develop and solve a general guaranteed-payoff resource-allocation problem for a finite number of options in a form convenient for application across a variety of settings. An advantage of such optimization, compared with maximizing total payoff resource-allocation problems, is that none of the options is neglected. We then show how this optimization can be incorporated into different game-theoretic scenarios.

In particular, we apply it to model the communication of an operator with several nodes, such as drones, operating in zones protected by jammers. It has been shown that, even in the presence of jammers, and regardless of whether the jammers are smart or regular, the anti-jamming equilibrium strategy maintains equal throughput for each node. Such a proven egalitarian property analytically confirms the reliability of communication with each node. Finally, an approach is illustrated for finding a trade-off between the number of served nodes and the required resource.

On the Applications of scaling the entries of a matrix

T. E. S. Raghavan,
University of Illinois at Chicago, USA

Various biological, statistical, and social science data come in the form of cross-classified counts tables commonly known as contingency tables. Scaling the cell entries of such multidimensional matrices involves both mathematically and statistically well-posed problems of practical interest. In this talk, we first describe several situations where scaling can be useful.

We also describe a natural scaling algorithm in the problem of scaling a nonnegative matrix to obtain the prescribed row and column sums. we consider the problem of maximum likelihood estimation in contingency tables.

This area of statistics, which forms part of discrete multivariate analysis, is of considerable interest to researchers at present. We will motivate this topic of scaling with examples chosen from 1. Budget allocations 2. Infra structure planning, 3. Gaussian elimination and problems of accuracy. 4. Arriving at approximate maximum likelihood estimates in say a 2 by 2 by 2 contingency table.

At the very end, we will just mention a general existence theorem (Bapat and Raghavan) which subsumes all such problems. We also propose several intuitive algorithms to handle some of these problems.

The power of weak threats in stochastic games

R.A.M.G. Joosten (Reinoud)

University of Twente, The Netherlands

In ‘The power of threats in stochastic games’, Thuijsman & Vrieze [1998] advocate extensions of the Folk Theorem for repeated games to analyze stochastic average reward games. Crucial in the Folk Theorem approach is the establishment of

1) a set of feasible limiting average rewards,

2) a threat point being a vector of limiting average rewards, for each player indicating the amount that (s)he can be kept at if all opponents try to minimize his/her limiting average reward.

The Folk Theorem for stochastic games states that any tuple of rewards giving each player at least his/her threat point reward, can be supported by a Nash equilibrium involving threats. Similar, yet slightly more general, approaches have been used for ESP-ETP games (in the terminology of Joosten & Samuel [2020]) in order to establish large sets of rewards which can be supported by (subgame perfect) Nash equilibria involving threats.

The term 'weak' in the context of threats and threat points, indicates a threat or punishment inducing an amount that a player can be kept at by his/her opponents which is not necessarily the lowest amount (s)he can be kept at.

We demonstrate the usefulness of weak threats in two contexts: computational complexity and sustainability of threats. It may be considerable more convenient from a computational point of view to establish a weak threat point than to find the threat point. The computational complexity of the latter in stochastic games may be staggering as the corresponding strategies may be history dependent. The price to pay is that presumably equilibrium rewards are not recognized as such, i.e., the set of equilibrium rewards relative to weak threat points is always a subset of the one relative to the threat point. However, elements of the former set Pareto tend to dominate all elements of the latter. So, if one is interested mainly in Pareto optimality, nothing seems lost by focusing on the former.

Another aspect is that in applications, weak threats may be sustainable, i.e., can be exercised forever, where the traditional threats fail. In an oligopoly, firms punishing with maximal severity may incur losses for an infinite period, which must induce their bankruptcy. As a result, the firm to be punished might turn out to be the sole survivor on the market, and if that occurs, monopoly profits will be its share. Such a threat must then be regarded as unsustainable and hence inconsistent. Weak threats allow sophisticated fine-tuning such that the punishee has sufficiently low rewards, but the punishers(s) can obtain non-negative profits in order to survive, hence such threats are sustainable. Analogous problems may surround threats in fishery games with complex price-scarcity relationships which cannot be sustained, but weak threats can.

Sequential Voting and the Reliability of Collective Decisions: Game-Theoretic Insights from Condorcet Juries to Digital Platforms

Bo Chen*

The University of Warwick, UK

How reliable are collective decisions when individuals vote sequentially, observing earlier votes before casting their own? This talk revisits the classical Condorcet Jury Theorem through the lens of game theory and operations research, and asks what it implies for the design of modern decision systems in juries, committees, and digital platforms. I present a model of sequential binary voting in which agents are heterogeneously informed and forward looking, and study equilibrium behaviour and decision accuracy in small and large groups. The studies bridge social choice theory, game theory, and computational models of social learning, and connect naturally to optimization questions about how to

structure voting order, information disclosure, and delegation. I will discuss applications and outline open problems at the interface of operations research, game theory, and the design of reliable collective intelligence.

*Joint work with Steve Alpern

Farkas' Lemma, Gale's Theorem of the Alternative, and the Bondareva-Shapley Theorem in the Infinite Case

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We present a generalized variant of Farkas' Lemma to handle infinite systems of linear inequalities in a purely algebraic way in an infinite-dimensional vector space. Henceforth, let F be a linearly ordered (commutative or skew) field, such as the field of the real numbers, $F = \mathbb{R}$, or that of the rational numbers, $F = \mathbb{Q}$, to handle the common cases. In general, the linearly ordered field F can, but need not, be commutative. Let the primal variable space W be any vector space over the field F, such as the finite-dimensional space, $W = \mathbb{R}^n$, the space of continuous functions on a compact interval, $W = \mathcal{C}_{[0,1]}$, or any other function space. In general, we do not assume any additional structure (such as topology or ordering) on the vector space W. Given an index set M, consider a collection of linear forms $\alpha_i : W \to F$ for $i \in M$. Assume, however, that only finitely many of the forms α_i are non-zero at a time; that is, the set $\{ i \in M : \alpha_i(x) \neq 0 \}$ is finite for every $x \in W$. We can thus consider the finite or infinite homogeneous system of linear inequalities $\alpha_i(x) \leq 0$ for $i \in M$, which we write in a more compact way as $Ax \leq \mathbf{0}$, where $A : W \to F^{(M)}$ is the linear mapping consisting of the linear forms α_i, yet $F^{(M)}$ is the space of generalized finite sequences; that is, the space of indexed collections $(\mu_i)_{i \in M}$ with $\mu_i \in F$ such that the set $\{ i \in M : \mu_i \neq 0 \}$ is finite. Furthermore, let V be a linearly ordered vector space over the linearly ordered field F, such as the real additive group, $V = \mathbb{R}$, if F is a subfield of the real numbers, which is the most common case. More generally, we can let V be the space F^N with the lexicographical ordering for a natural number N, or yet a more general linearly ordered vector space. Finally, let $\gamma : W \to V$ be a linear mapping. Our original motivation is to study an infinite linear programming problem to maximize $\gamma(x)$ subject to $Ax \leq \boldsymbol{b}$ for a given $\boldsymbol{b} \in F^M$, where $x \in W$ is variable; that is, the mapping γ is an objective function of such a linear program.

Consider an indexed collection $\boldsymbol{u} \in V^M$, which consists of any vectors $u_i \in V$ for $i \in M$. The collection induces the linear mapping $\iota \boldsymbol{u}^{\mathrm{T}} : F^{(M)} \to V$ defined by $\iota \boldsymbol{u}^{\mathrm{T}} : \boldsymbol{\mu} \to \iota \boldsymbol{u}^{\mathrm{T}} \boldsymbol{\mu} = \sum_{i \in M} \mu_i u_i$ for any indexed collection $\boldsymbol{\mu} \in F^{(M)}$ consisting of $\mu_i \in F$ such that the set $\{ i \in M : \mu_i \neq 0 \}$ is finite. Then $\iota \boldsymbol{u}^{\mathrm{T}} A$ denotes the composition of the linear mappings $A : W \to F^{(M)}$ and $\iota \boldsymbol{u}^{\mathrm{T}} : F^{(M)} \to V$. For any $x \in W$, we have $\iota \boldsymbol{u}^{\mathrm{T}} A x = \sum_{i \in M} (\alpha_i(x)) u_i$. Likewise, for any indexed collection $\boldsymbol{\lambda} \in F^M$, which consists of any scalars $\lambda_i \in F$ for $i \in M$, we put $\iota \boldsymbol{\lambda}^{\mathrm{T}} \boldsymbol{\mu} = \sum_{i \in M} \mu_i \lambda_i$ and $\iota \boldsymbol{\lambda}^{\mathrm{T}} A x = \sum_{i \in M} (\alpha_i(x)) \lambda_i$ for any $x \in W$.

Given any subset $M^- \subseteq M$, we define that the indexed collection $(\alpha_i)_{i \in M^-}$ is *F-linearly independent* if and only if, for any $\boldsymbol{\lambda} \in F^M$, it holds that $\iota \boldsymbol{u}^{\mathrm{T}} A = o$ implies $\boldsymbol{\lambda} = \mathbf{0}$, where o is the zero linear form $o : W \to F$.

We define that the given linear mapping $A : W \to F^{(M)}$ *satisfies the constraint qualification (CQ)* if and only if, for any infinite subset $M^- \subseteq M$ such that the indexed collection $(\alpha_i)_{i \in M^-}$ is F-linearly independent, there exists a point $x_{M^-} \in W$ such that $\alpha_i(x_{M^-}) \leq 0$ for all $i \in M$ and $\alpha_i(x_{M^-}) < 0$ for at least one $i \in M^-$.

We have the following results:

The presented infinite variant of Gale's Theorem says in words that, under the constraint qualification (CQ), there is a solution $x \in W$ to the infinite system of linear inequalities $Ax \leq \boldsymbol{b}$, see $(\star\star)$, if there is some solution $x_I \in W$ to any finite subsystem $A_I x \leq \boldsymbol{b}_I$ of the system, for any finite $I \subseteq M$, see $(\star)$. Notice that this variant of Gale's Theorem exhibits the property of compactness thus.

We now turn our attention to transferable utility cooperative games (TU-games for short). Let N be a finite or infinite set of players. A *coalition* is any subset $S \subseteq N$. Let $\mathcal{A} \subseteq \mathcal{P}(N) = \{ S : S \subseteq N \}$ be the collection of all feasible coalitions. We assume that $\mathcal{A}$ is a field of sets; that is, a collection such that $\emptyset \in \mathcal{A}$ and, if $S, T \in \mathcal{A}$, then $N \setminus S \in \mathcal{A}$ and also $S \cup T \in \mathcal{A}$. A TU-game is represented by its *coalition function*, which is conventionally a mapping $v: \mathcal{A} \to \mathbb{R}$ such that $v(\emptyset) = 0$. Henceforth, we consider a generalized coalition function; that is, a mapping $v: \mathcal{A} \to V$ such that $v(\emptyset) = 0$, where V is a linearly ordered vector space over a linearly ordered (commutative or skew) field F.

The Bondareva-Shapley Theorem for the additive core. *Let V be a linearly ordered vector space over a linearly ordered (commutative or skew) field F. For any coalition function $v: \mathcal{A} \to V$, with $v(\emptyset) = 0$, it holds that* $\mathsf{a\text{-}core}(v) \neq \emptyset$ *if and only if the game is balanced.*

We establish this generalization of the Bondareva-Shapley Theorem by using the above infinite variant of Farkas' Lemma in a purely algebraic way, which allows us not to use the tools of functional analysis and/or topology, such as Alaoglu's Theorem or Tychonoff's Theorem (both of which relate to the notion of compactness).

Would congestion-based service systems with impatient users be in equilibrium?

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Congestion-based service systems such as call centers, telecommunication networks, and logistics platforms often experience user abandonment due to limited capacity. Admission control is therefore essential for such systems that minimizes the long-run average system cost. In such systems, quality of service (QoS) experienced by the user-base depends on the service provider's admission control policy, while users respond strategically through their abandonment behavior. This interaction naturally gives rise to a one-period, two-player non-cooperative game between the service provider and its user base.

We first establish the existence of the optimal admission control limit when the abandonment rate lies below a system-dependent threshold. We then analyze the existence and computation of pure-strategy Nash equilibria (PSNEs) for several QoS measures and prove their monotonicity with respect to key system parameters. When PSNEs fail to exist, we characterize an equilibrium set capturing cyclical

behavior of the system between low and high abandonment regimes and provide sufficient conditions for its existence. Finally, we extend the analysis to multi-server queueing systems with strategic, impatient users.

Reliability analysis of anti-UAV systems: an analytical approach

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Unmanned aerial vehicles (UAVs) have become a vital component of modern technology, widely utilized in various fields, including surveillance, communications, scientific research, and civilian applications. At the same time, the rapid growth and easy availability of UAVs have also created new security challenges, as they can be misused for unauthorized or malicious activities. To address these challenges, anti-UAV systems are developed to detect, track, and neutralize unknown UAVs and ensure the safety of protected areas.

In this work, our main focus is on the reliability analysis of the anti-UAV using the fundamental aspects of the anti-UAV system, in which the stochastic model is constructed to analyze the reliability attributes and the random nature of system operations and uncertainties. Two different analytical approaches are used for this purpose: the Continuous-Time Markov Chain (CTMC) model and the Semi-Markov Process (SMP) model. The CTMC model is used for the evaluation of both transient and steady state system behaviour, while the SMP model gives more flexibility in representing state transitions with more general time distributions. The steady-state probabilities of the SMP model are obtained using the two-stage method. Based on these models, important reliability performance measures are evaluated and analyzed. The numerical results are presented in graphical form to illustrate the system's reliability characteristics under different conditions clearly. It is observed that system reliability increases with increased redundancy in critical parts, while high failure rates significantly decrease system performance. Furthermore, a simulation method is employed to confirm the analytical findings, revealing a significant correlation between the theoretical and simulation results. The proposed analysis offers critical insights into the reliability and performance of anti-UAV systems, enabling their effective design, evaluation, and operational planning.

Essential stability for vector variational inequality problems

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The theory of vector variational inequalities started with the pioneer work of Giannessi [1] in 1980, as an extension of the classical variational inequality for scalar-valued functions in the setting of finite dimensional spaces. Since then, many researchers explored different aspects of vector variational inequalities. Stability theory in variational inequalities helps to analyse the nature of solution sets under perturbations of the involved function or parameter. In literature, different aspects of stability have been studied in terms of continuity of solution set maps and convergence of solution sets. One of the aspects of stability, namely essential stability ensures that a perturbed problem, whose objective is sufficiently near the original problem, has solutions lying arbitrarily near the solutions of the original problem. The idea of essential stability was first proposed by Fort [2] in terms of essentiality of fixed points of continuous maps defined on a compact metric space to itself.

In this presentation, we discuss essential stability for a vector variational inequality problem involving a set-valued map and for a vector variational inequality problem involving a single-valued map. We establish a relationship between solutions of a set-valued optimization problem and solutions of a vector variational inequality problem involving a single-valued map, by means of Clarke epiderivative. This helps to extend the essential stability results for the set-valued optimization problem.

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*Joint work with Sonia, Janki Devi Memorial College, University of Delhi, R. D. Sarma, Rajdhani College, University of Delhi

Partial cooperation in resource extraction on networks: sharing wealth versus sharing extraction rights

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We study a differential game of resource extraction in which players' resource deposits are interrelated and the spatial relations between resources of players can be modelled by a network. This holds if e.g., a marine fishery is divided into Exclusive Economic Zones of countries or if multiple farmers pump groundwater or deep water from a common aquifer. The interactions can be asymmetric and players' areas can have different reproduction rates.

For this game, we study the potential of cooperative behaviour. We compare the Nash equilibrium payoff to payoffs if at least a fraction of players cooperate, and we check stability of various types of coalitions. We also study the problem of sustainability. Besides the typical approach with coalitions maximizing sum of payoffs of its members when each players extract in their own node only and side-payments only are possible, we consider maximization of collaborative extraction when besides side payments, extraction rights can be shared.

Solving Mathematical Programs with Vanishing Constraints

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The talk presents effective numerical methods for solving mathematical programs with vanishing constraints. Owing to the presence of complementarity-type constraints, standard constraint qualifications fail to hold at any feasible point. Consequently, several stationarity concepts—such as Clarke, Mordukhovich, and strong stationarity—have been developed specifically for this class of problems. However, the corresponding stationarity systems involve unknown index sets, which has so far prevented their direct numerical solution.

In this work, we successfully eliminate the unknown index sets from these stationarity systems and reformulate them as systems of smooth equations with box constraints. To solve the resulting constrained equations, we propose a modified Levenberg–Marquardt method. Under weak local error bound conditions, we establish local super-linear convergence of the proposed method. Moreover, we provide

sufficient conditions ensuring the validity of local error bounds and illustrate, through several examples, that these conditions are not overly restrictive.

Approximate dynamic programming

based thresholds for cargo capacity management considering postponements

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We consider an airline that operates sequential flights in an origindestination pair. Cargo products are opa quein terms of which specific transportation vessel or routing is used to carry a shipment. Hence, based on the time sensitivity, shipments can be postponed to later flight departures to accommodate the high-value requests.

The objective is to assist the airline with joint capacity control and overbooking decisions, considering all the complexities associated with the cargo product. We model the master problem as an infinite-horizon dynamic program (DP) with frequent arrivals and infrequent departures, and relax the cargo divisibility assumption while computing offload costs. We decompose the master problem into several DP sub-problems,with each one focusing on individual flights considered in the study. As the proposed DP sub-problem solutionbecomes intractable, we resort to approximate dynamic programming to find an implem entable solution.

Specifically, the space of policies based on control limits or thresholds is looked upon as they are easily implementable. Hence, we use approximate policy iteration to find the implementable solution, where we prove the convergence and existence of such a solution. Numerical results illustrate that the proposed soution of the sub-problem performs 6%–9% better than the first-come, first served policy and approximates 88%–94% of the upper bound. Additionally, about 4% - 10% of revenue improvements are possible if the postponementstrategy is considered. Extensions to time-dependent thresholds, aircraft selection, and policy beyond allowable limits are also discussed.

Q_0-matrices revisited.

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We revisit the notion of Q_0-matrices. A short survey will be followed by a presentation of some new results.

Cooperative Games and Focal Point Inducing Mechanisms

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Indian Institute of Technology Bombay, India

In this talk, we discuss focal point inducing mechanisms in cooperative games. This helps in selecting a unique core by augmenting the original cooperative game.

A neural network approach for mathematical programming problems having vanishing constraints

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In this paper, we consider a mathematical programming problem with vanishing constraints (MPVC) and present a neural network model that employs smoothing and regularization techniques. Owing to the existence of critical kinks in the feasible set, we reformulate the (MPVC) problem into a smooth nonlinear programming problem (SNLP(r)), thereby addressing the shortcomings inherent in the original (MPVC) formulation. Subsequently, the optimal solution of the transformed nonlinear problem is approximated using a dual-based neural network model. The theoretical analysis demonstrates that the equilibrium point of the network is asymptotically stable and converges to the optimal solution of the problem (MPVC). Simulation results further support the theoretical findings and confirm the computational efficiency of the proposed model.

Unimodality and peak location of the characteristic polynomials of two distance matrices of trees

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Unimodality of the normalized coefcients of the characteristic polynomials of distance matrices of trees are known and bounds on the location of its peak (the largest coefcient) are also known. Recently, an extension of these results to distance matrices of block graphs was given. In this work, we extend these

results to two additional distance-type matrices associated with trees: the Min4PC matrix and the 2-Steiner distance matrix. We show that the sequences of coefcients of the characteristic polynomials of these matrices are both unimodal and log-concave. Moreover, we nd the peak location of the coefcients of the characteristic polynomial of the Min4PC matrix of any tree on n vertices. Further, we show that the Min4PC matrix of any tree on n vertices is isometrically embeddable in Rn−1 equipped with the 1-norm.

*This is joint work with Rakesh Jana and Iswar Mahato

Some Results on the Applications of Generalized Inverses in the Network Optimization Problems

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Applications of Generalized Inverse in Network Theory had been observed long way back in 60's of last century, when the theory of generalized inverse was in infant status. The subjects of generalized inverses and graph theory intersect and are extensively studied in the literature and found applications in different part of science. The matrices such as incidence matrix, adjacency matrix and Laplacian matrix play prominent role in studying the network flow, electrical networks, defining new distances on graphs and studying Markov process. For example, if Q is the incidence matrix of given network (muti-digraph) then Qx = b represents net inflow at each vertex when the flows through the edges of network is given by x. As the matrix Q is not invertible and the solution for Qx = b need not be unique or consistent, it is of natural interest that to find minimum inflow through n arcs of the network to achieve net inflow at m vertices are as close as possible to the desired net inflow. In the later part of last century and in the beginning of present century, these subjects have been developed independently and several matrix properties of graphs have been explored. At the same time several algebraic and combinatorial properties of Generalized inverses have been studied.

In this talk, some interesting applications of generalized inverses in the graph theory are revisited. Interesting properties of generalized inverses, established in the recent time, are employed to make the proof of several known results simpler, and several techniques such as bordering method and inverse complemented matrix methods are used to obtain simple expressions for the Moore-Penrose inverse of incidence matrix and Laplacian matrix. Some interesting and simpler expressions are presented in some special cases such as tree graph, complete graph and complete bipartite graph.

Second Order Conditions in Convex Multiobjective Opimization*

Joydeep Dutta,

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Second order conditions are of great theoretical importance in determining whether a point satisfying the first order condition is a local minimizer of maximizer in absence of convexity. This is true in both constrained and unconstrained optimization. This basic paradigm of scalar optimization does not hold for multiobjective optimization even in the presence of convexity. In this talk we show how second order conditions play a key role in detecting whether a point satisying KKT conditions is a Pareto minimizers. We will also dicuss several types of second order subderivatives and the role they play in multiobjective optimization.

*Based on an ongoing work with Kanchan Mittal , IIT Kanpur and Md. Abu Talah Ansary, IIT Jodhpur.

Distributionally Robust Single-Controller Chance-Constrained Stochastic Games

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Department of Mathematics

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We study a two-player single-controller stochastic game with known transition probabilities and random running costs whose distributions are only partially known. The true distribution of each player's running cost vector is assumed to lie within an ambiguity set constructed using available information on the first two moments. We consider two different moments-based ambiguity sets and establish the existence of a stationary Nash equilibrium in each case. Furthermore, we show that, for both ambiguity sets, the Nash equilibrium problem is equivalent to the global optimization of a suitably formulated mathematical programming problem. As an application to these games, we considered a moving target defense problem and compute its Nash equilibria by computing the global optimal solutions of corresponding equivalent mathematical programs.

On the Properties of Solutions of Absolute Value Equations and Related Matrix Classes

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In this talk, we investigate properties of the solution set of absolute value equations of the form Ax+|x|=b, motivated by two open problems posed in recent work by Hladík [*SIAM J. Matrix Anal. Appl.*, 44 (2023), pp. 175–195]. These problems concern the uniqueness of solutions, the existence of nonnegative solutions, and the dependence of these properties on the matrix A. In addition, we provide further insights into the convexity of the solution set of absolute value equations by using its equivalence with the corresponding linear complementarity problem.

Characterization and Optimality of Boolean and Crisp Boolean Petri Nets

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Boolean Petri nets form an important subclass of 1-safe Petri nets, characterized by their ability to generate all binary marking vectors. This talk investigates the structural properties, embedding results, and characterization problems associated with Boolean and crisp Boolean Petri nets. We show that every 1-safe Petri net can be embedded as an induced subnet of a Boolean Petri net, implying the nonexistence of a forbidden subnet characterization and highlighting the intrinsic complexity of the problem. Several necessary and sufficient conditions for Boolean and crisp Boolean Petri nets are presented in terms of initial markings, incidence matrices, and transition structures. Special attention is given to Petri nets containing strong chain cycles (SCCs), for which partial characterizations are obtained. Further, the notion of optimal crisp Boolean Petri nets is introduced, focusing on minimal order, size, and number of enabled transitions. Corollaries establishing bounds on self-loops and transition structures for optimality are discussed. The results contribute toward a deeper understanding of the structural and computational aspects of Boolean Petri nets, while also identifying open problems in the characterization of strongly connected Boolean Petri nets.

Abstract of the Contributed Talks

Sweet Little Lies: Strategic Manipulation by AI Shopping Assistants

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AI shopping assistants increasingly mediate consumer purchasing decisions, yet the platforms deploying these systems often earn differential margins across products. We develop a model in which a chatbot receives a noisy signal about product fit and sends recommendations to a Bayesian consumer. The platform profits more when consumers purchase its preferred product, creating incentives to steer recommendations regardless of true fit. False recommendations arise from two distinct sources: hallucination (technological error from imperfect diagnosis) and strategic steering (economic manipulation despite correct diagnosis).

Our central result is the Competence Paradox: as diagnostic accuracy improves, the optimal steering rate increases. More capable AI earns greater credibility, which the platform exploits by mixing in more manipulative recommendations while maintaining consumer obedience. Investment in AI capability thus transforms rather than eliminates errors—reducing hallucinations while increasing strategic steering. Despite this transformation, consumer welfare remains in- variant to accuracy improvements; the platform captures the entire surplus from enhanced diagnostic capability.

We extend the model to examine belief asymmetries and verification behavior. When consumers overestimate AI accuracy, they suffer a "hype penalty"—inflated trust enables greater manipulation. When consumers consult multiple chatbots for second opinions, welfare improves only if the chatbots are operated independently; connected chatbots coordinate an "echo chamber" that neutralizes the benefits of cross-referencing. Our findings suggest that accuracy mandates alone are insufficient for consumer protection and must be paired with transparency requirements, anti-steering regulations, and policies pre- serving independence among AI recommenders.

On the Equivalence of Monge and Kantorovich problems in discrete optimal Transport

Thirumulanathan D and J. Dutta

IIT Kanpur

Consider a discrete optimal transport problem that has at least two consumers. We show that the Monge and Kantorovich versions of such a discrete optimal transport problem are equivalent for all cost functions if and only if the supply from all the suppliers are equal, and the demand from every consumer is an integral multiple of the supply. When there is only one consumer, we show that the equivalence is trivially true irrespective of the supply and demand.

Duopoly Competition with Quality-Dependent Fixed Costs in Covered and Uncovered Markets

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This paper develops a theoretical framework of a vertically differentiated duopoly to examine how quality-dependent fixed costs influence equilibrium outcomes in covered and uncovered markets under an unregulated environment. The model is formulated as a two-stage game in which firms first choose quality levels and subsequently compete in prices. Consumer preferences are characterized by heterogeneous tastes for quality, and market coverage arises endogenously from firms' strategic decisions.

In the absence of quality regulation, the sub-game-perfect Nash equilibrium exhibits asymmetric quality provision: one firm selects the highest feasible quality, while the rival offers a lower quality level, generating an interior degree of quality differentiation. In uncovered markets, equilibrium qualities, prices, profits, consumer surplus, and social welfare are all positively related to quality-dependent fixed costs, while the degree of quality differentiation remains higher and largely independent of market coverage conditions.

By contrast, in covered markets, increases in quality-dependent fixed costs negatively affect the low-quality firm's output and social welfare, whereas prices, profits, and the degree of quality differentiation increase. Equilibrium prices and market outcomes are jointly determined by consumers' taste for quality and the extent of quality differentiation, with distinct equilibrium regions characterizing covered and uncovered markets.

Overall, the analysis highlights the central role of quality-dependent fixed costs in shaping firms' strategic behavior, market coverage, and welfare outcomes in vertically differentiated duopoly markets.

Generalized Inverses in Network Flow Optimization

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The Moore-Penrose inverse of the matrices associated with graphs such as incidence matrix and Laplacian matrix have interesting applications in studying the network flow, electrical networks and in defining new distances on graphs. The recent developments in the area of generalized inverses include the introduction of several new techniques of computing different generalized inverses of a given matrix. In the present talk, different computational techniques are employed to obtain the Moore-Penrose inverse of incidence matrix of a given connected graph. Further, an explicit bordering required to obtain the Moore-Penrose inverse of incidence matrix of a tree is described.

The Anatomy of Value Creation: Input-Output Linkages, Policy Shifts, and Economic Impact in India's Mobile Phone GVC

Sourish Dutta

VIPS-TC (GGSIPU, Delhi)

Motivation and Research Problem

The imperative for developing economies to generate large-scale, non-farm employment while fostering industrial deepening is a central challenge of our time. Integration into Global Value Chains (GVCs) is widely seen as a crucial strategy to achieve these goals. India's mobile phone manufacturing sector presents a compelling and high-stakes case study in this context. Propelled by policy shifts from the import-substitution-focused Phased Manufacturing Programme (PMP) to the export-oriented Production Linked Incentive (PLI) scheme, the sector has witnessed explosive growth in output and exports.

However, this success has been met with scholarly debate, with critics arguing that it may represent low-value final assembly with limited domestic value addition (DVA), questioning the net economic benefits once the high import bill for components is considered. This paper addresses this debate by moving beyond aggregate statistics to provide a granular, data-driven quantification of the sector's true economic impact.

Our primary research question is: To what extent has India's engagement in the mobile phone manufacturing GVC contributed to (a) domestic value addition, (b) employment generation

(disaggregated by skill and gender), and (c) aggregate wage earnings?

Conclusion and Policy Relevance

This paper provides robust, micro-founded evidence that India's engagement in the mobile phone GVC has catalysed significant domestic economic gains that extend well beyond final assembly. The findings demonstrate a substantial deepening of domestic backward linkages. From an Operations Research perspective, this study validates the SUT-IOT framework as a powerful tool for ex-ante policy impact assessment and for identifying strategic upstream sectors for targeted industrial policy. The results suggest that a strategy of GVC integration, even if initially assembly-led, can foster significant industrial capabilities and socio-economic benefits.

Application of Double Orbit Retrial Repair Model in Hydraulic Cylinder Repair Workshop

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Managing queue in the space-constrained machining workshop is crucial to minimizes downtime, lowers waiting costs, and improves productivity. This study investigates the waiting time of failed cranes in a hydraulic cylinder repair workshop (HCRW), where a single Hydraulic Cylinder Honing (HCH) machine acts as the server, analyzed through a double-orbit retrial machine repair model under Markovian assumptions. The framework assumes there is no waiting space in front of the HCH machine, so any failed crane that arrives while it is busy is directed to one of two retrial orbits, classified according to the type of crane or the manufacturing model. From these orbits, the cranes attempt to reaccess the HCH machine after a random time with distinct retrial rates. An admission control mechanism, the F-policy, is incorporated to manage the congestion in queueing system by suspending the entry of new arrivals when the HCRW becomes saturated and allowing them again once the number of failed cranes in the workshop drops below a pre-defined threshold level, F. The proposed model also incorporates queueing features such as two stage restoration for unreliable HCH machine and a feedback mechanism for inadequately serviced cranes. Various performance measures, such as the mean number of failed cranes in the orbits and the system, throughput, availability, etc., are evaluated using steady-state probabilities for all system states, where these probabilities are obtained by recursively solving Chapman-Kolmogorov difference equations. The system's operating cost is optimized using the quasi-Newton method. Numerical experiments are then carried out to study how parameters variation influences the system's performance measures.

Robust Optimization Frameworks for 3D Sensor Networks in Uncertain Terrains

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Sensors play a vital role in environmental monitoring, surveillance, and disaster management. However, uncertainties in their exact location or orientation often reduce their effectiveness. Robust optimization provides a mathematical framework to handle such uncertainties, ensuring that solutions remain feasible and efficient even under unpredictable conditions. In this work, we introduce the concept of the Radius of Robust Feasibility (RRF) as a measure of tolerance against positional errors in directional sensor networks. The RRF defines the maximum uncertainty within which the system can still guarantee coverage. We integrate this concept with directional and aerial sensor models, derive exact formulations for feasible coverage under uncertainty, and propose distributed orientation adjustment algorithms based on Voronoi partitioning. Results show that our framework significantly enhances sensing robustness and coverage performance compared to traditional deterministic methods, offering a strong foundation for reliable and resilient sensor network design.

Optimization of the Number of Variables for Model Development

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We came across 114 variables in the study of effective leadership and in order to optimize the number of variables we used factor analysis. Further we developed a statistical model for predicting Effective Leadership (Y). The decision variables used in the model are Leadership Style, Personality, Cultural Intelligence, Trust and Communication under which the variables are clubbed. A simple random sampling technique has been used to obtain the data.The data of 364 respondents were collected from the e-commerce industry and can be considered to be of Transformational Leadership Style which is one of the decision variables. The Reliability Test has been performed to understand the internal consistency of the variables, the acceptability of Reliability Test is measured and found to be acceptable for the decision variable and the predicting variables (George, D., and Mallery, M.,2003). A regression analysis was conducted on the model to test the model fitness and The Model Summary table tells us that the regression model is highly significant since $p < .01$, and accounted for approximately 77.9 % of the variance in leadership effectiveness, which means the five independent variables explains 77.9 % of the

dependent variable. It is observed that R^2 = 0.779 and adjusted R^2 = 0.776, which predicts that after adjusting for the number of predictive variables, the model still explains 77.6% of variance which shows a very good model fit. The Regression Equation formed is Leadership Effectiveness(Y) = 4.75 + 0.361(Leadership Style) + 0.206(Personality) + 0.2(Cultural Intelligence) + 0.217(Trust) + 0.138(Communication).

The study suggested an exploratory factor analysis to understand the underlying latent variables of the questionnaire used to measure the decision variable and the predicting variables. The Kaiser-Meyer-Olkin measure for adequacy of sample and The Bartlett's Test of Sphericity in all the decision variables showed an associated level of significance smaller than 0.01 which suggests that the correlation matrix has significant correlations among at least some of the variables and is sufficient to access the factorability of the data. The Total Variance Explained section presented the number of common factors extracted, the eigenvalues associated with these factors, the percentage of total variance accounted for by each factor, and the cumulative percentage of total variance accounted for by the factors. Using the criterion of retaining only factors with eigenvalues of 1 or greater, seven factors were retained for rotation out of twenty-one variables for decision variable Leadership Style. These seven factors accounted for a total of 65.32% of the total variance. Four factors were retained for rotation out of twenty factors for decision variable Personality. These four factors accounted for a total of 68.02% of the total variance. Five factors were retained for rotation out of twenty factors for decision variable Cultural Intelligence. These five factors accounted for a total of 72.59% of the total variance. Five factors were retained for rotation out of seventeen factors for decision variable Trust. These five factors accounted for a total of 74.53% of the total variance. Five factors were retained for rotation out of sixteen factors for decision variable Communication. These five factors accounted for a total of 66.06% of the total variance. Six factors were retained for rotation out of twenty factors for predicting variable Effective Leadership. These six factors accounted for a total of 68.94% of the total variance. The solution has also been verified from the scree plot.

A total of 32 variables were extracted and retained from 114 variable questionnaires predicting the decision variable Effective Leadership. After the process of reduction, the extracted 32 variables were clubbed to 19 variables in the model. The proposed model will help us in better understanding of Effective Leadership. So this model is helpful in the process of management decision making.

Variational Control Problems with Multiobjective Interval-Valued Functions: Optimality and Duality

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This paper addresses a multiobjective interval-valued variational control problem (MIVVCP). We introduce the concept of (weakly) LU-efficient solutions using partial ordering re-lations. Under generalized convexity assumptions, we derive the Karush-Kuhn-Tucker (KKT) necessary and sufficient optimality conditions for weakly LU-efficient solutions within the (MIVVCP) framework. Furthermore, we analyze the Wolfe-type dual (WD) and Mand-Weir dual (MD) models, presenting several duality theorems. To support our theoretical findings, we provide numerical examples.

Robust mean-variance portfolio selection with intractable claim under probability distortion

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We explore the robust mean-variance portfolio selection model with an intractable claim under probability distortion. The mean-variance theory is an investment decision making rule, which maximizes the expected return corresponding to a given risk or minimizes the risk corresponding to a given expected return of a portfolio, where risk is defined as the variance of the portfolio's return.

Investors usually face various financial claims during the investment period, which may not directly depend on the underlying market. Still, these can significantly impact the terminal payoff of an investment. A few examples of such claims are winning a lottery, a financial burden due to health risk, or a payoff of a real estate investment, among many others. Hou and Xu [2] referred to this type of claim as 'intractable claims' and studied robust mean-variance portfolio incorporating such claims.

Additionally, investors behave differently toward gains and losses, and often overestimate small probabilities and underestimate large ones. A probability distortion function can capture this investing phenomenon. The behavioral payoff represents a distorted version of the investment payoff, and its distribution is the reshaped distribution of the investment payoff, altered by a distortion function. In particular, if $w(\cdot)$ is a probability distortion function ($w(0) = 0$, $w(1) = 1$, and $w(\cdot)$ is strictly increasing differentiable function on $[0, 1]$) and X be investment payoff then we denote the behavioral payoff by $\tilde{X}$ whose distribution function is given by $1 - w(1 - F_X(x))$. Thus, the payoff of behavioral investors can depend heavily on the probability distortion. Bi and Li [1] examine the behavioral portfolio in the mean-variance framework.

We simultaneously integrate the behavioral payoff, influenced by the distortion function and the payoff of an intractable claim in terminal wealth, in the mean-variance portfolio settings. We assume the risky assets are driven by geometric Brownian motion, and $\{X^{\pi}(t) : t \in [0, T]\}$ is the evolution of the wealth process corresponding to the portfolio $\pi(\cdot)$. Let Θ be the payoff of an intractable claim. Therefore, the terminal wealth consists of $\tilde{X} := \widetilde{X^{\pi}(T)}$ and Θ. We consider the worst-case scenario among all possible identically distributed random variables representing the intractable claim and examine the robust investment problem (see [3]).

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Farmer's Game: A N-person Stag hunt game model

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This paper presents a new variant of the Farmer's Game, an extension of the N-person Stag Hunt, to model cooperative decision-making in crop residue management. Farmers choose between burning residue ("Red"), which yields a guaranteed but environmentally harmful return, and adopting a greener alternative ("Green"), which is collectively beneficial but requires coordination. The analysis identifies two Nash equilibria: a natural Pareto-inferior state with universal "Red" and a Pareto-

superior state with universal "Green."

To promote the optimal outcome, we propose a history-based payoff allocation that rewards players proportionally to their past cooperation, incentivizing early adoption and deterring free riding. The mechanism is self-sustaining, requiring no external subsidies, and converges to equal payoffs once full cooperation stabilizes.

The Farmer's Game offers a tractable framework for real-world collective action problems, with applications extending beyond agriculture to environmental sustainability, resource management, and climate cooperation.

On the Properties of Solution Set of Absolute Value Equations ∗

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We investigate the structural properties of the solution set of absolute value equations (AVE) of the form $Ax - |x| = b$. Extending the seminal work of Hlad´ık (SIAM J. Matrix Anal. Appl., 2023), we address his open questions originally posed for $Ax+|x| = b$ and establish analogous results for the alternative form considered here. Using the equivalence between AVE and the linear complementarity problem (LCP), we derive new results on the convexity and solvability of the AVE under various matrix classes, including positive semidefinite, Metzler, and Z-matrices. Further, we present sufficient conditions guaranteeing unique and nonnegative solutions for $b \geq 0$ or $b \leq 0$, and provide counterexamples showing that several properties valid for $Ax+|x| = b$ fail to extend to $Ax-|x| = b$. These findings contribute to the theoretical understanding of AVEs and enrich the connection between matrix theory and complementarity problems.

First and second order optimality conditions for nonsmooth multiobjective problems with equilibrium constraints

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In this talk, we first extend the constant positive linear dependence (CPLD) condition in terms of convexificators given by Rimpi and Lalitha [Constraint qualifications in terms of convexificators for nonsmooth programming problems with mixed constraints. Optimization. 2023;72(8):2019-2038] for nonsmooth scalar optimization problems to nonsmooth multiobjective optimization problems with mixed constraints (MOP) which we denote by MOP-CPLD. It also extends the CPLD condition given by Andreani et al. [On the relation between constant positive linear dependence condition and quasinormality constraint qualification. J Optim Theory Appl. 2005;125(2):473-483] involving continuously differentiable functions. We establish a strong Karush-Kuhn-Tucker (KKT) optimality condition to identify local Pareto efficient solutions under the MOP-CPLD framework. We also introduce a suitable CPLD condition for a nonsmooth multiobjective optimization problem with equilibrium constraints in terms of convexificators which is denoted by MOPEC-CPLD. We introduce several nonsmooth strong Pareto stationary points for the MOPEC which extend the notions of strong Pareto stationary points given by Zhang et al. [Constraint qualifications and proper Pareto optimality conditions for multiobjective problems with equilibrium constraints. J Optim Theory Appl. 2018;176:763-782] for continuously differentiable functions. We provide necessary and sufficient optimality conditions to identify a stationary point as a Pareto efficient solution of the MOPEC under the MOPEC-CPLD condition. Further, we introduce Abadie constraint qualifications for MOPEC which is denoted by MOPEC-SOACQ in terms of Clarke generalized derivative and second-order upper directional derivative given by Pales and Zeidan. This notion utilizes second-order ACQ given by Anchal and ´Lalita [Second-order optimality conditions for locally Lipschitz vector optimization problems. Optimization. 2023;1-20] for multiobjective optimization problems. We derive second-order necessary optimality conditions in both the primal and the dual forms to identify weak Pareto efficient solutions and strict Pareto efficient solutions of order two for MOPEC by utilizing MOPEC-SOACQ. We give some applications of the results in interval-valued multiobjective optimization problems with equilibrium constraints and in portfolio optimization.

Generalized Fuzzy Entropy for Intuitionistic Fuzzy Soft Sets: Theoretical Insights and Decision-Making Applications

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The multi-criteria decision-making (MCDM) issues are likely to be incomplete, conflicting and filled with hesitant expert judgments that cannot be properly represented by classical representations of fuzzy,

intuitionistic fuzzy and soft-set. In an effort to close this modelling gap, this paper will apply the Intuitionistic Fuzzy Soft Set (IFSS) framework, which allows the representation of membership, non-membership and hesitation degrees of certain parameters, in which experts instinctively characterize uncertainty, such as in the application of healthcare appraisal, sustainability planning and risk assessment. Based on this, a new parameter-sensitive entropy measure is to be introduced to measure the uncertainty of IFSS structures. The proposed measure is the first of its kind to incorporate all three elements of the intuitionistic assessment directly and improve the distinction of alternatives in multi-criteria decision-making (MCDM), unlike current intuitionistic fuzzy measures of entropy, which are relatively parameter-insensitive and poorly sensitive to hesitation. The entropy is incorporated into a TOPSIS-based decision process, and the mathematical characteristics of it, such as boundedness, symmetry, and monotonicity under hesitation redistribution, are proved. An updated case study shows the feasibility of eliciting IFSS assessments by use of a structured linguistic-to-intuitionistic mapping protocol and how the proposed entropy enhances contrast in ranking ratings in comparison with classical methods. The findings underscore the ability of the method to model parameter-specific uncertainty in a better way, with limitations and opportunities for future validation using real-life datasets also being noted.

Evolutionary Game Theory for Optimizing LLM Performance, Compute Costs, Hallucinations, and Accuracy

Prasad K

Evolutionary game theory (EGT) provides a rigorous mathematical paradigm for automating optimal large language model (LLM) selection, balancing computational cost, accuracy, and hallucination risk as functions of query complexity. Let the set of candidate LLMs be $\mathcal{M} = \{M_1, M_2, ..., M_n\}$ and the set of incoming queries $\mathcal{Q}$, each with a complexity score $\kappa : \mathcal{Q} \to \mathbb{R}^+$. For each model M_i and query q, define:

- **Accuracy:** $A(q, M_i) \in [0, 1]$, the probability M_i produces a correct answer for q.
- **Cost:** $C(M_i) \in \mathbb{R}^+$, the normalized computational or monetary cost of invoking M_i.
- **Hallucination:** $H(q, M_i) \in [0, 1]$, the probability M_i generates a hallucinated (factually incorrect) answer for q.

The **fitness function** for model M_i on query q is:

$$U(q, M_i) = \alpha(\kappa(q)) \cdot A(q, M_i) - \beta(\kappa(q)) \cdot C(M_i) - \gamma(\kappa(q)) \cdot H(q, M_i)$$

where α, β, γ are non-negative, query-complexity-dependent weights, e.g., $\alpha(\kappa) = a_0 + a_1\kappa$, $\beta(\kappa) = b_0 - b_1\kappa$, $\gamma(\kappa) = g_0 + g_1\kappa$, with $a_0, a_1, b_0, b_1, g_0, g_1 \geq 0$.

In the EGT framework, each M_i represents a strategy in the population. At each timestep t, for query q_t, the **population state** is a probability vector $\mathbf{p}^{(t)} = (p_1^{(t)}, ..., p_n^{(t)})$, where $p_i^{(t)}$ is the probability of selecting M_i. The **expected fitness** for M_i is:

$$\mathbb{E}[U(M_i)] = \mathbb{E}_{q\sim\mathcal{Q}}[U(q, M_i)]$$

Population dynamics evolve via the **replicator equation**:

$$p_i^{(t+1)} = \frac{p_i^{(t)} \cdot \mathbb{E}[U(M_i)]}{\sum_{j=1}^{n} p_j^{(t)} \cdot \mathbb{E}[U(M_j)]}$$

This iterative process converges to an **evolutionarily stable strategy (ESS)**, maximizing accuracy and minimizing cost and hallucination relative to query complexity. The Nash equilibrium of this game yields an optimal, adaptive model selection policy $\pi^*(q)$ that maps each query to the LLM maximizing expected utility. This mathematically principled EGT approach ensures scalable, cost-efficient, and hallucination-averse LLM deployment across diverse tasks.

Optimization modeling of dea for measuring hospital performance efficiency with python coding

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Decision-making units (DMUs) are regarded in the standard DEA technique as entities that transform numerous inputs into multiple outputs so that their relative efficiency may be evaluated. The performance of hospital branches is assessed in this study using the CCR and BCC models, respectively, under constant and variable returns to scale. The paper's goal is twofold: Its objective is to evaluate the performance of seven branches of a hospital in a state Rajasthan. Evaluating the operational performance of hospitals has always been crucial because of their importance to the health and well-being of society. The primary goal is to assess the effectiveness of seven branches of Hospital locations in Rajasthan. The secondary goal is to demonstrate the applicability and effectiveness of Python-based Data Envelopment

Analysis (DEA) using the CCR model for operational efficiency assessment. Hospital management will be able to examine and contrast operational efficacy across branches. The CCR and BCC models of Data Envelopment Analysis (DEA), which are implemented in Python, are used in the study to describe the effectiveness of these branches. Python offers strong modules and an adaptable syntax for Data Envelopment Analysis (DEA) that make data processing, visualization, and model implementation easier. It is ideal for both small- and large-scale efficiency assessments due to its adaptability and integration capabilities. To analysis the proposed method with computational calculation, a numerical example solves to validate the model. Finally, conclusion and future research directions are also presented.

Cooperative Games With Shared Constraints Under Uncertainty

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Individuals often face challenges in choosing strategies when coalition formation is permitted; one such economic example is the tragedy of the commons. In this study, we consider games in which players operate under shared resource constraints and face uncertainty in both their payoff functions and the quantities of available resources. First, we establish the existence of an equilibrium, referred to as a Generalized Nash Equilibrium under Uncertainty (GNEPU). Subsequently, we reformulate the cooperative game using a risk measure and show that the core of the cooperative game with shared constraints is non-empty under certain conditions.

When Priority Fails: A Bilevel Framework for Resolving Passenger-Freight Conflicts in Indian Railways

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Indian Railways operates under a mixed-traffic regime in which passenger services share saturated infrastructure with freight trains exhibiting heterogeneous operating characteristics. This structural heterogeneity generates persistent scheduling conflicts and recurrent delays, particularly on resource-intensive corridors such as the South East Central Railway (SECR) and South Eastern Railway (SER) zones. The Bilaspur-Nagpur corridor in SECR and the Jharsuguda section in SER illustrate how passenger punctuality objectives interact with freight movements that are critical to national energy and industrial supply chains.

This paper formulates mixed-traffic train dispatching as a Stackelberg game within a bilevel optimization framework, where a Zonal Planner acts as the leader and Section Controllers respond optimally as followers. The upper level seeks to minimize system-wide welfare loss, while the lower level minimizes

operational penalties subject to safety, capacity, and feasibility constraints. Freight traffic is classified into high-volume conventional freight, which primarily contributes to congestion through dense headway interactions, and long-haul freight, which additionally induces geometry-driven infeasibility at loop stations due to excessive train lengths. To address these inefficiencies, the paper proposes a class-aware dynamic shadow-pricing mechanism for track slots that internalizes congestion and feasibility externalities, thereby aligning local dispatching decisions with corridor-level economic priorities. The proposed framework explicitly captures geometry-driven operational infeasibility caused by long-haul freight formations, a feature absent from existing bilevel railway dispatching models. The framework provides a principled explanation for observed delays on India's resource corridors and offers a value-based approach for resolving passenger-freight conflicts when rigid priority rules fail.

Optimal Replenishment Policy for a Dual-Warehouse Fractional-Order Inventory System with Memory-Dependent Deterioration and Shortages

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Effective inventory management for deteriorating goods requires accounting for past system states, yet traditional models often overlook these historical dependencies. This paper investigates a dual-warehouse inventory framework where the stock depletion process is governed by memory effects. By applying the Caputo fractional derivative, we model the inventory flow to capture non-local behavior, resulting in state equations that utilize two-parameter Mittag-Leffler functions. This approach provides a more realistic representation of how market memory and historical degradation patterns influence current stock levels. The study aims to minimize the cost performance per unit time, framed as a constrained non-linear optimization problem. We integrate fractional-order calculus not only in the state equations but also in the cost accumulation process, allowing for a power-law weighting of various cost components, including for storage, deterioration, and shortage over the replenishment cycle. Due to the mathematical complexity introduced by fractional integrals and transition constraints between the rented and self-owned

warehouses, we employ a Genetic Algorithm to identify the optimal replenishment period and order quantity. Our numerical results over a realistic case-based implementation confirm that the fractional-order parameter significantly shifts the optimal policy, suggesting that ignoring memory-driven learning effects on maintenance can lead to substantial cost inaccuracies in storage management. Stability analysis through rigorous computations further confirms on the stability of the improvised decision-tool developed in this research work.

Efficiency is not Stability: An Endogenous Coalition formation game in Last-mile delivery

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In recent years, rapid urbanization and the deep penetration of internet-enabled commerce have pushed last-mile logistics to the forefront of supply chain challenges, turning into critical bottleneck (Luo et al., 2022). Despite being the final leg of delivery, it accounts for a disproportionately large share of logistics costs, traffic congestion and emissions. To tackle this, both academicians and practitioners have increasingly utilized collaboration especially horizontal collaboration among delivery service providers (DSPs) as a tool to improve delivery density, reduce vehicle miles travelled, and enhance resource utilization (Malacina & Teplov, 2022). A substantial body of operations research literature have significantly recognized that firms have to join forces to overcome these challenges while vying for enhanced performance, resilience, and competitiveness (Marty & Ruel, 2024). However, in reality evidences suggests that collaborative initiative either in many cases fail to materialize or dissolve after short trial periods (Fawcett et al., 2012). Despite being cost-efficient at the system level, various collaborations often break down due to asymmetric characteristics at firm level, incentive issues, and strategic partner selection (Faramarzzadeh & Akpinar, 2025; Lozano et al., 2013). Moreover, the current literature falls short to explain the phenomenon of the difference between efficiency and stability, assuming that formation of coalition among all participating firms exclusively brings economic, social and environmental efficiency. In collaborative last-mile literature, works typically rely on deterministic optimization models such as capacitated vehicle routing problems (CVRP) or density-based cost formulation to quantify efficiency gains (Singh et al., 2025). In co-operative game theory literature, cost and profit allocation mechanisms like Shapley value, nucleolus etc are extensively studied under the assumption of grand coalitions. While these mechanisms are used for fairness and stability of allocations

within a coalition, they do not explain whether the feasible coalition will emerge or not. Through this research work, we are bridging these streams by integrating a last-mile cost optimization model with a coalition formation game between DSPs, thereby distinguishing between cost-efficiency and strategic stable collaboration. In this model, a set of independent DSPs operating in the same urban market will be taken into consideration, with each provider serving geographically distributed customer demand and incurring exceeding delivery cost when operating independently. DSPs may choose to collaborate based on delivery operations within subset of firms, thereby exploiting economies of density and route consolidation. Moreover, collaboration is voluntary and non-binding:

• Firms may leave a collaboration, to improve their outcome elsewhere.

• Firms may reject new entrants to improve or reduce their own payoff.

The aim of the work is to determine which coalition structures will be stable based on expected payoff, when firms behave strategically and delivery costs are determined endogenously through optimization.

The proposed framework consists of two layers: Cost Optimization Layer and Payoff Construction. In the first layer, the optimization model will be producing the minimum feasible delivery cost for each coalition. This model is solved repeatedly for all feasible coalitions of firms. In the second layer, Collaborative delivery costs are allocated to individual firms using a transparent, demand-proportional allocation rule, ensuring budget balance and managerial interpretability. Each firm's payoff is defined as the reduction in delivery cost relative to operating independently. These payoffs serve as the input to the game-theoretic analysis.

Evaluation of strategic sustainability are adopted through individual stability solution concept. A coalition structure is individually stable if no firm can improve its payoff by unilaterally moving to another coalition or operating alone, provided that the move doesn't reduce the payoff of firms in the target coalitions. Stability is determined endogenously through a systematic procedure:

1. All feasible coalition structures are enumerated.
2. For each coalition, delivery costs and firm-level payoffs are computed.
3. All admissible unilateral deviations are tested.
4. Coalition structures admitting at least one profitable and acceptable deviation are eliminated.
5. Remaining structures are classified as stable equilibrium outcomes.

Optimization models are solved by using a deterministic solver, while coalition enumeration and stability checks are done algorithmically. Given the exponential growth in coalition structures, the analysis focuses on a realistic number of firms (three to six) sufficient to capture strategic asymmetries, as commonly adopted in coalition formation studies (Abou Mjahed et al., 2025). This study should bring to

light a basic efficiency-stability gap in last-mile collaboration. The main contribution of this paper is a predictive framework for the stability of collaboration in last-mile logistics. Integrating optimization and coalition formation game theory, this research provides reasons why many real-world collaboration initiatives fail despite obvious efficiency gains. From a managerial perspective, the framework allows firms and platforms to assess collaboration proposals ex-ante and to identify self-enforcing partnership structures. From a policy point of view, the results suggest that voluntary collaboration can only result in exclusionary outcomes and may thus call for targeted interventions when inclusiveness is a policy objective.

Integrating Game Theory and Linguistic Intelligence for Hindi Review Sentiment

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Sentiment analysis is a computational methodology that encompasses the recognition, retrieval, and measurement of affective states, opinions, or attitudes articulated by customers. The proliferation of digital data motivates businesses to employ sentiment analysis techniques to monitor the affective states and attitudes of their customers. Due to the vast amount of digital data, various computational methods have been proposed in academic literature to decipher the sentiment of textual content. Existing techniques of Hindi sentiment analysis heavily rely on machine learning and entail extensive dataset pre-training. To address this issue, we proposed the “MOORA & Game Theory Model Based Sentiment Tagger” (MOOGT-ST)” model for the sentiment analysis task. We identify the review's sentiments such as positive, negative, and neutral orientations. We leverage context scores derived from textual comments utilizing the HindiSentiWordNet (HSWN) lexicon and normalized rating scores for MOOGT-ST implementation. This study utilizes the MOOGT-ST model to perform sentence-level sentiment analysis of online reviews. This novel approach offers a promising solution by avoiding the need for extensive training procedures. We show competitive results for various domains of Hindi and English languages. The proposed model demonstrates independence in both domain and language. A statistical analysis was performed to verify its findings. In the end, we discuss various aspects of this model. The proposed model demonstrates a significant level of rationality and coherence in its results.

A bilevel approach to optimize farm subsidies in India

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India supports its agricultural sector through various subsidy mechanisms. Among these, the urea fertilizer subsidy (MoC&F, 2020) and the Minimum Support Price (MSP) (MoCAF&PD, 2021) scheme for crops, directly influence farmers' fertilizer use and crop production decisions. Together these account for nearly 60% of the total subsidy expenditure in India (MoF, 2025). The national average production cost of urea in India is approximately 42000 Indian Rupees (INR) per tonne (MoC&F, 2020) and farmers purchase it at a subsidized market price of 5360 INR per tonne (MoC&F, 2024). The price difference is compensated by the government through direct payments to domestic manufacturers and importers (MoC&F, 2020). With nearly 87% of its production cost subsidized, urea is available to farmers at a low price, leading to its excessive use (Goyal et al., 2024). Consequently, urea alone accounts for nearly 29% of India's total subsidy expenditure (MoF, 2025), imposing a growing fiscal burden on the government. Beyond fiscal concerns, the overuse of urea has contributed to elevated nitrate concentrations in groundwater (Sarkar et al., 2021; Sinha et al., 2022). In several regions of India, nitrate concentrations in groundwater often exceed the Bureau of Indian Standards' (BIS) safe drinking water limit of 45 mg/L (CGWB, 2023). Given that approximately 85% of India's population relies on groundwater as a main source of drinking water (Singh and Goyal, 2025), nitrate contamination poses significant public health risks , including methemoglobinemia (blue baby syndrome), thyroid dysfunction, and an increased risk of certain cancers (NRC, 1995; Ahada and Suthar, 2018). In addition to fertilizer subsidies, India supports farmers through the Minimum Support Price (MSP), which provides income assurance and influences cropping decisions (Mo-CAF&PD, 2021). Together, the urea subsidy and MSP shape farmers' incentives on both inputuse and crop production, highlighting the need for a coordinated pricing policy that jointly adjusts fertilizer and crop prices to curb excessive urea use while preserving farm incentives and reducing subsidy expenditure. To the best of the authors' knowledge, no existing study offers a pricing policy to address these challenges. To address this research gap, this study develops a bilevel optimization model for agricultural pricing policy. The model represents a bilevel (leader–follower) structure (Candler and Norton, 1977; Sinha et al., 2017) in which the gov-ernment sets the urea MRP and crop MSPs at the upper level, and farmers at the lower level determine urea fertilizer use and crop

production in response to those prices. By jointly considering urea fertilizer pricing and crop price support, the proposed framework helps identify price combinations that discourage excessive urea use and thereby reduce nitrogen (urea) pollution without compromising farm-level income. The proposed bilevel model is applied to empirical data of the year 2019, from 20 Indian states that are predominantly engaged in foodgrain production, representing a significant portion of the country's agricultural output. For the study area, total urea and MSP subsidy expenditure in 2019 was estimated at nearly 3.2 trillion INR, while total urea consumption was 38.35 million tonnes. The model generates a Pareto-optimal frontier between governments expenditure on MSP and urea subsidies. Each point represents a feasible combination of urea MRP and crop MSPs. For example, one policy outcome along the Pareto frontier corresponds to a higher urea MRP of 5675 INR per tonne, combined with adjusted crop MSPs. Compared to the baseline, this pricing combination lowers total subsidy spending by 0.31 trillion INR and reduces urea use by approximately 3 million tonnes. These gains are achieved without compromising farmer incomes or the overall crop demand across India. The Pareto frontier thus provides policymakers with a transparent framework to compare alternative pricing strategies and select those that best align fiscal and environmental objectives. This study high- lights the potential of a data-driven pricing framework for balancing environmental objectives, farmer incentives, and government expenditure.

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A hybrid ant colony optimization algorithm based on clark wright saving algorithm for vehicle routing problem with driver fatigue

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This article introduces the vehicle routing problem with driver fatigue (VRP-DF), which incorporates driver fatigue into routing decisions. This problem considers two objectives: first, to minimize the total traveling distance and second, to minimize driver fatigue. We present a mathematical model of the vehicle routing problem with driver fatigue. To solve this problem, we employ a hybrid approach that combines ant colony optimization with the clarke–wright savings algorithm. Finally, we test the performance of hybrid ant colony optimization on the Augerat et al. benchmark. A comparison of hybrid algorithm is made with other algorithms. Computational experiments show that hybrid ant colony optimization algorithm has a robust performance in finding solutions with lower traveling distance in most tested instances.The proposed methodology has been implemented using Matlab(R2023a,64-bit (win64)).

Ant colony optimization algorithm for solving capacitated vehicle routing problem with neutrosophic fuzzy stochastic demands

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This paper addresses the capacitated vehicle routing problem, aiming to find routes that start and end at a depot while minimizing costs and satisfying each customer's demand. Completing these routes requires overcoming real-world challenges such as weather changes, market fluctuations, and unpredictable delivery times. In such situations, forecasting demand in advance is often difficult, making it nearly impossible to provide accurate information about customer needs. The proposed model in this paper, which incorporates a neutrosophic fuzzy stochastic demand approach, aims to minimize travel costs

while introducing an effective failure cost metric to assess the impact of route deviations resulting from unforeseen events. The antcolony optimization algorithm used in this paper identifies optimal routes in dynamic and uncertain environments, providing better solutions compared to other algorithms. The proposed methodology has been implemented using MATLAB (version R2023a, 64-bit (win64)) and Python software.

A Closed-Loop Supply Chain Optimization Framework Incorporating Environmental Investment and Multi-Shipment Logistics

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Due to enhanced regulations, reduced resources, and increased stakeholder expectations, industrial systems have had to transition to more sustainable supply chain operations. Closed-loop supply chains (CLSCs) facilitate the recovery of used items, optimize resource utilization, and mitigate environmental impacts while maintaining efficiency and sustainability. This work presents a comprehensive analytical model for a two-tier CLSC model comprising a manufacturer and a retailer, where the manufacturer allocates resources towards environmental enhancements to enhance the sustainability characteristics of its products. The approach employs a multi-shipment policy, enabling the manufacturer to dispatch several shipments to the retailer. This reduces overall holding expenses and enhances operational coordination. The suggested framework effectively balances the period of the production cycle, the frequency of shipments, the selling price, and the expenditure on environmental considerations, while also accounting for carbon emissions from manufacturing and inventory processes. Furthermore, this model established the optimality for the CLSC. Sensitivity analysis demonstrates the impact of investment levels, cost parameters, and emission considerations on optimal decision-making. The findings suggest that synchronized decision-making and strategic environmental investments can significantly improve supply chain efficiency and ecological outcomes, offering guidance for firms transitioning to sustainable manufacturing practices.

Equilibrium and Evolutionary Stability in Multi-Threshold Dynamic Service Control of M/M/1 Queues: A Metaheuristic Optimization Approach

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This paper develops a generalized framework for analyzing customer equilibrium and social optimality in a single-server M/M/1 queueing system operating under a multiple threshold-based dynamic service policy with two information structures: unobservable and partially observable. The server remains idle when the system is empty and adjusts its service rate according to the threshold levels. We derive explicit conditions for equilibrium and socially optimal arrival rates in the unobservable case. For the partially observable case, we employ a backward recursive algorithm, rather than conventional methods, to compute expected sojourn times and subsequently determine both equilibrium and socially optimal strategies. Furthermore, we incorporate the nature inspired Particle Swarm Optimization (PSO) technique to identify the social optimum arrival rate that maximizes social welfare. Finally, numerical experiments reveal that, in the unobservable case, the strategies yielding higher customer benefits align with the evolutionarily stable equilibrium, rather than merely stable ones.

Bounded Rational Equilibrium in an M/M/1 Queueing-Inventory System with Random Replenishment and Quality Feedback

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We investigate the joining behaviour of boundedly rational customers in a single-server queueing-inventory system with random order size replenishment and quality feedback. Customer arrivals follow a Poisson process, while service times are exponentially distributed. A randomized order size policy with a discrete distribution governs the replenishment of inventory. Customers offer feedback upon service completion, where positive feedback sustains regular operation and negative feedback triggers immediate maintenance of the system. The maintenance period of the system follows exponential distribution. The

system is modelled as a continuous-time Markov chain, assuming that no new arrivals are allowed when the inventory is zero and also during the maintenance period. Under necessary stability conditions, we derived explicit steady-state probabilities, which enable the evaluation of key performance measures. Using a reward-cost framework, we characterize bounded rational equilibrium and socially optimal joining strategies under different information regimes. To assess efficiency losses arising from decentralized and behaviorally biased decisions, we analyze the Price of Anarchy, the Price of Conservatism, and the Price of Rationality. Numerical experiments demonstrate how system parameters and behavioural factors impact equilibrium behaviour, server revenue, and social welfare, providing insights for designing service and inventory policies under behavioural uncertainty.

Sustainable Biomedical Waste Optimization through Neutrosophic Decision Making

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Achieving a disease-free nation requires addressing the critical issue of biomedical waste management, that is the disposal of biomedical waste in the environment. Improper disposal of such waste poses serious risks to residents, healthcare workers, and the environment. To minimize these adverse impacts, it is vital to adopt a sustainable approach that ensures proper segregation, safe transportation, and efficient treatment and disposal of biomedical waste. Therefore, it is essential to manage this trash in a sustainable way to lessen its detrimental effects on the ecosystem. This study uses the Weighted Aggregated Sum Product Assessment (WASPAS) approach in conjunction with a Neutrosophic-based Multi- Criteria Decision Making (MCDM) framework to address indeterminacy and uncertainty in biomedical waste segregation. Decision-makers can model inaccurate, partial, and unclear information that frequently comes up while assessing waste segregation systems according to the neutrosophic approach. Relevant factors are methodically evaluated within this framework, including segregation accuracy, health and safety risk, operational cost, regulatory compliance, environmental impact, and simplicity of implementation. Alternative biomedical waste segregation systems are then ranked according to their overall effectiveness using the WASPAS method, which combines the benefits of weighted sum and weighted product models. A comprehensive sensitivity analysis is conducted to examine the robustness of the rankings against variations in criterion weights and neutrosophic parameters. Additionally, a stability analysis is performed to evaluate the consistency of the ranking results under changing uncertainty levels. The results indicate that the top-ranked segregation strategy consistently outperforms

the alternatives across different scenarios, demonstrating its effectiveness in ensuring safer handling, improved compliance, and enhanced sustainability in biomedical waste management. Consequently, the proposed neutrosophic–WASPAS-based MCDM model provides a reliable and practical decision-support tool for identifying the most effective biomedical waste segregation strategy under uncertain real-world conditions.

Stationarity conditions for nonsmooth interval-valued multiobjective semi-infinite programming problems with switching constraints via tangential subdifferentials

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The aim of this talk is to investigate optimality conditions for a nonsmooth interval-valued multiobjective semi-infinite programming problem with switching constraints. In particular, it employs a suitable constraint qualification to derive necessary M-stationary conditions using tangential subdifferentials. Additionally, sufficient optimality conditions are established under assumptions of generalized convexity. The theoretical findings are effectively demonstrated through a numerical example.

A Hybrid Approach for Box Constrained Multi-objective Optimization Problems Combining Quasi-Newton and NSGA-II Methods

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In this paper, a hybrid method is developed for multi-objective optimization by integrating the ideas of a gradient based technique (quasi-Newton method) and a genetic algorithm (NSGA-II). An initial parent population is utilized to generate two distinct offspring populations using NSGA-II and the quasi-Newton method separately. The next generation is selected from these offspring populations based on fitness and ranking. The proposed method promotes both global convergence and spread of the approximate Pareto front. A Python-based implementation of the proposed method is developed and compared against existing approaches using a set of benchmark test problems. Performance profiles using different metrics is used to compare different methods. The results demonstrate that the proposed method efficiently uses two search strategies to achieve superior convergence compared to conventional techniques while maintaining spread in most cases.

Replicator Dynamics on Bilinear Games with Exponential Strategies: A Comparison with Static Stability

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It is known from Lewis and Shaiju (2026) that exponential measures are invariant under the replicator dynamics for a broad class of bilinear games, and that the evolution of the rate parameters of these measures can be described by systems of ordinary differential equations. In this work, we study the corresponding mean dynamics of such games obtained by restricting the replicator system to exponential strategies. The dynamic stability analysis of the mean dynamics is carried out and contrasted with the static stability properties of the underlying games. This work complements the well known results on the invariance of Gaussian measures for quadratic games.

Sustainable optimization of E-waste management through neutrosophic applications: A comprehensive decision-making approach

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This study delves into the intricacies of e-waste management control by introducing a novel approach that leverages neutrosophic numbers. Focusing on crucial factors such as environmental impact, resource recovery, social impact, and economic viability, our research employs a superiority and inferiority ranking method enhanced by neutrosophic numbers. This methodology enables a nuanced and flexible evaluation of electronic products, considering the inherent uncertainties and indeterminacies associated with sustainability metrics. By incorporating neutrosophic numbers into the ranking process, the study aims to provide a more robust framework for assessing and prioritizing e-waste management strategies. The outcomes of this research contribute to advancing the understanding of e-waste management by incorporating the inherent uncertainties within a neutrosophic framework. This approach not only enhances the accuracy of ranking electronic products but also facilitates more adaptive and informed decision-making processes in the pursuit of sustainable e-waste management practices. Additionally, we conduct a comparative analysis by evaluating the performances by utilizing various Multi-Criteria

Decision-Making (MCDM) methods. To further validate the robustness of the proposed model, a comprehensive sensitivity analysis is conducted to observe how variations in criterion weights influence the final rankings. In addition, a stability analysis using Monte Carlo simulation is performed to assess the consistency of the results under probabilistic fluctuations. Further the comparative assessment aims to elucidate the strengths and limitations of neutrosophic-based ranking in contrast to other established decision-making approaches.

β-Discounted Approximations and Limiting Average Optimality in Zero-Sum Perfect Information Stochastic Games

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A zero-sum two-person Perfect Information Stochastic Game (PISG) under limiting average payoff has a value and both the maximiser and the minimiser have optimal pure- stationary strategies. We prove this result by considering the β-discounted game first and then showing that it has a uniformly discounted optimal pure stationary strategy pair of the players, which is undiscounted (limiting average) optimal as well. A crude but finite step algorithm is given to compute such an optimal pure stationary strategy pair of the players.

Advance Purchasing: Strategic Inventory or Forward Contracts?

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Introduction: Sellers and buyers engage in advance purchasing practices to hedge against supply and demand fluctuations. However, even without such uncertainties, advance purchasing is pivotal in supply chain interactions. For example, advance purchasing strengthens the buyer's bargaining position in her negotiations with the seller, pressuring down subsequent periods' prices (Anand et al., 2008; Arya et al., 2015). Such a use of advance purchasing is a common industry practice; for example, in the crude oil and steel sectors (Dunn et al., 2012; Mart´ınez-de-Alb´eniz and Simchi-Levi, 2013). Two common forms of advance purchasing are strategic inventory and forward contracts. In the former, the buyers purchase excess units at the spot price for immediate delivery and store them as inventory for future sales. In the latter, the buyer purchases extra units at a specified forward price for delivery in a future period. If the goods are slated for delivery in the subsequent period, we refer

to the forward contract as a short-term contract. In case the goods are scheduled for future delivery, we term the forward contract a long-term contract.

Strategic inventory, as coined by Anand et al. (2008), is carried by the buyer to promote supply-side competition between the seller and her inventory in future. This reduces the seller's monopoly and help the buyer bargain lower spot prices later. Anticipating the use of strategic inventory against him, the seller raises the current spot price to deter stockpiling by the buyer. Although the seller cannot eliminate the buyer's strategic inventory, he benefits from it due to a rise in current spot price. Akin to strategic inventory, both short-term and long-term contracts can drive down future spot prices (Arya et al., 2015). Therefore, in the absence of the inventory option, the buyer can utilize forward contracts as a substitute for strategic inventory to lower the future spot prices. In addition, the buyer can use long-term contracts to drive down future short-term contract prices, which may hurt the seller. In spite of this, according to Erhun et al. (2008), in the absence of the inventory option, the seller always offers both short-term and long-term contracts, albeit at higher prices than the current spot price. This helps the seller offset the anticipated loss from the drop in the future prices. In addition, the seller sets different prices for the short-term and long-term contracts, enabling non-linear pricing, which reduces double marginalization and benefits all players (Erhun et al., 2008).
Problem Definition: The seller's capacity to charge a higher forward price than the current spot price is, however, contingent upon the buyer's capacity to hold inventory: if holding inventory is viable and the holding cost is less than the price differential between the forward and the current spot prices, the buyer may prefer to carry inventory instead of purchasing forward contracts. Therefore, to encourage the buyer to purchase forward contracts, the seller must reduce the price differential by lowering the forward prices while increasing the current spot price. Such a decline in forward prices benefits the buyer at the expense of the seller. However, rising spot prices will reduce both the seller's and the buyer's current sales profits. Hence, it is unclear if the seller should offer a forward contract when the buyer can carry inventory, similar to the no-inventory case (Erhun et al., 2008). And if the answer is yes, should he offer both short-term and long-term contracts or offer only short-term contracts? The buyer also faces a dilemma: should she pre-commit to not carrying inventory to dissuade the seller from raising the current spot price? Or should she use her inventory option to lower the forward prices?
Methodology/Results: To answer the above questions, we consider a game-theoretic model whereby the seller sells goods to consumers via the buyer. Our study reveals several important insights. First, somewhat intuitively, we find that the seller always offers a forward contract while

setting the spot and forward prices such that the buyer's incentive to carry strategic inventory is eliminated. Nevertheless, when the inventory holding cost is sufficiently low, the buyer can leverage her inventory option to bargain a lower forward contract price. We refer to this buyer's strategy as the "threat of carrying inventory." But, as the inventory holding cost increases, this threat weakens and finally becomes non-credible.

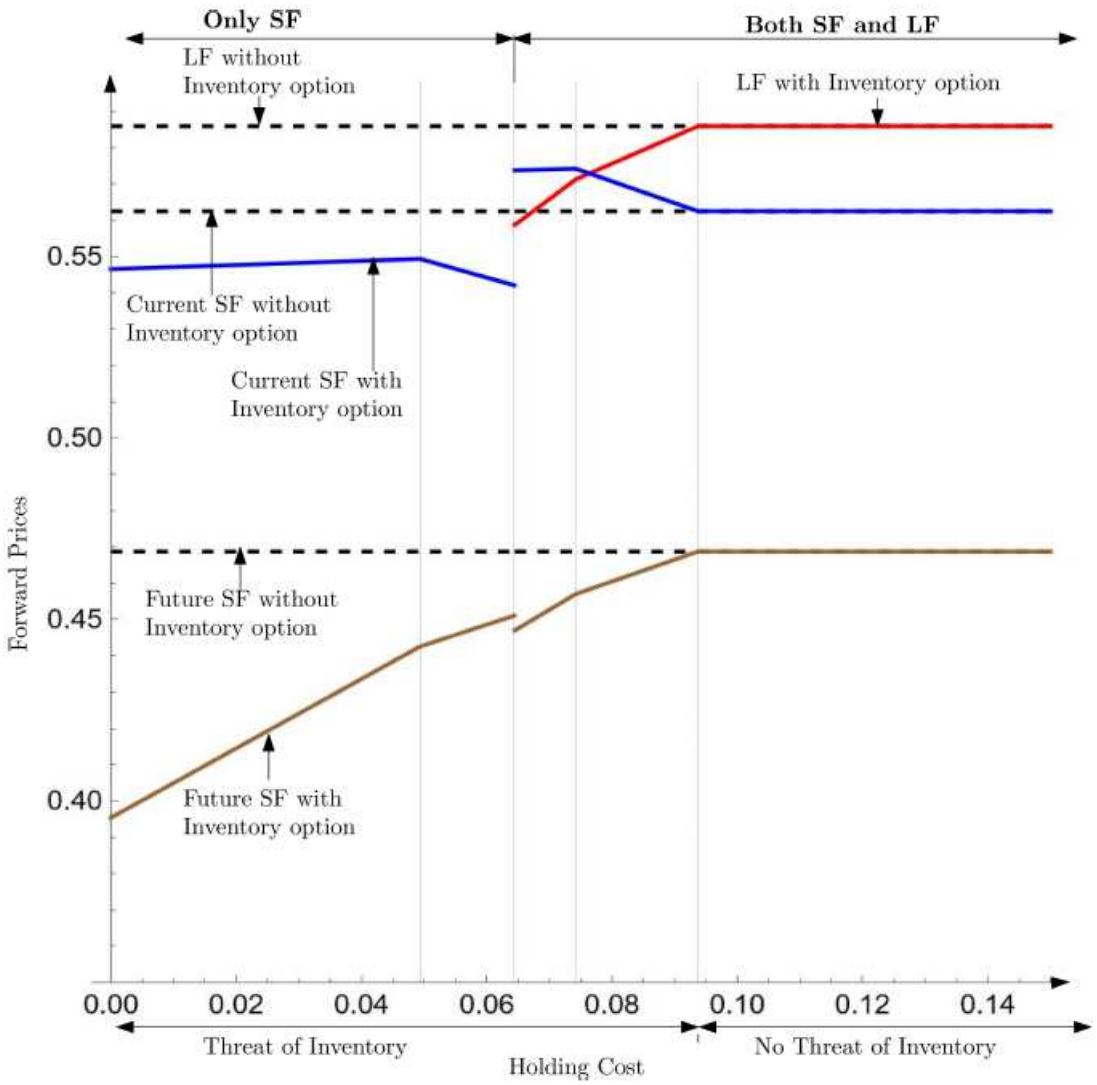

Figure 1: Short-term Contract (SF) and Long-term Contract (LF) Prices as a Function of the Inventory Holding Cost.

The second insight relates to the types of forward contracts the seller offers. While the seller would always like to offer both short-term and long-term contracts, as they allow for additional price differentiation and reduction in double marginalization, when the inventory holding cost is sufficiently

low, the seller only offers short- term contracts and abstains from offering a long- term contract (see Figure 1). This contradicts Erhun et al. (2008)'s no-inventory setting, where the seller always offers both the short-term and the long-term contracts. A short-term contract exerts downward pressure on the future spot price. When the buyer's threat of carrying inventory is credible, a decline in the future spot price will lead to a reduction in the future forward contract price as well.

This diminishes the buyer's incentive to purchase a long-term contract, who instead only purchases short-term contracts. To induce the buyer to opt for a long-term contract and limit her short-term contract purchase, the seller may reduce the long-term contract price while increasing the short-term contract price. When the inventory holding cost is sufficiently low, the drop in the long-term contract price and the rise in the short-term contract price are prohibitively high. Hence, the seller offers only a short-term contract. When the inventory holding cost is intermediate, the buyer's threat of carrying inventory is weak, allowing the seller to profitably offer a long-term contract by raising the short-term contract price and dropping the long-term contract price. Nevertheless, when the inventory holding cost is sufficiently high, the buyer's threat of carrying disappears, and the seller sets the long-term and short-term contracts price as if the buyer does not have the option to carry inventory.

Third, while the buyer's strategic inventory is known to benefit both her and the seller (Anand et al., 2008), we show that, quite surprisingly, if the seller offers a forward contract, the buyer's inventory option almost always backfires, hurting both of them unless the inventory holding cost is sufficiently high. When the inventory holding cost is sufficiently low, the seller cannot profitably offer a long-term contract. Therefore, he raises spot prices and drops the short-term contract prices so as to eliminate inventory and induce the buyer to purchase short-term contracts. The former price increase hurts corresponding sales, and hence, both the buyer and the seller end up being worse off. When the inventory holding cost is intermediate, the seller encourages the buyer to purchase a long-term contract and limits her current short-term contract purchase by dropping the long-term contract price and raising the short-term contract price. The latter price increase results in a drop in the short-term contract sales, hurting both the buyer and the seller. Therefore, in contrast to the existing studies, we find that unless the inventory holding cost is sufficiently high (as the threat of carrying inventory becomes non-credible), the buyer should signal to the seller her disinterest in carrying inventory.

Finally, we show that when the seller sells to the buyer through an intermediary, both the intermediary and the buyer carry inventory in the absence of a forward contract, although everyone would benefit if only the buyer carried inventory.

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Duality results for E-differentiable multiobjective fractional programming problems under E-B-invexity

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In this presentation, we address nonconvex multiobjective fractional programming problems involving E-differentiable functions (MFPE) under the generalized convexity structure of E-B-invexity. By exploiting E-differentiability, we reformulate the original vector fractional programming problem into an equivalent parametric form and establish the corresponding E-Karush-Kuhn-Tucker (E-KKT) optimality conditions under an explicit E-Abadie constraint qualification. Based on these conditions, we formulate Mond-Weir and Schaible-type dual models for (MFPE) and establish duality results between them. The framework developed here unifies and generalizes existing duality schemes for nonlinear fractional vector optimization in the presence of generalized invexity.

A Two-Step Smoothing Newton Method for Second-Order Cone Complementarity Problems

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Second-order cone complementarity problems (SOCCPs) provide a versatile framework for modeling and solving a wide class of optimization problems, including nonlinear complementarity problems (NCPs) and second-order cone programs (SOCPs), with applications in mechanics, optimization, signal

processing, and power systems. In this work, we present two-step modified smoothing Newton method for solving SOCCPs. By employing a newly introduced smoothing function, the proposed method ensures both theoretical soundness and practical efficiency. Convergence properties are established, and numerical results demonstrate the effectiveness of the method.

A study on solution criteria for bilevel multi-objective optimization problems

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This study examines a bilevel multi-objective optimization problem and derives new necessary optimality conditions under a nonsmooth regularity condition, defined through the notion of upper convexifactors. Within the scope of generalized convexity, sufficient optimality criteria have been established using upper convexifactors.

A Subgradient-Based Approach for Nonsmooth Quasiconvex Multiobjective Optimization

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This paper develops a methodology for solving a class of nonsmooth multi-objective optimization problems with quasiconvex objective functions. First, a subgradient-based algorithm is proposed for the unconstrained case, employing the Plastria subdifferential to handle the nonsmoothness of functions. The approach is then extended to constrained problems, where the feasible set is assumed to be nonempty, closed, and convex. Unlike classical methods, the pro-posed algorithms do not rely on scalarization techniques; instead, they operate directly on the original vector-valued objective functions. Under suitable assumptions, both algorithms are shown to possess a descent property at every iteration and to converge to a weak Pareto optimal solution. Numerical examples are provided to illustrate the effectiveness and practical applicability of the proposed methods.

Two-warehouse inventory model for imperfect production process under the effect of learning

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In today's highly competitive market, industries are under constant pressure to reduce production costs and maximize profits. In this work, an inventory model is developed for an imperfect item. Deterioration rates are constant in both warehouses. In this model, two warehouses are introduced; one is an owned warehouse, and the other is a rented warehouse, each with a distinct rate of demand. Since all producers desire to maximize profits from their firms and want to leave the RW as quickly as possible, they must pay the least amount of rent; hence, the rate of demand for the RW is determined by the price that is strictly increasing. Conversely, the demand rate for the OW is time- dependent since he can use his owned warehouses in a way that benefits the creator and allows him to adjust the inventory's selling price based on his profit. Due to the impact of certain demand-based presumptions, the rate of output is seen to be reliant on demand. Additionally, the shortage is taken into account.

A Hybrid WASPAS-CRADIS Decision Analytics Framework for Smart Power Grid Analyst Selection under Multi-Criteria Environments

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The growing complexity of smart power grids necessitates the selection of highly competent power grid analysts, a process inherently characterized as a multi-criteria decision making (MCDM) problem involving both quantitative and qualitative attributes. This study proposes a hybrid decision analytics framework integrating the Weighted Aggregated Sum Product Assessment (WASPAS) method with the Compromise Ranking of Alternatives from Distance to Ideal Solution (CRADIS) technique. In the proposed model, WASPAS is employed to compute criteria weights and aggregate candidate performance using a convex combination of additive and multiplicative utility functions. Subsequently, CRADIS refines the ranking by evaluating the relative distances of alternatives from ideal and anti-ideal solutions, yielding a compromise-based final ranking. The framework ensures computational simplicity, ranking stability, and decision consistency. A real-world case study on power grid analyst

selection demonstrates the effectiveness of the proposed approach. Comparative analysis with established MCDM methods and sensitivity tests confirm the robustness and discriminative capability of the hybrid model. The results highlight the suitability of the WASPAS–CRADIS framework for workforce selection in smart grid and energy systems, supporting transparent, data-driven, and sustainable human resource decision-making.

Neural Approximation of Optimal DDoS Defense Strategies

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Distributed Denial-of-Service (DDoS) attacks remain a major challenge for network service availability, motivating both theoretical and practical advances in mitigation. Existing neural approaches in the literature predominantly address traffic detection and classification, whereas strategic mitigation under adversarial resource allocation remains underexplored. In this work, we model the attacker–defender interaction as a Stackelberg game in which the defender first allocates defensive resources across multiple attack vectors and the attacker sub-sequently allocates bandwidth to maximize leakage-induced damage. We formulate the defender's optimization problem as a convex program that balances leakage cost against defense expenditure under bandwidth and cost constraints. The leakage model incorporates logarithmic saturation effects and quadratic defense penalties, producing a mathematically tractable yet expressive formulation for multi-vector DDoS scenarios. Solving this convex program repeatedly, however, introduces latency that hinders real-time deployment during dynamic attacks. To overcome this bottleneck, we train a neural network to approximate the optimal solutions obtained offline from CVXPY over a wide distribution of synthetically generated game parameters. The resulting predictor network replaces repeated solver calls with a single forward pass, enabling rapid adaptation to time-varying attack conditions. Empirical evaluation shows an average objective error of approximately 1.15% relative to solver solutions and a computational speedup of around 86×, reducing inference latency from ∼26 ms to ∼0.30 ms per instance. Additional experiments verify scalability with respect to the number of attack vectors and stable performance on smoothly evolving time-series inputs, demonstrating feasibility for dynamic defense settings. Overall, this work highlights that convex optimization-driven defense strategies can be effectively approximated via neural predictors, providing a principled and computationally efficient framework for real-time strategic mitigation in modern multi-vector DDoS environments.

Inverse Data Envelopment Analysis under Non-Homogeneity and Negative Data

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This paper introduces new inverse data envelopment analysis (DEA) models for non-homogeneous decision-making units (DMUs) that accommodate negative data. Building on the Range Directional Measure (RDM) framework, the proposed models determine the input adjustments necessary to achieve specified output targets while maintaining fixed efficiency scores. Unlike conventional inverse DEA models, which typically assume homogeneous DMUs and only positive data, this study presents the first inverse DEA - RDM framework to address output non-homogeneity and negative values simultaneously. The proposed models are validated using a real-world dataset from Cook et al. (2012). Overall, the proposed inverse RDM-based framework provides a robust and flexible tool for policy analysis, benchmarking, and decision-making in complex production environments.

Stationarity conditions and constraint qualifications for robust nonsmooth optimization problems with switching constraints

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In this talk, we examine nonsmooth mathematical programs with switching constraints in the presence of uncertainty in both objective and constraint functions, studied within a robust optimization framework and denoted as UNMPSC. We demonstrate that, even under fairly mild assumptions, UNMPSC generally fails to satisfy classical constraint qualifications such as the Mangasarian-Fromovitz and linear independence constraint qualifications. In contrast, the generalized Guignard constraint qualification may still hold in certain cases. Furthermore, we introduce appropriate modifications of these constraint qualifications, analyze the relationships among them, and derive robust Karush-Kuhn-Tucker-type stationarity conditions.

Duality results for quasidifferentiable mathematical programs with equilibrium constraints

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The aim of this article is to investigate nonsmooth mathematical programs with equilibrium constraints (MPECs) and their associated dual formulations. We develop Wolfe-type and Mond–Weir-type dual problems using the framework of quasidifferential calculus. Under suitable assumptions of quasidifferential invexity with respect to convex compact sets, we establish weak and strong duality theorems for the considered class of nonsmooth optimization problems with equilibrium constraints. Several illustrative examples are provided to validate the theoretical results, and a comparative discussion is presented highlighting the advantages of quasidifferentials over other generalized differential concepts.

Optimal Export Allocation and Growth Outcomes: Evidence from India

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In open economies Economic growth is often analysed as empirical relationships linking exports and GDP outcomes. Although such approaches provide valuable insights are provided by such approaches, they frequently consider growth as a direct outcome of export expansion rather than as the result of underlying economic decisions. The paper reframes economic growth as an equilibrium outcome driven by optimal export allocation decisions under resource and trade constraints. Using India as an empirical application, the study develops a simple optimization framework to analyse how sectoral exports structure affects long-run growth outcomes. The paper's core premise is that productive and policy resources are limited. These resources must be allocated across competing export sectors manufacturing, services, and agriculture. Each sector contributes differently to growth due to variations in productivity, global demand, and domestic economy. Therefore, Economic growth depends not only on the volume of exports but also on the equilibrium allocation of export effort across sectors. The theoretical framework treats export allocation as a constrained optimisation problem. A representative decision-maker allocates export across sectors to maximize growth subject to resource and sector specific constraints. Growth is

modelled as a function of sectoral exports, with parameters capturing their marginal growth contribution. The equilibrium outcomes depend on how exports are allocated, not just their total level. This implies suboptimal allocation can lead to low level growth equilibrium even when total exports rise. The model further highlights that the economy can shift from an equilibrium to another by relaxing constraints or altering sectoral growth contributions. To illustrate the relevance of the theoretical framework, the model is applied the to the Indian economy. India offers a natural case study. Its export structure is diverse and it has implemented major trade policy and economic reforms over time. Sectoral export and macroeconomic data are employed to examine whether the observed export allocation is consistence with the model's growth maximising equilibrium. Empirical analysis is employed not as the core contribution but as a validation tool to examine the consistency of observed outcomes with the theoretical predictions. The empirical analysis reveals that sectoral exports have significant variation in their effects on long run economic growth. Therefore, changes in export composition play a critical role in determinig growth trajectories. An association can be seen between periods characterized by a higher productivity export sectors and more favorable growth outcomes which are consistent with the equilibrium framework. In contrast, dependence on sectors with weaker growth linkages hampers overall economic performance. It reinforces the idea of multiple growth equilibria.

This paper contributes to the trade and growth literature in three ways by viewing economic growth as an equilibrium result of export allocation choices. First, it provides a conceptual link between empirical studies on trade and economic growth and formal optimization based economic modelling. Second, Rather than emphasizing on export expansion alone, it emphasizes the importance of export structure and allocation efficiency. Third, it provides a flexible analytical framework. This approach can be extended to include strategic interactions, dynamic elements and uncertainty. This versatility makes it highly relevant for future research in operations research and economic analysis. The findings of this research work have significant policy relevance. Sectoral export incentives are influenced by trade and industrial strategies which effectively modify the structure of optimization problem. That means it alters the constraints and parameters of the optimization problem. And consequently determine the long run equilibrium growth performance. Targeted policies that improve productivity, reduce structural constraints in high-growth sectors, and promote efficient export diversification, can play a critical role in drive the economy towards higher-growth equilibrium. In summary, the paper highlights that export-led growth should be understood as the outcome of equilibrium economic decisions rather than a linear outcome of trade volumes expansion. This framework is closely corresponded with optimization based techniques in operations research and offers a logical consistent analysis of trade and economic growth in developing economies such as India.

Additional classes of interval matrices in linear complementarity theory

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In this article, we characterize strong versions of several matrix classes that appear in the linear complementarity problem (LCP) for uncertain data represented by intervals. The properties of the constraint matrix reflect many characteristics of the LCP, including uniqueness, solvability, number of solutions, convexity of the solution set, etc. We discuss some of the computationally more difficult classes. In particular, we discuss the strong version of the class of almost semimonotone, E(d)-matrix, E͂(d)-matrix, L(d)-matrix, L͂(d)-matrix, and Q0-matrix. Finally, we intro-duce positive subdefinite interval matrices.

A Sustainable Inventory Model for Growing Items Considering Carbon Emission, Trade Credit, and Shortages.

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It is crucial to consider the environment in this fast-paced world where industries are growing at a high rate. The livestock sector contributes a significant amount of emissions during different processes. Various governments have introduced carbon regulations around the world to minimize it. In this work, we present an inventory model that considers the emissions and costs of main activities such as production, storage, and transportation. While existing models have considered emissions during various stages, most of them have not considered emissions in transportation, production, and holding, along with deterioration. Considering the emission, along with real-life factors such as mortality, deterioration, and delay in payment, helps in determining optimal solutions for inventory control decisions. The analytical result for the concavity of the objective function with respect to the decision variables is discussed.
The solution procedure is provided to find the optimal solution. A numerical example is presented to demonstrate the solution procedure. Finally, sensitivity analysis is performed to show the impact of key parameters on the net profit.

Ancient Wisdom to Modern System: An Indian Knowledge System (IKS) Driven Spherical Fuzzy WASPAS Framework for Circular Economy

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Circular economy is commonly approached through policies, technologies, and performance metrics however, its long term success fundamentally depends on human awareness, ethical governance, and collective responsibility principles deeply rooted in the Indian Knowledge System (IKS). Inspired by this philosophical foundation, this study proposes an IKS driven decision framework integrating spherical fuzzy sets with the WASPAS method to evaluate circular economy criteria under uncertainty. Spherical fuzzy logic is employed to capture expert judgments using membership, non-membership, and hesitancy degrees, enabling a realistic representation of linguistic uncertainty. The WASPAS method is then applied to generate priority rankings. The results indicate that End User Awareness of Circular Practices (CE11) achieves first rank, reaffirming the Bhagavad Gita's emphasis on Viveka (discerning awareness) as the origin of sustainable action. Legislation and Policies Formulation (CE14) ranks second, reflecting the Arth Shastra principle that righteous governance grounded in Dharma sustains social order. Consciousness among Supply Chain Partners (CE12) secures the third rank, symbolizing the IKS values of Kartavya (duty) and collective harmony. Unlike conventional decision models that interpret sustainability as a purely technical challenge, the proposed framework views circular economy as a convergence of awareness, governance, and shared responsibility. By harmonizing ancient Indian wisdom with modern spherical fuzzy WASPAS analysis, this study demonstrates that sustainability is not merely a system of practices, but a system of consciousness. The framework offers a culturally grounded, analytically robust, and practically relevant tool for reimagining circular economy strategies in contemporary decision-making.

A Bounded Variation–Based Probabilistic Intuitionistic Fuzzy C-Means Clustering Algorithm

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Euclidean distance measures are predominantly used in the formulation of probabilistic variants of intuitionistic fuzzy c-means clustering algorithms that converge to local optima. However, partitional clustering approaches that consider global optimality remain largely unexplored in the existing literature. The probabilistic intuitionistic fuzzy c-means (PIFCM) algorithm is a widely adopted method, but its convergence to local minima often results in variability in clustering outcomes. To address this limitation, researchers have investigated alternative distance measures to improve clustering robustness and performance. In this paper, we propose a bounded variation–based probabilistic intuitionistic fuzzy c-means clustering algorithm (BV-PIFCM) by incorporating a step-based distance measure with bounded variation and probabilistic weights. The proposed approach is particularly effective for datasets containing non-globular clusters or clusters with irregular geometries. Step-based distance measures closely resemble realistic scenarios by traversing ir- regular paths, thereby facilitating effective cluster detection even in regions with varying densities or sparsity. Experimental results on the car dataset and multiple benchmark UCI datasets demonstrate that the proposed BV-PIFCM algorithm out-performs the PIFCM and IFCM algorithms. Performance evaluation is conducted using accuracy, partition coefficient, and cluster entropy as benchmark metrics.

Intuitionistic Fuzzy Clustering Technique Emphasizing the Fuzzy Variant

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In this talk, I will present a novel intuitionistic fuzzy hierarchical clustering technique, referred to as NIFHC, in which the membership component of the intu- itionistic fuzzy set plays a dominant role in the clustering process. The proposed approach is designed to more effectively capture uncertainty and structure in com- plex datasets. To demonstrate its applicability, I will discuss experimental studies conducted on two benchmark datasets related to car market analysis and flood disaster assessment. The performance of the proposed NIFHC method will be systematically compared with several well-known

intuitionistic fuzzy set–based hierarchical clustering techniques. The effectiveness of the proposed approach will be evaluated using standard clustering validity indices, including the correlation coefficient, Silhouette score, Dunn index, Davies–Bouldin index, and Calinski–Harabasz index. The results show that the proposed technique consistently outperforms existing intuitionistic fuzzy hierarchical clustering methods across these evaluation measures.

Entropy based Intuitionistic Fuzzy Weighted Least Square Twin Support Vector Machine

Nauman Ansary, Niher Ranjan Das, and Q. M. Danish Lohani
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Imbalanced datasets are difficult to handle in classificationproblems, where some classes have significantly fewersamples than others. Support Vector Machines (SVMs) areknown for their strong performance in many areas, but theystruggle with imbalanced and noisy data as they treat alltraining samples equally, which causes the model to favour themajority class when forming the decision boundary. Althoughfuzzy SVM variants like entropy based fuzzy SVM (EFSVM)and intuitionistic fuzzy twin SVM (IFTSVM) reduce the impactof noise and outliers by assigning fuzzy membership values,they rely heavily on distance-based assumptions and assumeuniform uncertainty across the data. These methods computemembership and non-membership values based on the centres of the data. In this paper, we propose a new entropy based IFWLSTSVM(EIFW-LSTSVM) that combines intuitionistic fuzzytheory with local entropy to handle class imbalance better. Itassigns full membership to minority class samples and reducesit for the uncertain majority class. This dual approach enhancesthe model performance by focusing more on the minority class while reducing the influence of noisy majority samples, leadingto a more balanced and reliable decision boundary. Moreover, tovalidate the performance of the proposed method, experimentswere conducted on 14 imbalanced datasets from the KEEL repository,comparing it with several recent and widely recognizedSVM variants. For statistical validation of these findings, the Friedman test followed by the Dunn-Bonferroni post-hoc testwas applied at a 95% confidence level. The results indicate that the proposed method exhibits significantly superior performancecompared to existing state-of-the-art methods.

Standby Optimization for Airline Crew Scheduling: A Prescriptive Approach with Predictive Integration

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Efficient management of standby crew is critical for ensuring operational resilience and cost effectiveness in airline operations. While classical crew scheduling topics—such as crew pairing and rostering—have been studied extensively, the optimization of standby crew remains comparatively underexplored despite its operational significance and inherent complexity. Industry practice largely relies on heuristic and simulation-based procedures to plan and deploy standby crew, driven by simplified rule-based logic rather than optimization. This paper introduces a prescriptive optimization framework for constructing and optimizing both single and multi-duty standby trips. The framework links operational practice with mathematical programming by explicitly modeling real-world constraints including fleet compatibility, regulatory rest requirements, night-duty restrictions, and roster-stability considerations.

The proposed approach is formulated as a two-stage mixed-integer programming (MIP) model. In the first stage, the model minimizes the number of standby trips required to ensure complete coverage of eligible flight pairings. The second stage then maximizes the inclusion of additional duties within these trips to improve utilization and enhance operational flexibility. Practical implementation aspects—such as the generation of dummy duties and adherence to regulatory fatigue and duty-time rules—are incorporated to ensure crew legality and seamless integration with existing airline scheduling systems.

The framework is designed to interface with predictive analytics—leveraging historical disruptions, sickness behaviour, and network-level patterns to fore- cast standby demand. However, these predictive elements are positioned as extensible enhancements and are not implemented in the current study. The resulting decision-oriented, regulation-compliant optimization framework is adaptable across diverse operational contexts and scalable to airline-specific requirements. By formally integrating standby trip construction into operational decision-support processes, the work strengthens the role of prescriptive optimization in airline crew scheduling.

Pricing and Coordination in Refurbished Closed-Loop Supply Chain: a game-theoretic analysis

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This study develops a closed-loop supply chain (CLSC) pricing model for refurbished products that integrates consumer return incentives, effort-dependent refurbishment yield, product-condition effects, warranty decisions, and green nudge marketing. The system includes a refurbisher who sets the buyback price to stimulate returns and chooses refurbishment effort to improve the fraction of saleable units, and a seller who determines the retail price, warranty length, and green nudge effort to influence market demand. Demand decreases with price and increases with warranty and green nudges, while deteriorating with product age and usage due to lower perceived quality. The model is analyzed under three decision structures: an integrated model, a refurbisher-led Stackelberg game, and a seller-led Stackelberg game. Expected results indicate that integration yields the highest system profit and supports stronger joint investments in refurbishment effort, warranty, and green nudges. Under decentralization, channel power drives decision priorities: refurbisher leadership is expected to emphasize buyback incentives and refurbishment effort to expand effective supply and reduce disposal losses, whereas seller leadership is expected to prioritize demand-side instruments such as pricing, warranty, and green nudges. The framework offers managerial guidance on designing buyback programs and marketing strategies for profitable and sustainable refurbished markets.

Standby Optimization for Airline Crew Scheduling: A Prescriptive Approach with Predictive Integration

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This paper introduces a prescriptive optimization framework for con- structing and optimizing both single and multi-duty standby trips. The framework links operational practice with mathematical programming by explicitly modeling real-world constraints including fleet compatibility, regulatory rest requirements, night-duty restrictions, and roster-stability considerations. The proposed approach is formulated as a two-stage mixed-integer programming (MIP) model. In the first stage, the model minimizes the number of standby trips required to ensure complete coverage of eligible flight pairings. The second stage then maximizes the inclusion of additional duties within these trips to improve utilization and enhance operational flexibility. Practical implementation aspects—such as the generation of dummy duties and adherence to regulatory fatigue and duty-time rules—are incorporated to ensure crew legality and seamless integration with existing airline scheduling systems. The framework is designed to interface with predictive analytics—leveraging historical disruptions, sickness behaviour, and network-level patterns to forecast standby demand. However, these predictive elements are positioned as extensible enhancements and are not implemented in the current study. The resulting decision-oriented, regulation-compliant optimization frame work is adaptable across diverse operational contexts and scalable to airline-specific requirements. By formally integrating standby trip construction into operational decision-support processes, the work strengthens the role of prescriptive optimization in airline crew scheduling.

Discounted Robust stochastic games

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Sequential decision-making in multi-agent systems arises in many real-world applications, where agents repeatedly choose actions over time to minimize their long-run cumulative cost. Stochastic games provide a principled framework for modeling such interactions: they generalize one-shot games to a multistage multistate setting and extend Markov decision processes (MDPs) from a single controller to a multi-controller setting. In this framework, each player seeks a strategy that is mutually consistent with the strategies of the other players, since each player's cost depends on the joint strategy profile. This notion is captured by the Nash equilibrium, where no player can improve their payoff by unilaterally

deviating, given that the other players' strategies are fixed. Classical results establish the existence of Nash equilibrium strategies under complete information. However, practical settings often involve incomplete information and uncertainty in the parameters, namely, running costs and transition probabilities, as they are estimated from historical experiences.

Robust game theory addresses these uncertainties by optimizing against the worst-case realization over a prescribed uncertainty set. Recent work extends these ideas to robust stochastic games under structured ambiguity sets, such as s-rectangular uncertainty. In particular, when uncertainties are polytopic, a multi-linear optimization formulation can be found whose globally optimal solutions characterize the Nash equilibrium. In our work, we study the robust stochastic game with more general and complex ambiguity sets that capture the complex real-life environments. We study a general s-rectangular ambiguity set (not just polytopic) and derive a non-convex optimization problem, whose global optimal solution characterizes the Nash equilibrium.

We further study the ambiguity set, namely the factor matrix uncertainty set. While an s-rectangular ambiguity set assumes independence of uncertainty across states, a factor-matrix ambiguity set introduces shared factors across uncertainties, making it well-suited for modeling complex environments. We establish the existence of a Nash equilibrium in the stationary class of strategies when the transition probabilities are uncertain and are modeled using a factor-matrix uncertainty set. We also derive a non-convex formulation whose global solution characterizes the Nash equilibrium.

A new decision-making framework using an improved aggregation operator in intuitionistic fuzzy soft sets

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Soft set theory plays a significant role in managing vagueness and uncertainty in data by incorporating parameters as its fundamental mechanism. This theory has been successfully applied to decision-making challenges in complex real-world scenarios. Aggregation operators are significant tools for aggregating decision information collected from different decision- makers. The existing Intuitionistic fuzzy soft weighted average operator has been widely used in the literature to aggregate decision information in an intuitionistic fuzzy soft framework. However, it has its own limitations when dealing with real-world problems. In this paper, we define an improved Intuitionistic fuzzy soft weighted average operator based on novel operational laws to address these limitations. Various mathematical properties of the suggested

aggregation operator are also discussed and proved. Further, the applicability and efficiency of the proposed operator are demonstrated through multiple-attribute decision-making and illustrated with a numerical example.

On analysis the different modeling approaches for index tracking problem

Vrinda Dhingra1, **Amita Sharma**2 Anubha Goel3

Index tracking, also known as passive investing, has gained significant traction in financial markets due to its cost-effective and efficient approach to replicating the performance of a specific market index. This review paper provides a comprehensive overview

of the various modeling approaches and strategies developed for index tracking, highlighting the strengths and limitations of each approach. We categorize the index tracking models into three broad frameworks: optimization-based models, statistical-based models and recent data driven and machine learning approaches. A comprehensive empirical study conducted on the S&P 500 dataset demonstrates that the tracking error volatility model under the optimization- based framework delivers the most precise index tracking, the convex co-integration model, under the statistical-based framework achieves the strongest return-risk balance, and the deep neural network with fixed noise model within the data-driven framework provides a competitive performance with notably low turnover and high computational efficiency.

Optimal Crop Mix for Wheat, Rice and Vegetables to Maximize Profit Under Resources Constraints

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This study employs Operation Research methodology to establish an appropriate crop mix consisting of wheat, rice, and vegetables with the goal of maximizing far profit despite restricted land, water, and fertilizer resources. The linear programming model is created by combining crop -specific resource requirements, predicted yields, and net returns. The limits describe farmers' realistic limitations in cultivable land, irrigation water, and fertilizer usage. The model discovers the optimal resource allocation across wheat, rice, and vegetable crops, as well as key food grains such as wheat and rice , which greatly enhances overall profitability when compared to traditional farming practices. The study demonstrates the practical utility of operation research methodologies in agricultural planning and provides a scientific decision-making tool for farmers and policymakers to achieve efficient and sustainable resource usage.

Solutions of Binary Mean Payoff Games and its Matrix Classes

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In this article we discuss the solvability of binary MPGs using pivoting algorithms. A binary MPG can be formulated as an LCP which has always terminated in a complementary solution in numerical experiments, but has not yet been proven either the processability of MPGs by Lemke's algorithm or a counter example that it will not terminate with a solution. Till now, the processability of MPGs by Lemke's algorithm remains open. Several properties of the matrix which arise in this context are also discussed.

A Statistical Assessment of the Impact of Machine Learning Inputs on the Performance of Integer-Valued Markowitz-Type Portfolios

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Harry Markowitz in 1952 proposed the mean-variance model for optimal portfolio selection (Ruppert, 2004). Many variations on this approach have since been developed, and in recent times, the incorporation of inputs generated from machine learning (ML) methods within Markowitz-based portfolio optimization models has also been considered (Brogaard & Zareei, 2023). However, in our knowledge, there has been no published study that performs a comprehensive statistical assessment of whether ML inputs indeed improve the performance of Markowitz-based optimal portfolios.

In this paper, we consider the integer-valued or 'round-lot' version of the classical Markowitz model, which allows analysts to directly compute the number of shares of each stock to be purchased. This model is given below.

$$\begin{aligned} \underset{w}{\text{maximize}} \quad & w^T\mu - \gamma w^T \Sigma w \\ \text{subject to:} \quad & \mathbf{P}^T w \leq \mathbf{B} \\ & w_i \geq 0, w_i \in \mathbb{Z}, \quad i = 1, \ldots, 53 \end{aligned} \tag{1}$$

In equation 1, $\mathbf{P}$ is the price vector of the stocks under consideration, and B is the total budget available for investment. $w \in \mathbb{Z}^{\kappa+} \cup \{0\}$ represents the portfolio allocation (with each component w_i being the fraction of the budget allocated to a stock). μ and Σ represent the mean returns vector and covariance matrix of the returns, and $\gamma > 0$ is the risk aversion parameter (higher values indicate lower risk tolerance and vice versa). In this work, we consider, in addition to the model in equation 1, its variants that (a) ensure diversification of the portfolio, (b) allow short-selling and (c) include Black-Scholes inspired stock price normalization by its volatility. We use these, along with a stock market-weighted index (the Indian SENSEX index) based portfolio, as benchmarks for our ML-based portfolios. ML model outputs are incorporated in the following ways in the above variants of the Markowitz model: (a) instead of using average stock prices / returns (i.e., μ), we use ML predictions of stock prices, and (b) we include a function of ML model prediction accuracy for each stock as a measure of its risk. We also develop an approach to hedge risk across portfolios, called the '*meta-Markowitz*' model. We consider daily portfolio reallocations, and use the XGBoost ML model to generate the next-day stock closing price predictions.

We then conduct a comprehensive statistical assessment of the performance of each ML-based Markowitz portfolio against the benchmarks, wherein the performance of each portfolio is measured across five different metrics, including the Sharpe and Sortino ratios. The statistical testing pipeline includes assessments of autocorrelation and stationarity of each portfolio's returns across the test period, tests of normality to determine the appropriate test procedure to be used to assess performance against the benchmarks, and the performance assessment tests themselves. A subset of the formulations considered in our work are provided in Table 1.

Table 1.: Portfolio Optimization Formulations

Formulation	Objective Function	Constraints
ML-Based Formulations		
Type 1: Using Predicted Prices ($\mu = \hat{C}_t$)		
Type1-Standard-Normal (ML1-N)	$\max_w \; w^T \hat{C}_t - \gamma w^T \Sigma w$	$P^T w \leq B$; $w_i \geq 0$; $w_i \in \mathbb{Z}$
Type1-Standard-Diversification (ML1-D)	$\max_w \; w^T \hat{C}_t - \gamma w^T \Sigma w$	$P^T w \leq B$; $0 \leq w_i \leq \lfloor 0.5B/P_i \rfloor$; $w_i \in \mathbb{Z}$
Type1-Both-Normal (ML1-B-N)	$\max_w \; w^T \hat{C}_t - \gamma_1 w^T a_l - \gamma_2 w^T \Sigma w$	$P^T w \leq B$; $w_i \geq 0$; $w_i \in \mathbb{Z}$
Type1-Both-Diversification (ML1-B-D)	$\max_w \; w^T \hat{C}_t - \gamma_1 w^T a_l - \gamma_2 w^T \Sigma w$	$P^T w \leq B$; $0 \leq w_i \leq \lfloor 0.5B/P_i \rfloor$; $w_i \in \mathbb{Z}$
Traditional Markowitz Formulations		
Markowitz-Normal (MKW-N)	$\max_w \; w^T \mu - \gamma w^T \Sigma w$	$P^T w \leq B$; $w_i \geq 0$; $w_i \in \mathbb{Z}$
Markowitz-ShortSelling (MKW-S)	$\max_w \; w^T \mu - \gamma w^T \Sigma w$	$P^T w \leq B$; $w_i \in \mathbb{Z}$ (unconstrained sign)
Markowitz-Diversification (MKW-D)	$\max_w \; w^T \mu - \gamma w^T \Sigma w$	$P^T w \leq B$; $0 \leq w_i \leq \lfloor 0.5B/P_i \rfloor$; $w_i \in \mathbb{Z}$

Our study demonstrated, via a comprehensive statistical assessment, the superior performance of machine learning-integrated portfolio optimization over traditional benchmarks as well as the SENSEX-weighted portfolios. Our study provides a framework for a statistically sound assessment of the impact of incorporating ML predictions of stock prices within Markowitz-based portfolio optimization formulations.

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Applications of Stochastic Game and Graph Theory in Network Security

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Modern networked systems face increasingly sophisticated and intelligent cyberattacks that evolve dynamically over time. To address the strategic and temporal nature of attack and defense processes, this study proposes a non-zero-sum stochastic game-theoretic framework for modeling network security interactions. The problem is formulated as a two-player stochastic game, where the state space represents different security states of the network. The network and its evolution across multiple stages are modeled as a directed weighted graph, with nodes representing network assets and systems, and edges denoting various interdependencies and relationships among them. State transitions are governed by the exploitation of vulnerabilities, deployment of defensive mechanisms, and recovery processes. Players are assumed to adopt stationary (Markov) strategies, implying that decisions depend solely on the current network state rather than the history of play. This assumption facilitates long-term behavioral analysis of the system. The solution concept employed is the Markov Perfect Nash Equilibrium, which characterizes optimal strategies in both equilibrium and out- of-equilibrium states. The proposed problem is formulated as nonzero sum stochastic game problem. The problem of computing value vector and optimal stationary strategies is presented as a nonconvex nonlinear programming problem. We apply a heuristic iterative method for obtaining a solution of this problem. Simulation-based case studies involving network structures and known vulnerabilities demonstrate how optimal defensive strategies can be derived and evaluated under stochastic dynamics. The proposed framework is mathematically robust and offers practical insights for assessing and designing adaptive network defense strategies.

Normal Cones in the Discrete Setting of Groups

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Convex analysis has been extensively studied in the setting of vector and topological vector spaces due to its importance in the theory of continuous optimization problems. Over the last decade, there has been a growing interest among researchers to develop a discrete counterpart of the classical convex analysis. Adivar and Fang [1] studied discrete convex sets and functions in finite-dimensional integer spaces. Parallelly, Borwein and Giladi [2] developed a canonical theory of convexity for additive groups and

semigroups. Recently, in 2025, Li and Mastroeni [3] introduced the notion of quasi core of a set in the group setting and used it to obtain separation results and certain saddle point type optimality conditions. Motivated by the preceding work, we delved further in the development of discrete convex analysis by obtaining useful analogues of classical notions related to convexity in the setting of groups and monoids. In this paper, we have introduced the notion of normal cone to sets in commutative groups and studied various properties of normal cone. To obtain the representation of normal cone to an intersection of convex sets in terms of the normal cones to the individual sets, we derived some proper separation results. For this, we investigated certain properties of the core and quasi core of a convex set in the setting of groups and monoids. With appropriate assumptions on the groups involved, we established the subdifferential sum rule. These results in turn lead to some necessary and sufficient optimality conditions for constrained optimization problems in terms of normal cones and subdifferentials.

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Vector Optimization Problems and Vector Variational Inequalities via Lower Global Subdifferentials

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In this talk, we discuss nonsmooth and nonconvex vector optimization problems using the framework of lower global subdifferentials. This notion allows a global analysis of vector-valued functions beyond the classical convex setting and provides both necessary and sufficient optimality conditions under suitable assumptions. We establish precise relationships between generalized convexity of vector-valued functions and generalized monotonicity of their associated lower global subdifferential mappings. Based on these results, we introduce Stampacchia- and Minty-type vector variational inequalities defined via lower global subdi_erentials and derive characterizations of e_cient and weakly e_cient solutions of vector optimization problems. Several examples are presented to illustrate the theoretical developments.

Paper for consideration for the Best Paper Award

Inertial proximal point algorithm on Hadamard manifolds: convergence analysis and finite termination

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This paper deals with a class of nonsmooth multiobjective quasiconvex optimization problems (abbreviated as, NMQOPs) in the framework of Hadamard manifolds. We introduce the inertial proximal point algorithm (abbreviated as, IPPA) in terms of Mordukhovich limiting subdifferential to solve NMQOP. We establish the well-definedness of the sequence generated by the IPPA algorithm. Subsequently, we derive that the sequence generated by the IPPA algorithm converges to the Pareto-Mordukhovich critical point of NMQOP. Moreover, we deduce that if the components of the objective function of NMQOP are geodesic convex, then
the sequence converges to the weak Pareto optimal solution of NMQOP. In addition to this, we establish the finite termination of the IPPA algorithm under appropriate assumptions. Finally, we furnish several numerical examples to demonstrate the effectiveness and competitiveness of the IPPA algorithm.

Gap functions and existence results for approximate vector variational inequality problems on hadamard manifolds

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This paper is concerned with the study of a class of weak approximate vector variational inequality problems on Hadamard manifolds. We formulate a gap function and a regularized gap function to solve the considered weak approximate vector variational inequality problems on Hadamard manifolds. We derive the conditions for the existence of solutions for the considered problem without monotonicity and relaxed compactness assumptions on Hadamard manifolds. Moreover, we also establish the existence results for the solutions of the considered problem using geodesic a-monotonicity assumption on

Hadamard manifolds. Some nontrivial numerical examples have been given to demonstrate the significance of these results. The results presented in this paper extend and generalize some existing results in the literature.

Lagrange duality and saddle point criteria for semi-infinite variational programming problem with Caputo-Fabrizio fractional derivative

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In this paper, we deal with a semi-infinite variational programming problem (SIVP) involving the Caputo-Fabrizio (CF) fractional derivative operator. Firstly, we formulate the Lagrange dual model for (SIVP) and then by using Slater's constraint qualification (SCQ) and convexity assumption, we establish the weak and strong duality theorems between primal and dual problems. Later on, the saddle point criteria associated with the Lagrange functional of the corresponding (SIVP) is discussed.

On quasidifferentiable interval-valued multiobjective optimization

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The aim of this talk is to investigate approximate solutions in an interval-valued multiobjective optimization problem with inequality constraints involving quasidifferentiable functions, which is denoted by QIVMOP. We establish the Karush-Kuhn-Tucker-type necessary optimality conditions to identify a type-2 E–quasi weakly Pareto solution of the QIVMOP under the assumption of a suitable constraint qualification. We also deduce the conditions under which the necessary optimality conditions become sufficient under the assumptions of generalized convexity in terms of quasidifferentials. The effectiveness and applicability of these conditions are demonstrated through several numerical examples.

Well-posedness of multidimensional semi-infinite variational inequalities with applications

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In this paper, we investigate a class of multidimensional semi-infinite variational inequality problems and analyze their well-posedness by examining the distance between approximate and exact solutions, as well as the strict monotonicity of the functional. Further, we utilize the monotonicity and hemicontinuity of the real-valued functional to investigate both the well-posedness and the well-posedness in the generalized sense of semi-infinite variational inequality problems. Moreover, we formulate a gap function for multidimensional semi-infinite variational inequality problems and establish a relationship between the well-posedness of the aforementioned variational inequality problem and its corresponding gap function. In addition, we present a water distribution problem, where a municipality aims to minimize the cost of supplying water as an illustrative example to demonstrate the validity and applicability of the theoretical results.

Normal Cones in Groups and Optimality Conditions

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In this paper, we introduce the notion of normal cone to a set in the setting of groups. With appropriate assumptions on the groups involved, we establish various calculus rules including the normal cone intersection rule and the subdifferential sum rule. These results in turn lead to optimality conditions for constrained optimization problems in terms of normal cones and subdifferentials.

Enhanced Indexing using Cumulative Prospect Theory Utility Function with Expectile Risk

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In this article, we explore portfolio selection strategies for enhanced indexation, focusing on integrating behavioral insights from cumulative prospect theory (CPT) to address investor preferences and risk appetite while aiming to achieve returns that outperform the benchmark index. We incorporate loss

aversion and probability distortion biases through the CPT utility function and expectile risk measure to mitigate portfolio risk. We propose dynamically adjusting reference points within the CPT utility function as the sum of the index return and a specified excess return to exceed the index's performance. The excess return is calculated as the average of the positive alphas of the stocks in the benchmark index, derived from the capital asset pricing model. The proposed model is nonlinear, nonconvex, and nondifferentiable. From an algorithmic standpoint, we design and implement the Real-Coded Genetic Algorithm to solve the newly proposed nondifferentiable nonconvex model. The efficacy of the model is tested using global datasets from Dow Jones, DAX, FTSE 100, and S&P 100. Our empirical evidence shows that by taking a lower risk than the index (measured by the portfolio's beta), our proposed CPT-based EI model outperforms the ordinary least square regression-based enhanced indexing model, the quantile regression-based enhanced indexing model, the naive strategy, and the benchmark index across nearly all performance metrics. Moreover, increasing the loss aversion parameter in the CPT value function improves the out-of-sample performance metrics up to a certain threshold. To further validate the consistency of our model, we tested it under different market phases of the FTSE 100 index and found favorable results.

The Price of Anarchy in Queueing-Inventory Systems with Delay-Sensitive Customers

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This paper explores the Price of Anarchy in a single-server queueing-inventory system with delay sensitive customers. The arrival follows the Poisson process, and the service time follows an exponential distribution. Upon arrival, the customers strategically decide whether to join or to balk the system based on the available information. Our study delves into equilibrium and socially optimal behaviours in fully unobservable and partially observable contexts. The Price of Anarchy measures the system's inefficiency resulting from customers' selfish behaviour, providing insights into decentralized system efficiency. We derive this inefficiency for these scenarios to highlight how customers' self-interested actions affect the system's overall performance, supported by a detailed numerical analysis. This research provides deeper insight into the dynamics of customer behaviour and their effects on system optimization.

Assessing the Impact of Replenishment Policies and Repair Mechanisms on Energy Management System Reliability

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This paper presents the reliability analysis of an energy management system in which the solar photovoltaic panels are modeled as a k-out-of-n: G system. To address component failures and ensure continuous operation of the system, we developed a framework considering a repair strategy for failed panels and a dual replenishment process. The steady-state probabilities of the system are evaluated explicitly. Key performance measures, along with some system distributions, are derived. We formulated a cost optimization problem, considering overall repair, replenishment, holding, and penalty costs. The robustness of the proposed strategy is examined using Tornado plot sensitivity analysis. Finally, the Morris method and one-parameter variation approach are used to examine the impact of different parameters on the performance measures. Optimal values of decision variables are determined to achieve the trade-off between system performance and economic efficiency.

An optimized model for pseudo-random and deterministic construction of sensing matrix

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Perfect signal recovery is one of the oldest and most challenging problems in science. Many attempts have been made to conquer the challenges associated with the perfect recovery of signals. Compressive sensing is one such technique that has gained much attention as it allows us to break the bounds of the Nyquist–Shannon sampling theorem. Mathematically, it is possible to achieve perfect signal recovery using the compressive sensing theory. One of the main challenges in compressive sensing is the construction of the sensing matrix, which arises due to the formulation of the system as an underdetermined linear system of equations. Essentially, solving a compressive sensing problem is equivalent to solving an ill-posed problem. In this setup, the sensing matrix plays a vital role in the success of the compressive sensing method. In this paper, two different approaches have been proposed to design a sensing matrix. The first approach is pseudo-random, which is unique in its use of the desirable properties of random matrices and is computationally efficient compared to the existing methods. The second is the deterministic approach. Simulation results have shown a significant improvement for both approaches compared to the existing and well-known methods in the literature.

A Note on some open problems on quitting games

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In this paper, we consider some open problems related to Q-matrix and quitting games raised by Solan and Solan (Math Oper Res 45(2):434–454 , 2020). We revisit the connection between Q-matrix, ϵ-equilibrium, and sunspot ϵ-equilibrium; addressing these open problems and presenting some important characterization of the Q-matrix. Further, we discuss how the concept of principal pivot transform is useful for identifying a Q-matrix and related characterization of ϵ-equilibrium/ sunspot ϵ-equilibrium. We obtain a new characterization for sunspot ϵ-equilibrium for the class of matrices that belongs to Q\M.

Robust Portfolio Optimization via Linear Deviation Risk Measures

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This paper examines the three deviation risk measures based portfolio optimization (PO) models within the robust framework. The three deviation risk measures are taken as Semi Mean Absolute Deviation (SemiMAD), Deviation Conditional Value-at-Risk (DCVaR), and Deviation MiniMax (DMM). We frame robustness in the PO models with respect to underlying probability distribution belonging to three most common uncertainty sets, namely, the mixed, box, and ellipsoidal. The robust counterparts of SemiMAD, DCVaR, and DMM PO models result in linear programs under mixed and box uncertainty whereas the models are second order cone program under ellipsoidal uncertainty. By testing the models on eight global data sets, we find that robust PO models outperform their respective nominal models in terms of risk and financial ratios, which contradict those studies emphasizing the under-performance of robust counterparts. Among the robust PO models, box uncertainty yields least risk as compared to mixed and ellipsoidal uncertainty, and hence box uncertainty is most suitable for risk-averse investors. Further findings reveal that robust model of DCVaR results in less risky portfolios than the other two robust models for the case of mixed and box uncertainty, while for the case of ellipsoidal, robust model of SemiMAD performs well in terms of risk. In terms of reward, a robust model of DMM generates highest mean return under the box and ellipsoidal uncertainty sets. Consequently, we setup an educated fusion between the three PO models with the three uncertainty sets that helps investor to take better investment decisions under the robust optimization framework.