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Abstracts

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Contents

Service Level Differentiation

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Abstract: At the Stock Keeping Unit (SKU) level, a higher service level typically requires an increase in the average inventory value. At the assortment level, Service Level Differentiation can simultaneously boost the aggregate service level and lower inventory investment. So, the improvement potential is higher at the assortment level than at the SKU level. Surprisingly, though, in our experience very few companies exploit this (fully), which may be related to the mathematical complexity of approaches in the literature. We discuss simple approximate approaches that are very easy to implement in e.g. a spreadsheet, and show using real data that they lead to considerable cost savings.

Integrating pricing, routing and scheduling decisions in the optimization of demand responsive transport

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We consider the operation of a demand responsive transport (DRT) service in which a fleet of vehicles are used to transport customers between their individual pick up and drop off locations. Unlike a taxi service, typically customers will share a vehicle. Such rideshare services have been introduced across the world in recent years as a way of reducing the environmental impact of transport. We aim to improve the financial sustainability of DRT using dynamic pricing in combination with routing and scheduling. Within a DRT system, customers first submit a request for service including when they wish to travel and their pickup and drop off points. The system then returns a set of options for them to choose from.

Bookings can be taken either before or on the day of travel, while the vehicles are en route. We set up the problem of maximising the expected profit as a dynamic program where a choice model is used to estimate the probabilities that a customer will choose each of the offered options and the no-purchase option. Data from a stated preference survey among Leeds residents is used to fit the choice model while demand data is determined from transport surveys carried out by Leeds City Council. We use approximate dynamic programming techniques combined with routing and scheduling heuristics to estimate the optimal prices to charge for a journey and the routing of the vehicles. Prices depend on the journey characteristics, the current accepted journeys, and forecasts of future demand. The talk will describe the context of the work, the methods we have designed and will present some preliminary results.

Towards flexible multi-mode travel planning via Markov models and traffic equilibrium

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Classic traffic equilibrium models utilise a discrete-choice framework to derive a system of equations that assess the probability that travellers will select each option from a set of prescribed paths for any feasible origin-destination pair. Recursive choice models add flexibility by considering that travellers' routes result from sequential decisions taken at each time they reach a new node in the network. This gives rise to a sequential decision problem that can be mapped into a Markov decision process (MDP), a model that is often applied to trips involving a single mode of transport.

This work develops an MDP approach for multi-mode traffic equilibrium that combines impulse control theory and recursive choice models. The transfer between modes is tackled via impulse control, considering node-specific mode transfer costs whenever a node is served by more than one transport mode. This approach allows for a recursive calculation of multimode equilibrium without the need to enumerate all possible mode transfers, an innovation with respect to the literature.

The proposed approach allows for a fully recursive model that can be seamlessly extended to multiple travel modes whilst incorporating mode-change costs and sequential decisions taken recursively during each journey. The model will enable decision-makers to fully evaluate the effect of system parameters and available infrastructure into contemporary flexible transport systems, thereby enabling adjustments towards a low-carbon transportation network with added incentives to active travel.

Enhancing carsharing pricing and operations through integrated choice models

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Balancing supply and demand in free-floating one-way carsharing systems is a critical operational challenge. This paper presents a novel approach that integrates a binary logit model into a mixed integer linear programming framework to optimize short-term pricing and fleet relocation. Demand modelling, based on a binary logit model, aggregates different trips under a unified utility model and improves estimation by incorporating information from similar trips. To speed up the estimation process, a categorizing approach is used, where variables such as location and time are classified into a few categories based on shared attributes. This is particularly beneficial for trips with limited observations as information gained from similar trips can be used for these trips effectively.
The modelling framework adopts a dynamic structure where the binary logit model estimates demand using accumulated observations from past iterations at each decision point. This continuous learning environment allows for dynamic improvement in estimation and decision-making. At the core of the framework is a mathematical program that prescribes optimal levels of promotion and relocation. The framework then includes simulated market responses to the decisions, allowing for real-time adjustments to effectively balance supply and demand.

Computational experiments demonstrate the effectiveness of the proposed approach and highlight its potential for real-world applications. The continuous learning environment, combining demand modelling and operational decisions, opens avenues for future research in transportation systems.

Optimizing Workforce Dynamics on Gig Platforms: The Role of Forecast Sharing and Trust

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In the gig economy, balancing workforce supply with market demand is crucial. However, planning the working hours of self-scheduled gig workers presents a challenge, as they prioritize flexibility over monetary incentives. This study examines how a gig economy platform can achieve this balance through information sharing. We model a multi-period workforce supply planning problem between a gig platform and a representative gig worker, incorporating voluntary communication of earning rate forecasts. In the first stage of each period, the platform shares an expected earning rate with the worker. The worker, based on their level of trust, adjusts their expectations of the earning rate and decides on their optimal working hours to maximize his expected utility. In the second stage, the worker delivers these hours, after which the platform receives revenue and distributes a predetermined share to the worker. The worker then observes the actual earning rate and updates his trust for future periods. Our findings highlight how strategic information sharing can enhance workforce planning, reducing the reliance on monetary incentives. By fostering trust, platforms can better align workforce supply with demand, ultimately improving efficiency in the gig economy.

Key words : Gig economy, Workforce planning, Information sharing, Trust, Modeling

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Trust and Fairness in Platform-Supplier Contracts: Navigating Supplier Concerns in the Sharing Economy Short running title: Trust & Fairness in Platform-Supplier Contracts

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Trust and fairness are critical to the sustainable development of the sharing economy. We study a contracting problem between a platform and its content supplier, in which the platform either offers to manage the content for the supplier and share revenue afterward (contract A) or lets the supplier manage their content and report trade while charging them a commission fee (contract B). The platform decides the revenue-sharing ratio and how much revenue information to disclose. The supplier evaluates a contract based on their expected utility, considering their trust in the disclosed information and their fairness concerns over the revenue-sharing ratio. Using a game-theoretical model, we derive the optimal contracting mechanism under different conditions and uncover the rationale for optimality. Our results first show that in a take-it-or-leave-it situation, while trust isn't always a decisive factor, trustworthiness is consistently significant. Second, the optimal revenuesharing ratio of contract A increases either with the element of trust or with the element of fairness, but never both. Third, although honesty doesn't always pay for the supplier under contract B, dishonesty always costs. We also find that the supplier who wants to be treated fairly will cheat more and there is a vicious circle between the commission fee and the supplier's under-reporting behavior. By developing an online experiment and letting 277 participants play as the platform, we further demonstrate the practical potential of our model.

The Hidden Supply Chains of AI: Ethical Sourcing, Recycling, and Geopolitical Implications

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Abstract

The ethical supply chains of artificial intelligence (AI) are becoming increasingly critical as AI technologies permeate various sectors. This research investigates the supply chain dynamics of AI, which involve the transfer of energy, critical raw materials, and expert knowledge to produce safe and reliable AI products for public use. Our study addresses pressing supply chain issues, including the high energy demands of AI systems, the ethical sourcing of essential raw materials, and the responsible acquisition and retention of expert knowledge. We also explore AI's competition with other supply chains for resources and the geopolitical tensions that may arise from these dependencies. Through interviews with practitioners, government agencies, leading companies such as Tesla, and academic experts, we provide a comprehensive perspective on the challenges and opportunities in creating ethical and sustainable AI supply chains. The findings emphasize the need for collaborative strategies that balance innovation with ethical considerations, resource sustainability, and enhanced recycling initiatives to reduce dependence on non-renewable materials and minimize environmental impact.

What’s New in FICO® Xpress

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We will give an overview of the latest enhancements, the newest features, and the most recent performance improvements in the FICO® Xpress Solver for mixed-integer linear and nonlinear optimization problems. These include new heuristics, cutting and branching techniques, a more streamlined API, and updates to our global MINLP solver.

Category Captains, Assortment Decisions and Exclusion: A Game-Theoretical Model

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Category captain (CC) agreements, where a retailer delegates category management decisions to a manufacturer, have become increasingly common in retail. While these agreements can enhance supply chain efficiency, they also raise concerns about competitive exclusion of rival brands, potentially harming consumers. We develop a game-theoretic model to examine the incentives for a dominant manufacturer and a retailer to form such an agreement and analyse its impact on competition, consumers, and businesses.

We model consumer preferences using a quadratic, strictly concave utility function, which yields a linear demand function that captures substitutability between both brands and retailers. Unlike much of the existing literature, our model incorporates the delegation of both pricing and assortment decisions to the CC, reflecting more accurately real-world practices.

Under retail category management, manufacturers set wholesale prices to maximise their profits, and retailers subsequently set retail prices. We model CC agreements as a three-stage game. In the first stage, the dominant manufacturer offers to become a retailer's category captain. If the offer is accepted, the CC decides whether to supply rival retailers and whether the retailer it serves will carry the competing brand. Finally, the CC sets the retail prices for the retailer it serves to maximise joint profits.

By comparing equilibrium outcomes under CC agreements and the benchmark scenario, we find that CC agreements always increase profits for the alliance but has mixed effects on other stakeholders. When retail competition is weak, consumers benefit from lower prices, but competing retailers lose profits. Conversely, under strong retail competition, consumers face higher prices and reduced variety through complete exclusion of the rival brand, while competing retailers gain. By distinguishing between retail and brand competition, our model highlights the critical role of retail competition in determining these outcomes. Thus, our research offers valuable insights for firms, consumers, and policy.

A four-objective mean-variance-CVaR-ESG model for portfolio selection problem

Erindi Allaj*
November 28, 2024

Abstract
Environmental, Social and Governance, or simply ESG, has become an increasingly important topic in recent years. On the other side, the conditional value-at-risk (CVaR) is often used to quantify losses beyond the value-at-risk (VaR). In this work, we propose a four-objective portfolio optimization model, where the portfolio choice is made based on four criteria: the expected portfolio return, the portfolio variance, the portfolio CVaR and the portfolio ESG score.

The four-objective problem is transformed into a single-objective problem using the ϵ-constraint technique. The resulting single-objective problem consists in minimizing the portfolio variance with constraints on the target levels of the expected portfolio return, portfolio CVaR and portfolio ESG score. Assuming a discrete probability space, the above problem is formulated as a convex quadratic programming problem. We compare the out-of-sample performance of the proposed portfolio optimization model against two competitive models. The datasets used to evaluate the out-of-sample performance are the Dow Jones Industrial Average (DJIA) and the Euro Stoxx 50. Our analysis demonstrates that our model is a valid alternative to existing models in the literature.

Keywords: multi-objective optimization problem; portfolio selection model; ESG score; conditional value-at-risk.

The 'je ne sais quoi' of algorithms that foster human centric analytics design

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There have been developments recently in interpretable and explainable AI as well as moves to understand ways to do human centered analytics design. As technology and the use of algorithms in business becomes more ubiquitous, we need to understand what parameters in algorithm design can facilitate human centered approaches. Ways to do this ethically and sustainably become ever more pressing as business moves into a world of ESG reporting and increasingly cybernetic systems.

This talk initially outlines the parameters (defined by prior research) needed by algorithms and AI/ML techniques that make them amenable to integration with human practice. We then take a quick look at the philosophical underpinnings needed by research into cross paradigm work. This sets the stage for a tour of some currently available mathematical tools and techniques that can work with human practice and the contexts they are likely to work under.

We cover explainable and interpretable AI looking at the distinction and how human centered work can be translational by providing inspiration for algorithmic design. Also covered, are ways to crowd source explanations and provide libraries of tried and tested techniques.

A fundamental part of Operational Research is improvement and often that won’t happen without by in from human users. What can we do as Mathematicians to embed mathematics into practice and how can we learn from the process to create translatable designs and methods for integration? We hope, at least in part, to begin answering these questions.

Federated Learning with Sample Selection: A Robust Optimization Approach

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Federated learning concerns training global models in a decentralized manner. Federated learning is important in many applications, especially when training data come from different sources that cannot be shared with the central server due to restrictions on data sharing. With the increasing capacity of data sources, training samples are usually collected and stored on a regular basis, which leads to an additional issue of sample selection from data sources when one needs to train a global model using the federated learning framework. In this talk, we propose a robust optimization model to incorporate sample selection into global models and develop the robust federated learning framework to train such models.

A Network DEA Two-stage Model for Efficiency Evaluation of Wind Power Plants in India

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India, like many other countries, is increasingly focusing on renewable energy to meet its growing electricity needs at an affordable cost. Among renewable sources, wind energy has evolved from being a minor component of the energy mix to becoming a key player, largely due to its positive environmental impact and inherent safety advantages. However, evaluating the performance of operational wind power plants across different regions is essential to ensure their optimal operation. The existing literature focuses on basic DEA models like CCR or BCC to evaluate the efficiency of operational wind power plants, often overlooking the underlying causes of inefficiency. In this study, a network SBM-DEA two-stage model is proposed to assess the performance and efficiency of wind power plants existing across nine states in India and provide a detailed insight into the causes of inefficiency. Results suggested that Gujarat is the only state in which wind power plants are performing efficiently in overall process, while Tamil Nadu is the least efficient state. Further, the Tobit regression model is applied to measure the effect of uncontrollable variable on the efficiency value. Site elevation shows a positive impact on the efficiency value, while wind curtailment has significant negative influence. This study's findings can assist stakeholders and policymakers in identifying key factors affecting India's wind power plant performance and in optimizing operational policies and strategies.

Forecast Congruence: a quantity to align forecasts and inventory decisions

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Forecasting is a step undertaken in many business decisions. For instance, in inventory management, demand forecasts are the cornerstone of inventory decisions, namely how much and when to order. It is widely recognised that accurate demand forecasts lead to effective and efficient inventory decisions. However, in practice the forecasts are produced in isolation, i.e., the models are selected and evaluated on accuracy metrics that do not account for important aspects of inventory management. Even though there are good reasons in support of this practice, for the alternative approach, to help managers calibrate their forecasting process from a decision standpoint, we lack appropriate measures of forecast quality. We address this limitation by introducing the quantity of forecast congruence, which measures the `jitteriness' of forecasts over the decision period. We investigate its characteristics and connection to accuracy and demonstrate with simulations and a real case on an FMCG manufacturer that congruence is connected with the volatility of inventory decisions. We show that accounting for congruence in forecast design and selection can achieve favourable inventory performance, without necessitating evaluations that rely on complex inventory simulations. We conclude by discussing its connection with estimation uncertainty and the bullwhip effect.

Forecasting Demand During & After Supply Chain Disruptions using a Shock Smoother ETS

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Global disruptions such as Brexit, the Russia-Ukraine conflict, and the COVID-19 pandemic have underscored the difficulties supply chains face in accurately predicting demand during and after major disruptions. Traditional forecasting methods, while effective under normal conditions, often fail to deliver reliable forecast when demand patterns are disrupted. This has led many decision-makers to rely more on subjective judgment than on statistical models for demand planning. Despite these challenges, precise forecasting remains critical, particularly during periods of disruptions. To tackle this problem, our work offers two main contributions. First, we conduct a comprehensive evaluation of traditional forecasting methods using both simulated and real-world data, examining their performance and effectiveness across various phases of disruption. This evaluation reveals their shortcomings in managing disrupted demand patterns. Second, we introduce a shock-smoothing model, an adaptation of the single-source-of-error state-space framework used in exponential smoothing (ETS), enhanced with additional components designed to address disruption periods. Our results show that this proposed model not only improves overall forecasting accuracy but also maintains greater resilience across different disruption phases, positioning it as a potential valuable tool for data-driven demand planning during and after disruptions.

Economic Indicators to Optimise Sales Forecast Accuracy in the Consumer Goods Sector

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Given the profound structural changes in macroeconomic conditions in the current decade, which have induced substantial, sometimes abrupt fluctuations in consumer sales patterns, this research presentation examines the integration and relevance of leading economic indicators within quantitative, multivariate forecasting models. The presentation content is based on a three-part study structure consisting of systematic literature review (Muth, Lingenfelder, & Nufer, 2024), a conceptual framework (Muth, 2025), and an empirical analysis (Lingenfelder, Litzinger, Muth, & Parsegyan, 2025). In part (1), potential leading economic indicators are classified using a structured taxonomy. Indicators around real economic activity, financial markets, labour markets, consumer sentiment, and industry-specific factors are evaluated for their informational value for future sales. In part (2), methodological approaches for selecting and validating economic indicators are discussed, including causality analyses to assess temporal precedence as well as regularisation and dimensionality reduction techniques. Part (3) focuses on the modelling process incorporating leading economic indicators. Theoretical considerations are substantiated with empirical evidence, including forecasting passenger car sales in the German consumer goods sector—selected as an example due to its macroeconomic sensitivity. A comparative analysis of univariate and multivariate models demonstrates the impact of leading economic indicators on forecast accuracy. Both state-of-the-art linear stochastic time series models and non-parametric, non-linear machine learning methods are considered for this analysis. Part (4) is dedicated to the interpretation of leading economic indicators and their integration into managerial decision-making. Additionally, the potential of models incorporating leading economic indicators is investigated within scenario analyses to simulate the effects of economic developments—as a current example, United States trade tariffs—on company-relevant sales. Overall, the presentation aims to support the integration of leading economic indicators in forecasting consumer goods sales to enable companies to anticipate upcoming market dynamics proactively and thus stabilise their business position in times of crisis.

Strongly connected orientations and integer lattices

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Let D = (V, A) be a digraph whose underlying graph is 2-edge-connected, and let P be the polytope whose vertices are the incidence vectors of arc sets whose reversal makes D strongly connected. We study the lattice theoretic properties of the integer points contained in a proper face F of P not contained in $\{x : x_a = i\}$ for any $a \in A, i \in \{0, 1\}$. We prove under a mild necessary condition that $F \cap \{0, 1\}^A$ contains an integral basis B, i.e., B is linearly independent, and any integral vector in the linear hull of F is an integral linear combination of B. This result is surprising as the integer points in F do not necessarily form a Hilbert basis. In proving the result, we develop a theory similar to Matching Theory for degree-constrained dijoins in bipartite digraphs.

Our result has consequences for head-disjoint strong orientations in hypergraphs, and also to a famous conjecture by Woodall that the minimum size of a dicut of D, say τ , is equal to the maximum number of disjoint dijoins. We prove a relaxation of this conjecture, by finding for any prime number $p \geq 2$, a p-adic packing of dijoins of value τ and of support size at most $2|A|$. We also prove that the all-ones vector belongs to the lattice generated by $F \cap \{0, 1\}^A$, where F is the face of P satisfying $x(\delta^+(U)) = 1$ for every minimum dicut $\delta^+(U)$.

Based on joint work with Gerard Cornuejols, Siyue Liu, and Olha Silina.

Sparsity and proximity transference in integer programming

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We discuss new transference bounds that connect the additive integrality gap and sparsity of solutions for integer linear programs. Specifically, we consider the integer programs min{c · x : x ∈ P ∩ Z n}, where P = {x ∈ R n : Ax = b, x ≥ 0} is a polyhedron in the standard form determined by an integer m × n matrix A and an integer vector b. The main result presented in this talk gives an upper bound for the integrality gap that drops exponentially in the size of the support of the optimal solutions corresponding to the vertices of the integer hull of P. Additionally, we obtain a new proximity estimate for the ` 2-distance from a vertex of P to its nearest integer point in P. We also strengthen previously known bounds for the integer Carath´eodory rank, a key sparsity characteristic which estimates the minimum size of the support of an integer point in P in terms of the matrix A. The proofs make use of the results from the geometry of numbers and convex geometry.

Based on joint work with Martin Henk and Marcel Celaya.

A Tutorial on Dual Ascent

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Most people working in integer programming have heard of solution methods like branch-and-bound, cutting planes, dynamic programming and Lagrangian relaxation. Dual ascent is however much less well known. Dual ascent is an elegant procedure that enables one to very quickly produce lower bounds for certain integer programs of minimisation type. In some cases, it can yield upper bounds as well. One big advantage of dual ascent is that it scales well with problem size, since one does need to solve any linear or integer programs at all. This tutorial will introduce dual ascent and survey the main applications, and then we will go through a couple of worked examples together.

New Bounds for the Integer Carathéodory Rank

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Given a finitely generated rational pointed cone $C \subset \mathbb{R}^n$, what is the smallest k such that every integer point of C can be expressed as a non-negative linear combination of at most k extreme vectors of the cone? Carathéodory (1911) proved the answer to this question is n. The integer analogue of this question is known as the integer Carathéodory rank problem. Specifically, the question is

> *Given a finitely generated rational pointed cone $C \subset \mathbb{R}^n$, what is the smallest k such that every integer point of C can be expressed as a non-negative linear integer combination of at most k vectors in the Hilbert basis?*

This is currently an open question. Given a cone $C \subset \mathbb{R}^n$ with Hilbert basis $H(C)$, and $\boldsymbol{x} \in C \cap \mathbb{Z}^n$ the representation length of $\boldsymbol{x}$ is

$$\sigma(\boldsymbol{x}) = \min\{\ell : \boldsymbol{x} = \sum_{i=1}^{\ell} \lambda_i \boldsymbol{h}_i, \lambda_i \in \mathbb{Z}_{\geq 0}, \boldsymbol{h}_i \in H(C)\}.$$

The integer Carathéodory rank $\mathrm{CR}(C)$ of C is

$$\mathrm{CR}(C) = \max\{\sigma(\boldsymbol{x}) : \boldsymbol{x} \in C \cap \mathbb{Z}^n\}.$$

For $\boldsymbol{A} \in \mathbb{Z}^{m \times n}$ with full column rank, $\Delta(\boldsymbol{A}) = \max\{|\det(\boldsymbol{B})| : \boldsymbol{B}$ is an $n \times n$ submatrix of $\boldsymbol{A}\}$. Cook, Fonlupt, and Schrijver (1986) proved the bounds $CR(C) \leq 2n-1$ for $C \subset \mathbb{R}^n$, and $CR(C) \leq 2$ for $C \subset \mathbb{R}^2$, the case for $C \subset \mathbb{R}^1$ being trivial. Sebö (1990) improved this upper bound to $CR(C) \leq 2n-2$, and proved $CR(C) \leq 3$ for $C \subset \mathbb{R}^3$ (this was also independently, proven in Aguzzoli and Mundici (1994) and Bouvier and Gonzalez-Sprinberg (1995)). The integer Carathéodory property conjecture $CR(C) \leq n$ for $C \subset \mathbb{R}^n$ was disproven in Bruns et al (1999) by the counterexample of a cone $C \subset \mathbb{R}^6$ with $CR(C) = 7$. This cone can be embedded in higher dimensions and so for $n \geq 6$ there exists a cone $C \subset \mathbb{R}^n$ with $CR(C) \geq \lfloor \frac{7}{6} n \rfloor$.

The asymptotic integer Carathéodory rank $CR^a(C)$ of the cone C is the smallest positive integer k such that the following limit exists and satisfies the equality

$$\lim_{\delta \to \infty} \frac{|\{\mathbf{x} \in C \cap \mathbb{Z}^n : \sigma(\mathbf{x}) \leq k\} \cap [-\delta, \delta]^n|}{|C \cap \mathbb{Z}^n \cap [-\delta, \delta]^n|} = 1. \tag{1}$$

The first results for the asymptotic integer Carathéodory rank were found by Bruns and Gubeladze (1999) where they found $CR^a(C) \leq n, n \in \{1,2,3\}$, $CR^a(C) \leq 2n-3, n \geq 3$ and that there exists a cone $C \subset \mathbb{R}^n$ such that $CR^a(C) > n, n \geq 6$.

In this talk I will present the following new parametric and asymptotic bounds. For a rational pointed cone $C \subset \mathbb{R}^n$ we have $CR^a(C) \leq \lfloor \frac{3}{2} n \rfloor$. Let $\mathbf{A} \in \mathbb{Z}^{m \times n}$ be a matrix of full column rank with $\Delta(\mathbf{A}) \leq 2$ and $C = \{\boldsymbol{x} \in \mathbb{R}^n : \boldsymbol{A}\boldsymbol{x} \geq \mathbf{0}\}$, then $CR(C) = n$. Let $\mathbf{A} \in \mathbb{Z}^{n \times n}$ be a nonsingular matrix. If $1 \leq \Delta(\mathbf{A}) \leq 4$ then $CR(C) = n$. If $\Delta(\mathbf{A}) \geq 5$ then $CR(C) \leq n + \Delta(\mathbf{A}) - 3$.

Based on joint work with Iskander Aliev, Martin Henk, Stefan Kuhlmann and Timm Oertel.

On robust inventory optimization for bike sharing

Haoxiang Wang

Abstract not available

Algorithms for shipping container delivery scheduling

Dimitrios Letsios

Abstract not available

Creating a Cross-Sector Vehicle Route Optimiser for Heavy Freight

Presenter: Adil Rahman

Co Authors: Alexander Green, Ameya Joshi, Callum Walker, Ishbel Hughes-d'Aeth, Ivan Nedjalkov, Jeremy Bradley, Jessica McQuade, Kiko Rullan, Kit Fagan, Louisa Sober, Matthew Simmons, Michael Sutherland, Mollie O'Neill, Ruth Walton, Simas Silacinas, Thomas Jeffries, Ying Tan

Abstract

Developing an effective vehicle routing solution for heavy freight—capable of handling a high volume of customer requests—is a complex challenge, especially when aiming to serve multiple industries with distinct operational needs. Many existing routing solutions are built for specific sectors, limiting their flexibility and scalability. Our goal was to create a highly configurable and scalable product that can adapt to diverse operational constraints while maintaining high performance.

This talk explores our journey in productising a vehicle routing optimiser, built on Adaptive Large Neighborhood Search (ALNS) running in a large cloud environment and parallelised to deliver high-performance scheduling. Our system is designed to accommodate the requirements of multiple industries through support for a wide range of configurable parameters, including vehicle types, capacities, time windows, delivery types, and sector-specific constraints. By engaging with organisations operating at scale—managing over £4 billion in operational costs—we have consistently demonstrated 5–10% objective savings over existing industrial tools through improved routing efficiency.

A major challenge in building a cross-sector optimiser is ensuring that it is both generalisable and customisable without incurring onerous configuration debt for new problem instances. To address this, we developed a modular system where organisations can configure their own constraints and objectives without extensive re-engineering. By taking advantage of large-scale parallel computation in cloud environments, our solution delivers optimisation of industry-scale problems, finding efficiencies even in high-volume, complex logistics operations.

This talk will cover our approach to designing a cross-sector vehicle route optimisation product, highlighting how we use cloud computing to provide value to a diverse range of customers, each with their own operational requirements and constraints.

Optimising Warehouse Picking with Simulation

Ying Tan(*), Paula Fermin Cueto,
Jessica McQuade, Jeremy Bradley

Abstract:
Order picking is a critical function in any warehouse or distribution centre, yet inefficiencies such as suboptimal worker and equipment utilisation, bottlenecks, and excessive travel time can hinder productivity – usually measured in the number of picks/orders processed per hour. Traditional optimisation methods often depend on trial-and-error and domain knowledge, but making operational changes in a live environment is often costly and impractical—especially when order fulfillment must continue without disruption. It is also important that, if substantial operational changes are going to be made to a complex warehouse environment, that key processing deadlines are maintained and simulations provide an excellent tool for being able to scenario-test these requirements.

This presentation will explore the key elements and considerations involved in accurately modeling warehouse simulations, highlighting common pain points from industrial users and demonstrating how simulation-driven metrics can drive smarter decision-making and operational improvements.

Constrained Markov decision processes for response-adaptive procedures in clinical trials with binary outcomes

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A constrained Markov decision process ("CMDP") approach is developed to construct response-adaptive procedures in clinical trials with binary outcomes. The resulting CMDP class of Bayesian response-adaptive procedures can target an objective such as maximizing expected treatment outcomes while using constraints to control other operating characteristics such as the type I error rate. The constraints can be formulated under different priors, enforcing (Bayesian) average control of trial operating statistics given that the parameters lie in a specific part of the parameter space (e.g., following from a statistical hypothesis). A solution method is developed to find an optimal policy, while we propose a computationally efficient approximation method based on a cutting plane algorithm that uses backward recursion at every iteration, yielding a feasible policy accompanied by a respective optimality gap. In our applications, we impose constraints on the Bayesian average type I error rate, power, and mean-squared error. Comparison of the constructed CMDP procedures with the constrained randomized dynamic programming procedure known from the literature shows a stronger frequentist type I error control and similar performance in the other operating characteristics when constraining the Bayesian average type I error rate, power, and mean squared error, whereas CMDP additionally shows substantial outperformance in terms of expected treatment outcomes when the constraints are only on the type I error rate and power. Although omitted in this talk, the CMDP approach can also be used to protect patient benefit to misspecification of the prior under which optimization is performed (shown in the paper) and can also be used to consider different objectives than patient benefit.

Keywords: Adaptive treatment allocation, Bayesian optimisation, Mean-squared error control, Power constraints, Prior misspecification control, Type I error control

Exact statistical analysis for response-adaptive clinical trials: A general and computationally tractable approach

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Response-adaptive designs of clinical trials allow targeting a given objective by skewing the allocation of participants to treatments based on observed outcomes. Response-adaptive designs face greater regulatory scrutiny due to potential type I error inflation, which limits their uptake in practice. Existing approaches for type I error control either only work for specific designs, have a risk of Monte Carlo/approximation error, are conservative, or computationally intractable. We develop a general and computationally tractable approach for exact analysis in two-arm response-adaptive designs with binary outcomes. We use the approach to construct exact tests applicable to designs that use either randomized or deterministic response-adaptive procedures, allowing for complexities such as delayed outcomes, early stopping or allocation of participants in blocks. Our efficient forward recursion implementation allows for testing of two-arm trials with 1,000 participants on a standard computer. Through an illustrative computational study of trials using randomized dynamic programming we show that, contrary to what is known for equal allocation, a conditional exact test has, almost uniformly, higher power than the unconditional test. Two real-world trials with the above-mentioned complexities are re-analyzed to demonstrate the value of our approach in controlling type I error and/or improving the statistical power.

Keywords: Conditional test, Design and analysis of experiments, Exact test, Markov chains, Unconditional test

Optimizing Packaging for an eCommerce Business

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In any retail business, packaging is essential for the protection and transportation of products. Excessive packaging however, increases costs, and can be off-putting to environmentally-conscious customers. It is therefore important to reduce packaging as much as possible.

In this work, we consider the problem of selecting packaging options for dispatching eCommerce orders. In particular, we need to select around a dozen box sizes to use for dispatch in such a way that: (i) we can cover almost all orders, (ii) the selected boxes satisfy courier restrictions on size and (iii) we optimize key metrics such as packing efficiency.

We model this as a two-stage stochastic program which explicitly incorporates how selected boxes are used for packing for large sample of orders. We demonstrate this approach using data from a large UK retailer, and our results show that significant improvements in packing efficiency are possible compared to the set of boxes currently being used for dispatch.

Revolutionizing Production Scheduling: Optimized Multi-Constraint Solutions for sustainable Manufacturing

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In the dynamic landscape of manufacturing, optimizing production planning is critical for enhancing operational efficiency, minimizing waste, and ensuring timely order fulfillment. This presentation explores an advanced scheduling solution developed for a leading cardboard packaging manufacturer. Leveraging optimization techniques, this approach addresses multi-stage sequencing challenges and incorporates constraints such as machine utilization, waste minimization, and inventory management. The proposed methodology achieves shorter scheduling times, increased operational responsiveness, and sustainable growth while boosting revenue and customer retention.

Dancing to the Rhythm of Demand: Inventory Control for Compound Renewal Demand

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The demand for many items is intermittent. As a consequence, managing the inventories for those items efficiently and effectively can be challenging. Intermittent demand patterns are not well modeled by a single distribution of demand per period. It is therefore common to model the time between demand occurrences and the size of demand occurrences separately. Such models typically implicitly assume that times between demand occurrences are Markovian. Data from practice, however, indicate that the time between demand events is often not Markovian but–-contrary to implicit model assumptions— displays a certain rhythm. Consequently, the time since the last demand occurrence is an important predictor for future demand for those items.

We use the discrete compound renewal process to model such periodic intermittent demand. In a periodic review inventory system, we show that the optimal inventory policy is a state-dependent base-stock policy, where the order-up-to-levels are non-decreasing in the time since the last demand, regardless of the nature of the distribution of time between demand occurrences.

We benchmark the performance of our approach against heuristic policies both in a numerical experiment, in which demand processes are known, and on five real data sets, where the demand process is not known and needs to be estimated, in terms of average inventory costs. We find that using information on the demand rhythm and the time since the last demand occurrence is valuable when demand occurs at regular intervals, with limited deviations. Additionally, when demand is more intermittent, using such information is increasingly beneficial. Nonetheless, a trade-off with data availability exists.

A Fractional-Order Inventory Model for Deteriorating Items with Dynamic Demand, Trade Credit, and Hybrid Payment Policies: A Meta-Heuristic Optimization Strategy

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This research develops a comprehensive inventory model integrating critical factors such as advertisement, selling price, product reliability, and memory-dependent demand while addressing practical complexities like product deterioration, preservation technology, shortages, lost sales, and hybrid payment policies involving partial advance and delayed payments. Emphasizing trade credit policies, the model employs fractional-order calculus, specifically the Caputo fractional differential and integral equations system, to capture memory-dependent dynamics of demand and deterioration behavior. The Laplace transform technique ensures computational precision, while a meta-heuristic algorithm optimizes total profit. Numerical examples, sensitivity analyses, and graphical representations validate the model and evaluate the influence of key parameters. The findings demonstrate that incorporating advertisement expenditure, pricing strategies, preservation investment, and trade credit terms significantly enhances inventory performance and profitability. The fractional-order approach effectively models memory-dependent demand dynamics, offering deeper insights into system behavior and optimization. The study emphasizes sustainable inventory management practices, addressing shortages, reducing lost sales, and promoting efficient resource utilization. By integrating trade credit policies, the model strengthens customer-retailer relationships, fostering economic growth and competitiveness. This research contributes to inventory management literature by introducing a novel framework that combines fractional-order systems, trade credit policies, and memory-dependent demand modeling. It provides actionable insights for designing robust inventory strategies that balance demand stimulation, hybrid payment policies, and operational efficiency in competitive markets.

Keywords: Perishable item, Memory effect, Variable demand, Shortage, Hybrid payment policy, Trade credit.

On managing the dynamics of pure remanufacturing Systems

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Pure remanufacturing systems and their respective supply chains are increasingly common in many industries. However, the scientific community has paid little attention to such systems, and thus their dynamics are still not well understood. To address this gap, we build an archetype by generalising the real-world closed-loop supply chain of pure remanufacturers across different industries. Through control engineering, we study its mathematical properties and their impact on performance. We benchmark it against two extensively studied models: traditional manufacturing systems and hybrid manufacturing-remanufacturing systems. We show the proportional order-up-to policy to be a promising approach to streamline the operations of pure remanufacturers, and we highlight critical trade-offs that need to be recognised by decision-makers to improve their control. Through simulation, we identify effective management strategies for these closed-loop supply chains, enabling remanufacturers to improve customer satisfaction while reducing inventory and capacity requirements. Key drivers for enhancing closed-loop supply chain dynamics include increasing pre-evaluation accuracy, reducing remanufacturing lead times, and improving the quality of reverse logistics operations. Additionally, synchronised tuning of the different inventory controllers becomes imperative for optimising overall performance.

Dynamic Impacts of Rationing in Supply Chains: Analysing the Bullwhip Effect and Inventory Fluctuations

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Driven by the challenges in supply chains caused by demand surpassing supply, we introduce a stochastic state space model to examine the impact of the rationing game on the bullwhip effect and inventory fluctuations. The rationing game is represented using a proportional gain factor, which regulates the amount of goods sent to downstream supply chain nodes. This study focuses on a two-echelon supply chain, consisting of one distributor serving two retailers. Each retailer's inventory replenishment follows base stock policies in response to customers' stochastic demand profiles. The model's dynamic characteristics are encapsulated in a closed-form covariance matrix, articulated as a function of the proportional control parameters and the distributor's inventory percentage allocated to the retailers. Analyzing the model under stationary conditions allows us to explore the effects of the distributor's inventory variances and correlated demand profiles on the bullwhip effect (demand amplification) and associated supply chain instabilities.

Mixed-Integer Convex Optimization for Statistical Learning

Simge Küçükyavuz

Many statistical learning problems involving sparsity and other structural constraints can be formulated as mixed-integer convex optimization problems involving indicator variables and constraints on these indicators. As motivation, the first part of this talk will focus on the problem of learning directed acyclic graphs (DAGs) from continuous observational data, also known as the causal discovery problem. Current state-of-the-art structure learning methods for this problem face significant limitations: (i) they lack optimality guarantees and often yield suboptimal solutions; (ii) they rely on the restrictive assumption of homoscedastic noise. To address these shortcomings, we propose a computationally efficient mixed-integer programming framework. Numerical experiments demonstrate that our method outperforms existing algorithms and is robust to noise heteroscedasticity.

In the second part of the talk, we address the challenge of weak continuous relaxations inherent in natural mixed-integer convex formulations for such structured learning problems, which hinder the performance of branch-and-bound-based solvers. We develop novel methods to strengthen these formulations by deriving a convex hull description of the associated mixed-integer set in an extended space. Notably, this approach reduces the convexification of these problems to the characterization of a polyhedral set in the extended formulation. Our new theoretical framework unifies several previously established results and provides a foundation for applying polyhedral methods to strengthen the formulations of such mixed-integer nonlinear sets.

Early Career Researcher Event: Life After a PhD

1*Early Career Mathematicians & 2 Early Career Researcher Network
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1 IMA
2 OR Society

There are lots of options for those completing a PhD in Applied Mathematics, Statistics or Operational Research, from data science roles in large companies, consultancies and government, to academic roles, either post-doctoral or lecturing. Picking which route is not always easy. So, what are the options? What are they like? And what do you need to get a foot in the door? This event, jointly run by the Early Career Mathematicians of the IMA and the Early Career Researcher Network of the OR Society, will try to explore these. We will have a panel that mixes academic and industry experience of post-PhD life. This is a great opportunity for PhD students to come and ask questions about what each of the routes are like and what skills are required in each case.

Multi-Objective Optimization for Better Decisions: Methods and Applications

Banu Lokman, University of Portsmouth, UK

In today's complex landscape, organisations have to deal with optimization problems which are not single-objective in nature. Decision-makers are required to address several objectives simultaneously,
such as minimizing cost, maximizing quality, enhancing sustainability, or managing risk. In many cases, there does exist a unique solution that is optimal across all objectives. Therefore, the goal is to identify Pareto-optimal or nondominated solutions where any improvement in one objective can only be achieved by sacrificing performance in another. However, as the problem size grows, the number of nondominated solutions can increase significantly, making the problem more challenging. This talk will address these challenges and explore multi-objective optimization techniques and methods which are proven to work well in producing a well-distributed set of the true nondominated points. The talk will focus on multi-objective integer and mixed-integer programs, which are widely used to model real world decision problems across various domains, including healthcare, energy, supply chain
management, and logistics. The talk will also highlight a real-world application involving the optimization of prostate biopsy sampling plans, demonstrating the practical impact of these methods.

Operational Decision Support in hospital care: Scheduling patients and predicting pathways with Patient Catalyst

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In the NHS, Hospital operational managers and administrative staff decide which patients get treated when - 100's of times a day. They need support. The impacts are significant for individuals waiting for care, and for staff and the hospitals ability to treat as many patients as possible. In comparison with the push for more evidence-based medicine and clinical decision support tools, often, data and modelling is only used in the planning for these services, but not to inform these decisions on a day to day basis. Working with a number of NHS Hospitals, PA Consulting have developed software implementing a number of methods for more efficient patient selection, scheduling and tracking patient through their pathways. This presentation will introduce the concept of Operational Decision Support and go through some of the methods used particularly in the scheduling of operations in theatres.

Wait Time Forecasts in NHS Mental Health Hospitals: A Success Story with Discrete Event Simulation

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In 2023 Sussex Partnership NHS Foundation Trust (SPFT) undertook a project to implement Discrete Event Simulation (DES) to forecast varying capacity in mental health hospitals to reduce wait times and alleviate acute hospital bed pressure. Since 2023 the forecasts have accurately followed experience, and DES has been adopted for modelling various interventions to improve patient flow and make more effective use of funding.

Discrete-time vs Flow-based: The Multi-Mode Resource Constrained Project Scheduling Problem in Telemedicine

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With telemedicine coming to the forefront during the COVID-19 pandemic, flexibility in terms of modes of care delivery has emerged. We are working in partnership with TEC Cymru, who worked to rapidly implement video consultations within NHS Wales during the pandemic and continue to promote the use of telemedicine in Wales. In this paper, we consider the scheduling of patients' appointments via three different modes of delivery: traditional face-to-face, video conferencing platforms, and telephone. The solution of the model not only has an impact on satisfying patient and clinician preferences,but also could potentially reduce travel for patients and staff. We model the problem as a multi-mode resource constrained project scheduling problem, with the aim of maximising patient and clinician preferences for delivery method.

Two model formulations are presented to solve this problem. The first, a discrete-time formulation, assigns appointments to timeslots while the second is a flow-based formulation which instead assigns an ordering of appointments. We compare these two formulations, evaluating which is more useful when tested on a variety of generated instances.

Geospatial Route-planning, an algorithmic approach

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This presentation outlines a geospatial route-planning project designed to help NHS staff, such as district nurses and health visitors, minimise travel time and environmental impact. By leveraging the Travelling Salesman Problem (TSP) and efficient algorithms, including greedy heuristics and systematic permutations, the solution can handle up to 12 patient addresses efficiently, accounting for millions of possible route permutations.

Initially developed in Python with the Streamlit framework, the software is open source and highly adaptable, allowing NHS trusts to configure it to their unique requirements without exposing sensitive patient data to external servers. The application can display optimised routes on an interactive map, incorporating peak and off-peak driving times, as well as walking and cycling options. This helps reduce fuel consumption, cut carbon emissions, and free staff to spend more time with patients.

Beyond route optimisation, additional modules suggest the shortest path to critical healthcare facilities and identify optimal locations for new services, such as vaccination centres, by analysing local population data and travel distances. As part of an ongoing effort to evolve and scale this tool, I've developed the platform with Node.js, ensuring broader compatibility and performance enhancements. The project highlights how data science and mathematical optimisation can drive impactful, real-world change in healthcare logistics.

Analytical Tools for Hostility Prediction: A Case Study for Fire and Rescue Services

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Firefighters frequently encounter hostility when they arrive at critical incidents. Such attacks have repercussions ranging from effects on physical and mental wellbeing of firefighters to preventing effective response to the critical situations firefighters are called to manage. This study focuses on supporting the readiness of front-line respondents by identifying key antecedents that may lead to these hostile attacks. We employ decision trees to model and predict factors contributing to hostility, thus enabling a data-driven approach to mitigating risks. The study aims to synthesize behavioural elements with predictive analytics work towards developing an analytical toolbox to enhance risk assessment, improve situational awareness, and ultimately boost operational safety for fire and rescue services.

Randomized Bundle Pricing with Patient Customers: Theory and Experiment

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We focus on the problem of a retailer who employs a randomized bundle pricing policy, where two products are offered together at a discounted price at intervals that are random from the customers' perspective alongside the individual purchase option, over an infinite selling horizon. The market is heterogeneous in customer valuations for the bundled products and their willingness to wait for the bundle offer. We investigate two key aspects: (1) conditions under which this intertemporal bundling policy enhances revenues, through an analytical model and numerical experiments, and (2) the effectiveness of human decision makers in implementing this policy, via behavioural experiments. Our results highlight the practical challenges of implementing randomized bundling in retail environments. Our numerical experiments emphasize the need for a thorough understanding of customer behaviour and market dynamics in selecting pricing strategies, while our behavioural analysis suggests that observed revenue improvements may fall short of projections due to the gap
between theoretical recommendations and actual managerial practices, and managers may encounter difficulties in leveraging randomized pricing in practice.

Harnessing Behavioural Nudges to Reduce Food Waste: An Experimental Approach

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Reducing food waste is a critical challenge for businesses and society, driven by its environmental, economic, and ethical implications. This research investigates the effectiveness of behavioral interventions in encouraging customers to purchase nearexpiration products, thereby mitigating food waste. Using experimental studies, we explore how traditional pricing strategies, such as discounts, interact with behavioral nudges to influence customer decisions. Our findings reveal that social norm message nudges outperform both quality and social image-related message nudges and are even more effective than offering higher discounts. These insights suggest that managers can complement traditional discount strategies with carefully crafted behavioral nudges, such as social norm messaging, to enhance their food waste reduction initiatives while maintaining profitability.

Mutual validation of discrete-event simulation and system dynamics models

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Operational validation of discrete-event (DES), agent-based (ABM) or system dynamics (SD) simulations is critical for certifying the usefulness of a model in decision support. For DES and AB models, the literature has emphasized qualitative assessment of dynamic behavior through plots and animations as well as validating the statistical distribution of static measures of the DES simulation output. For SD models, validation is typically based on trajectory matching: either of model output vs. expected dynamics or model output vs. Historical dynamic data. Here, we focus on validation of the dynamic behavior of companion models: either DES and SD or ABM and SD. The fitted coefficients permit conceptual model validation of the DES and SD models simultaneously. If the validation fails, then anomalies in the coefficients may suggest model modifications. Alternatively, DES and SD models could be developed independently and their dynamic trajectories compared (e.g., through Fourier analysis). This exercise can also provide mutual validation in the positive case and give insight on conceptual errors in the negative case. Similarly, studies with companion ABM and SD models provide new mutual validation strategies. We describe such approaches to such mutual validation and illustrate them through two examples.

Sequential optimisation of stochastic systems using streaming simulation

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When optimising complex stochastic systems, analytical intractability often necessitates the need to implement simulation models. In settings where observations of a physical system are obtained sequentially, we have the opportunity to re-tune simulation input parameters, allowing for a simulation model that improves over time. These improvements can also enable improved decision-making capabilities.

As a motivating example, we consider the problem of determining the optimal number of servers in a multi-server queueing system with an unknown arrival rate. The objective is to achieve the best possible balance between system running costs and user congestion levels.

We consider the data streaming setting, where observations of the target system arrive in sequential batches, allowing for the incremental improvement of arrival rate estimates. Decisions on the number of servers to employ are made after each successive observation period.

We focus on a greedy decision-making policy that always sets the number of servers in order to optimise the objective function, under the assumption that the latest arrival rate estimate (acquired using the streaming simulation output) is correct. In addition, we obtain necessary conditions regarding the simulation budget and the objective functional form for the greedy policy to converge asymptotically to the optimal solution.

Derivative-free and blackbox stochastic optimisation solvers for simulation optimisation under fixed oracle budgets

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In this talk, we provide extensions to derivative-free stochastic approximation methods for high-dimensional black-box simulation optimisation with an aim to reduce the number of evaluations of the simulation oracle. In practice, the efficiency of solvers is hindered by calls to the simulation oracle, which can be expensive to query. Stochastic approximation methods improve convergence by leveraging local curvature information of the function. In a trustregion setting, this curvature information is obtained through constructing a local model using interpolation. The number of interpolation points required to construct a local model scales with the problem dimension, making it expensive to construct in a high-dimensional setting. Solving this problem requires us to make the complexity of the model construction independent of the problem dimension. Recently developed methods such as ASTRO-DF and STORM combine stochastic approximation with derivative-free methods, such as direct search and trust-regions. These trust-region methods have helped to alleviate the issue of oracle complexity through local model construction using interpolation. We reduce the oracle complexity of trust-region algorithms by employing active subspace methods to map to a lower-dimensional vector space. We provide an adaptive method of constructing a transformation to the active subspace at each iteration, and a method of adaptively selecting the reduced dimension number. We demonstrate the computational superiority of including these alterations when dealing with high-dimensional simulation problems. The talk will include a discussion of recent work in the area as well as a description of the methods that we employ. We will highlight numerical results demonstrating the benefits of applying these methods to simulation-optimisation problems in practical applications.

Digital twin validation with multi-epoch, multi-variate output data

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This talkconsiders the validation of a simulation-based process digital twin (DT). We assume that at any point the DT is queried, the system state is recorded. Then, the DT simulator is initialized to match the system state and the simulations are run to predict the key performance indicators (KPIs) at the end of each time epoch of interest. Our validation question is if the distribution of the simulated KPIs matches that of the system KPIs at every epoch. Typically, these KPIs are multi-variate random vectors and non-identically distributed across epochs making it difficult to apply the existing validation methods. We devise a hypothesis test that compares the marginal and joint distributions of the KPI vectors, separately, by transforming the multi-epoch data to identically distributed observations. We empirically demonstrate that the test has good power when the system and the simulator sufficiently differ in distribution.

Simulation and Optimization of an Emergency Medical Service System Under Heavy Rainfall Conditions

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Climate change has increased the frequency of natural disasters and poses major challenges to Emergency Medical Services (EMS). This study presents an AnyLogic simulation model that uses Agent-Based Modeling (ABM) to represent the dynamic and stochastic nature of a local EMS system in Brandenburg, Germany. The model integrates patient demand and interaction, ambulance deployments, travel conditions and facility locations to provide a realistic platform for decision making. Focusing on heavy rainfall scenarios, the model simulates events where roads become impassable and the frequency of emergency calls increases enormously. It assesses the quality of care achievable with current resources and identifies the additional resources required to maintain the desired level of care. Innovative strategies, such as the use of Unmanned Aerial Vehicles (UAVs), can also be tested for their effectiveness. In addition, the model supports the analysis of solutions derived from other Operations Research (OR) methods such as Mixed-Integer Programming (MIP) for solving facility location-allocation problems. It serves as a testbed for Artificial Intelligence (AI) techniques and enables experimentation with algorithms to solve complex EMS challenges. By simulating different scenarios and evaluating AI-driven strategies, this work promotes the development of more efficient and adaptable EMS systems and illustrates the potential of simulation-based approaches for disaster response and emergency planning.

Sports League Scheduling with Minitournaments

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In sport scheduling for leagues with professional teams, game days with single matches are necessary to achieve fairness, which is a fundamental criterion. Thereby, the resulting high number of required game days is accepted and the length of a season not important. In amateur or youth sports leagues, these priorities change since the teams play all matches during their leisure time. A schedule with a smaller number of game days is preferred and the teams are willing to partly renounce on the fairness for this. Thus, the idea of minitournaments arised. In this format, multiple teams meet at one home team, which is one of them, and play against each other. The travel times of all teams now depend on their assignment to the respective minitourmanets and the choice of the home team. We consider in this talk a league with minitournaments of three teams at each game day and two legs, requiring each team to play against each other team exactly twice. These legs have not to be separated, i.e., the second match against any team can take place before all first encounters are complete. Furthermore, the home field advantages should be divided as evenly as possible during the season to minimize the fairness loss. We present a combinatorial optimization model to compute a feasible league schedule with minimal total traveling distances for all teams, discuss its computational efficiency, and evaluate existing schedules for amateur basketball leagues in the State of Brandenburg.

Supply Chain Stackelberg Differential Game for a Manufacturer with Cheap Innovation

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A single manufacturer-single retailer competition is studied. It is assumed that (i) both competitors maximize their profit; (ii) the manufacturer tries to increase the customers' loyalty by the innovation investments; (iii) the retailer sells the manufacturer's product and in parallel invests in promoting a competing substitute; (iv) the manufacturer's innovation is "cheap" yielding a high investment potential. The competition is modeled by a two-player finite horizon linear-quadratic Stackelberg differential game (with the manufacturer as a leader) with the players' scalar controls. A cheap manufacturer's innovation implies that the leader's control cost in the cost functionals of both players is much smaller than the state cost and the cost of the follower's control. This feature constitutes a novel contribution to manufacture-retail competition problems. For this cheap control game, an open-loop solution is sought. By a proper change of the state variable, the initially formulated game is transformed equivalently to a simpler cheap control Stackelberg game. Dynamics equation of the latter consists of two modes. The first mode is controlled directly only by the follower, while the second mode is controlled directly by both players.

The solution of the transformed game reduces to the solution of the linear singularly perturbed boundary-value problem which dimension is four times larger than the dimension of the game dynamics. This boundary-value problem is of the conditionally stable type. Based on the Boundary Functions Method, the first-order asymptotic solution is derived, yielding asymptotic expansions of the optimal open-loop controls of the players, as well as asymptotic expansions of the optimal values of their cost functionals. Based on these results, asymptotically suboptimal open-loop controls of the players are designed.

Can machine learning models better volatility forecasting? A combined method

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Volatility forecasting for Bitcoin constantly gains attention due to the increased investment interest and the high riskiness of cryptocurrencies. The traditional forecasting models, such as the GARCH family models, are widely adopted. However, there should be careful consideration whether they can capture extreme shocks and the long-term volatile feature. Hence, we fit several GARCH models and the EGARCH shows the best goodness of fit. We further take its historical volatility observations for an automated forecasting solution, using the Long short-term memory (LSTM) neural network to take predictions. Our results show clear improvement in volatility forecasting regarding both the model's in-sample and out-of-sample accuracy. More importantly, the LSTM can optimize information intake through the short- and long-memory states. Overall, our new LSTM neural network model is more robust in reflecting to market shocks and regime changes.

KEYWORDS
Bitcoin, Volatility, Forecasting, LSTM, GARCH

Decomposable Impulsive Markov Decision Processes with application to series-parallel systems in logistics

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Markov Decision Processes (MDPs) and continuous-time MDPs (CTMDPs) together provide a flexible framework for modelling sequential decision-making problems under uncertainty. Three variations of the MDP are considered. CTMDPs with impulsive control are an extension of the CTMDP which allow for actions that result in an instantaneous change in the state, foregoing the typical non-zero sojourn times. Decomposable MDPs are those which can be thought of as being somehow separable, i.e. made up of compartments which are stochastically independent, where it can help to imagine controlling the compartments separately. Such a method of control may not have guarantees for optimality, but instead evades the curse of dimensionality. Multi-objective MDPs are those with vector costs instead of scalar costs. As such, the notion of optimising such processes changes from the minimisation of one objective to the striking of balances between multiple objectives. In this talk, the Decomposable Impulsive CTMDP with multiple objectives is introduced, and an approximate solution methodology is presented. The dynamic maintenance of a series-parallel system is modelled and approximately optimised under this framework. Such systems are often used to model unreliable supply chains, manufacturing systems, or other systems with redundant components for reliability.

Semi-Lagrangian relaxation for the simple plant location problem

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The Simple Plant Location Problem (SPLP) is a much-studied combinatorial optimisation problem with many applications. Beltran-Royo et al. (2012) devised an intriguing exact algorithm for the SPLP, based on semi-Lagrangian relaxation. We show that one can speed upthat algorithm considerably by eliminating certain variables based on the problem structure as the algorithm proceeds. The enhanced algorithm performs well on several hard benchmark instances.

References:
Beltran-Royo, C., Vial, JP. & Alonso-Ayuso, A. Semi-Lagrangian relaxation applied to the uncapacitated facility location problem. Comput Optim Appl 51, 387–409 (2012).

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Inventory Management for Preventive and Corrective Maintenance under Supply Chain Risks

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We consider an example of a production plant with many machines, each of which consists of multiple parts that may break at any point in time. If a part breaks, the company has to decide whether to conduct maintenance immediately or whether to keep the part in reserve in case a more critical machine also fails. Inventory management helps to ensure that there are sufficient spare parts available for maintenance to be performed. It can be costly to order and hold spare stock, and it is also expensive to shut down a piece of machinery due to not having enough spare parts for it to be fixed; therefore, it is ideal to have a balance between ordering more units than necessary and not ordering enough units to meet the stochastic demand. By modelling this problem as a Markov Decision Process (MDP), we are able to find optimal ordering and maintenance policies which minimise expected future costs while accounting for the criticality of different machines.

Periodic review inventory control for an omnichannel retailer under partial lost-sales

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Motivated by collaboration with a large retail company, Tesco Mobile, we investigate the management of stock for a business with integrated online and offline storefronts selling products facing uncertainty in demand. The integration of channels includes an opportunity for customers to have items sent directly to their home in case of a store stockout. We model a two-echelon divergent, periodic-review inventory model, with partial lost-sales at the store level and an online demand channel. The problem is developed as a Stochastic Dynamic Program minimising inventory costs. We highlight the effectiveness of adding order caps to reduce system costs.

In an extensive numerical study, we reduce costs by up to 19% compared to standard heuristic methods from the literature. Further, we apply methods to real life data with our method outperforming the internal benchmark method. We show that the proposed method results in 75% to 99% less inventory at the store level than the company's current approach while achieving the target service level.

By focusing on effective yet interpretable policies, we suggest methods that can be used to aid a decision maker in a practical context.

Queue & A & E: what mathematical modelling can tell you about your waiting times

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It is well known by now that A&E departments in NHS hospitals across the country are under intense pressure and are struggling to handle heavy usage and the heavy burden of the winter months. On the face of it, it seems to be a usage problem, but could there be more to it? In this talk, we will demonstrate how we have been collaborating with NHS Sussex to produce and calibrate a digital twin of an A&E ward in one of the hospitals within Sussex. In order to do this, we have used queueing theory, the mathematical modelling and analysis of queues. A queue requires three main components: understanding the arrival rate of patients, understanding the departure rate of patients, and understanding the queueing framework. Whilst patient level data can easily help calibrate the arrival and departure process, it is not so easy to use it to fully understand the queueing framework. This challenge is the main result of this work and what will be presented.

Mathematical Modelling for Decision-Making in Healthcare: A Case Study on Hospital Mergers

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The integration of healthcare systems presents significant challenges in data management, operational efficiency, and decision-making. This study explores the application of mathematical modelling and analytics during the merger of a local General Hospital into Manchester University Hospitals Trust. Using predictive analytics, optimisation techniques, and data integration frameworks, we facilitated seamless consolidation of patient records, operational metrics, and financial data, ensuring compliance with GDPR regulations. Post-merger, performance tracking dashboards were developed to provide real-time insights into patient care, resource allocation, and staffing needs. Additionally, legacy hospital systems were modernised with forecasting models and decision-support tools, enabling data-driven hospital management. This case study demonstrates how mathematical modelling can enhance operational decision-making in complex healthcare environments, improving efficiency and patient outcomes.

A Behavioral Study on Telemedicine Acceptance

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Despite the growing prevalence of telemedicine applications, research on telemedicine adoption remains limited. The influence of context-specific factors such as cultural differences, healthcare infrastructure, and socio-economic status on patients' acceptance of telemedicine services has not been thoroughly explored either globally or within the UK. Additionally, the impact of specific healthcare situations (e.g., the type and severity of the problem, the physical distance to nearest facility and the waiting times on this facility, etc.) on patient trust and intention to use these services is often overlooked. Our study aims to address these gaps by designing a behavioural experiment to systematically examine patient preferences, trust, and intention to use telemedicine across various scenarios. The presented scenarios will vary based on situational factors such as the experience and
perceived expertise of the medical professional, distance to the nearest face-to-face facility, perceived severity of the medical issue, and the nature of medical problem. In using the scenarios, we will conduct a Best-Worst Method (BWM) analysis and determine a significance ranking among the factors influencing trust and intention to use these services. The proposed approach is expected to enhance our understanding of patients' adoption and trust in telemedicine services, ultimately supporting professionals in designing and delivering effective telemedicine solutions.

Balancing Advice: Decision-Making with Multiple Forecasting Inputs under Asymmetric Loss

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We investigate the accuracy and performance of human decision-makers under asymmetric loss when provided with varying amounts of algorithmic advice. To explore this, we conduct a between-subject newsvendor experiment where participants forecast demand ranges for upcoming periods while determining order quantities that satisfy the constraints. Our findings show that receiving advice reduces the "too-high" ordering bias commonly observed in low profit-margin newsvendor settings, though it does not fully eliminate it. Accuracy improves when decision-makers receive one piece of advice but diminishes slightly, albeit insignificantly, when a second piece of advice is introduced. Additionally, decision-making behavior varies at different ends of the confidence interval, though these differences remain statistically insignificant compared to conditions with less advice. Notably, decision-makers prioritize their own intuition over any single piece of advice. From a managerial perspective, our findings suggest that selectively offering well-calibrated advice may improve decision accuracy, but overloading decision-makers with excessive input may dilute its effectiveness.

Bridging the Gap: Behavioral Insights into Human-Machine Collaborative Decision-Making

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Businesses increasingly implement analytics-driven tools and advanced technologies, such as algorithms and artificial intelligence, to address complex operational challenges. Human supervision remains a critical component for effectively integrating these technologies into decision-making processes, highlighting the importance of understanding human behavior in human-machine collaboration. This study investigates the dynamics of human-machine interaction using an experimental methodology, focusing on how humans respond to, interpret, and utilize machine-generated predictions. The study examines the conditions under which collaboration improves decision-making performance, and the role of human judgment in refining machine outputs. Our findings provide actionable insights for managers, emphasizing the importance of designing systems that balance machine efficiency with human intuition to maximize decision-making effectiveness.

Triple-loop learning in retail demand forecasting: a systematic evaluation of benchmarking and reproducibility of Machine Learning models and roadmap for research

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In recent years, Machine Learning methods have gained more popularity in retail demand forecasting, aided by the availability of Big Data. Many algorithms have been proposed and applied, but there is no systematic understanding of how effective they are, and under what conditions. In this paper we incorporate the single-, double- and triple-loop learning theory as a theoretical lens in order to systematically categorise the retail demand forecasting literature from 2014 to 2024, especially on the goal of achieving triple-loop learning with three variant conceptualisations.

Two main issues identified from the literature are the lack of robust benchmarking and reproducibility. We apply analytical hierarchy process (AHP) to further analyse the literature on the two issues and provide insight and guidance for future research.

Why do zeroes happen? A model-based view on demand classification

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Intermittent demand forecasting has been considered a challenging task for many years. The conventional models typically do not work as intended in such situations, and special ones need to be used to capture the tendencies in such data. Yet, the problem of classifying demand into intermittent or not has not been fully resolved. Practitioners tend to use simple heuristic rules, usually deciding that demand is intermittent if the number of zeroes in the data exceeds some threshold. Academic literature has not thoroughly studied the problem, assuming that any number of zeroes in the data already implies intermittence. However, reality is typically not as straightforward, and zeroes can appear in demand for a variety of reasons, including stockouts and recording errors. In this presentation, we propose a new model-based classification scheme that separates demand into finer groups, acknowledging different possible structures in the data. We demonstrate how the proposed scheme can be efficiently used in a controlled environment and how it can be applied to a real dataset.

Alternative Approaches to Bootstrapping for Intermittent Demand Forecasting

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Bootstrapping previous observations in individual time series is a well-established approach for intermittent demand forecasting. It can be advantageous, especially when the series does not conform to any standard probability distribution. However, bootstrapping approaches are known to suffer from some biases because of resampling with replacement and from the treatment of disturbances from resampled values (known as 'jittering' in the literature). Moreover, jittering procedures are often somewhat ad hoc in functional and distributional form.

Some improvements to 'jittering' have been proposed in the literature and other modifications are suggested in this paper. These are evaluated in terms of the accuracy of predictive distributions and implications for inventory performance.

An alternative approach entails resampling observations from multiple series, which have been identified as having similar demand probability distributions. Such series are grouped using some clustering methods. An empirical comparison of single-series and multiple-series approaches is conducted, based on accuracy and inventory performance. The empirical investigation uses spare parts demand data from the aeronautic and automotive sectors. The empirical results show a higher inventory efficiency of the alternative bootstrapping approaches as compared to a benchmark bootstrapping approach commonly used in the forecasting literature.

Keywords: intermittent demand, forecasting, bootstrapping, clustering, inventory performance

Industry 5.0: Technology adoption to support data-driven decision-making in a hybridised working environment

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ABSTRACT
Despite growing interest in Industry 5.0 and challenges of Human-Centric adoption for businesses who have previously embraced Industry 4.0, extant literature lacks examples of nuances in human-technology interactions. While prior research exists in certain areas, for example COBOT's and social well-being, gaps remain for emerging technologies and the ability to embrace the recent exponential growth of AI technologies within production environments. Moreso, the growth in data analytics and data science methods to inform data driven decision making. This often attributed to over-automation, knowledge retention challenges and confusion over the skills required to implement and adopt AI, Machine Learning and Generative AI opportunities.

Prior focus on Industry 4.0 and automation has diluted the appetite for skills and knowledge retention in the quest for full automation and efficiency gains. This research identifies these challenges and adopts a multi-case approach investigating a UK based international business. conducting interviews with key stakeholders. Then using a semi-structured survey questionnaire across the sector to validate findings. Highlighting issues such as full automation, low volume/high complexity manufacturing challenges and dark factory enablement.

Enablers and Inhibitors to human-centric adoption are established alongside risks associated with over-reliance on fully automated technologies before identifying opportunities to enable human-centricity. Expanding on extant literature, we argue that a strategic approach is required to ensure human skills and knowledge retention are key components for Industry 5.0 and human-centric adoption. Culminating in the introduction of a theoretical framework to enable the adoption of hybridized strategies.

Challenges and expectations of utilising a Digital Testbed for Supply Chain Optimisation

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Keywords:
Digital Twin, digital supply chain, soft systems, supply chain optimisation

Abstract:
Despite recent stimulus in AI-based digitalisation, there is a novelty in broader implications of utilising AI-based comprehensive collaborative digital platforms such as digital Testbed. The Testbed facilitates collaborative real time data sharing and analytics for predictive and prescriptive innovative solutions for better planning, resilience and efficiency in the end-toend manufacturing supply chain (SC). The novelty and fuzziness of the idea leads to some challenges for stakeholders wanting to adopt digital Testbeds. Therefore, we aim to address some of these challenges and expectations for stakeholders utilising the Testbed.

Having designed the digital Testbed for SC optimisation and informed by the findings from interviews, we captured diverse views of using this AI-based digital twin in relation to challenges posing a complex and messy problem in identifying challenges. Therefore, we decided to form a structured rich picture of these challenges using tacit issues. We invited the business leaders in the manufacturing SC to our two workshops to open visual and audio communication and build a rich picture of the challenges and capture emerged expectations through “Appreciative Enquiry Method” as part of soft systems.

Having analysed the visual and audio views, we found three major clusters of the challenges. These include cost-orientation, data communication and training. Strategic planning with upskilling efforts to handle varied data and technology infrastructure in the current highly dynamic and uncertain SC ecosystem alongside clear evidence of Return on Investment were found as key expectations to foster feasibility of utilizing Testbeds. This study has strong contribution in research and practice bridging the digitalisation gaps across manufacturing SC.

Algorithmic Foundations and Applications of a Digital Testbed for Supply Chain Optimization

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Keywords: Digital Twin, Supply Chain Resilience, Predictive Analytics, Multi-objective Optimisation

Abstract:
Developing a scalable and robust digital testbed for supply chain optimisation demands advanced algorithms to model and respond to dynamic operational scenarios. This study focuses on algorithmic development to enable the functionality of such a testbed, designed to simulate, analyze, and optimize supply chain operations in real time, addressing challenges in decision-making, resilience, and efficiency within complex systems.

Central to the testbed is a digital twin (DT)—a dynamic virtual representation of supply chain processes—that synchronizes real-time data with computational models to optimize operations. To address the inherent complexities of supply chains, the testbed employs multiobjective optimization algorithms that dynamically balance cost, service level, and sustainability. Unlike static methods, these algorithms adapt to real-time data, enabling context-aware optimization aligned with evolving conditions. Machine learning modules enhance the system's adaptability, including sentiment analysis to predict supply-demand shifts and non-linear demand drivers. Real-time data pipelines continuously refine forecasts, maintaining responsiveness to stochastic patterns and disruptions. Scenario analysis tools further support the evaluation of disruption impacts, simulation of response strategies, and assessment of performance trade-offs.

Iterative validation with real-world datasets demonstrates the system's ability to improve forecasting accuracy, reduce costs, and enhance resilience, offering actionable insights for both theoretical advancements and practical decision-making across diverse industrial contexts. This research contributes to operational research by integrating advanced predictive analytics, optimisation techniques, and DT technology into a cohesive platform. The testbed provides a robust foundation for studying and improving supply chain systems, emphasising adaptability, scalability, and sustainability as key drivers of operational efficiency in dynamic environments.

Systems of rating players

James Reade, University of Reading.

No abstract available

EDI in Maths Sciences

Chair: Howard Haughton

Panel: Martine Barons, Aniko Ekart, Nicholas Beale

This session explores the role of the mathematical sciences in developing AI and machine learning systems that are fair, accountable, and transparent. It will examine how mathematical insights can contribute to reducing bias and building technological solutions that better serve society, while also addressing the inherent limitations and challenges in achieving truly equitable outcomes.

WORAN Event - Disrupting Gender Bias: Taking up Space in OR and Maths Professions

Antuela Takou and Corina Constantinescu

This panel explores the persistent gender imbalances in the operational research and mathematical professions —and what it truly means to challenge them. This panel brings together bold voices pushing beyond representation toward structural change. We'll unpack the barriers women and marginalised genders face, highlight strategies for claiming space in male-dominated disciplines, and ask: what does real disruption look like, and how do we make it happen?

Bias in AI

Chair: Howard Haughton.

Panel: Martine Barons, Aniko Ekart, Nicholas Beale

No abstract available

On insurance mechanisms in low-income communities

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This study addresses the group-based nature of financial vulnerability in the low-income environment. Adopting a highly flexible stochastic dissemination model, we assess the impact of insurance on the resilience of a low-income group to wealth shocks. Moreover, the probability of falling below the poverty line is determined and the impact of insurance in reducing this probability considered under varying levels of subsidisation.

Alternative Payment Strategies: Adapting to Change in the Mobile App Industry

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In recent years, prominent app distribution platforms such as Apple App Store and Google Play have been attacked on many fronts and are presently fighting off antitrust lawsuits throughout the world. One of the key issues that prompts app developers to protest and take legal action against platforms is the monopoly of the latter over the user payment process. Consequently, platforms are under increasing pressure to allow app developers to offer alternative billing options to users, and indeed, steps have already been taken in this direction. Recently, Apple and Google updated their developer guidelines so as to allow US- and EU-based developers to offer users alternative payment methods outside of the platform's app store. In this paper we study a new business model designed by prominent distribution platforms in the mobile-app industry, following the court rulings against the platforms' monopoly provision of the payment process. The model is based on new guidelines in which platforms allow app developers to offer additional payment options for users of apps distributed via the platform's store. Using a game-theoretical approach, we investigate the decisions made by the developer, platform and app users. Two counterintuitive results are analytically obtained: (i) The developer's profit increases in the user's inconvenience cost—the cost associated with choosing the developer's billing system; and (ii) Both parties may share a common interest in reducing the level of differentiation between the payment options and in increasing the user's inconvenience cost.

ESG news-enhanced volatility prediction

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We study the predictive ability of news for stock price crashes for a set of governance failure events across world markets, over the past 15 years. Our industry partner Mettle Capital has a database of open-source daily news items for 5000 European and American companies tagged as positive, negative or neutral, from a variety of online sources. From this data, we construct a simple and easily explainable extension of GARCH model which uses positive and negative news sentiment as exogenous inputs. We demonstrate that this significantly enhances ability to predict an increase in volatility due to governance failure at a company. Broad objectives of the work, which is still ongoing, are (i) to provide hard quantitative evidence for good corporate behaviour (as evidenced in a larger or increasing number of positive news items as compared to negative news items) generally leading to good stock price performance (as evidenced by 'buy' or related investment signal); (ii) to combine E, S and G sentiment scores for standardised ESG reporting, with a peer-reviewed and open source methodology.

Sustainable future communication networks - Introduction and Background

Session organized by Carla di Cairano-Gilfedder and Keith Briggs, BT Research and Networks Strategy.

In the evolution of communication networks through 2G to 5G, we have seen an enormous improvement in performance, as well as a vast increase in the number of services provided over these networks. However, these developments have required the networks to use very much more energy to deliver their services. There is a general view that 6G, now in the planning stages, will need to avoid any energy consumption increases, and indeed a reduction is envisaged. This will be achieved by a combination of improved technologies, smarter overall network management, and above all, better algorithms for the low-level control of the network.

There is thus a potentially large role for mathematics here, for example in algorithm design and optimization of the management processes. This session would invite talks in these areas, and would aim to create an interaction between mathematicians, OR specialists, and radio engineers in order to improve the performance of the new sustainability features being proposed for 6G.

This presentation will give the necessary engineering background and mathematical models for the task of managing networks to maintain a desired quality of service, while using minimal energy. We will also introduce the topic of energy modelling in the radio access network (RAN).

Energy management via time series modelling of traffic patterns

Richard Mackenzie, BT

A key part of energy saving in mobile networks depends on accurate load forecasting. Here we will compare a range of load forecasting tools, using real network data, and evaluate their performance in terms of accuracy, practicality, and computational efficiency. This presentation will also show how these forecasting tools are implemented in energy saving algorithms, and the resulting energy saving behaviours.

Network energy management – is ML useful?

Ahmed Rashwan, University of Bath

Compared to 4G long-term evolution (LTE), 5G networks are designed to deliver 100 times more data per unit area and despite an overall increase in energy efficiency, 5G base stations still consume more than twice as much energy as their 4G counterparts. Consequently, network energy efficiency is becoming a key figure of merit in communication networks. We focus on radio resource allocation problems, which attempt to distribute limited network resources, such as time slots, frequency bands, or transmit power -- to optimize overall network performance. We explore the application of machine learning (ML) techniques, including graph neural networks and reinforcement learning, to solve these allocation tasks. We argue that generic ML models are often ineffective in this context. Instead, we illustrate, through examples, how integrating traditional optimization methods into ML models can introduce inductive biases that are better suited to specific problems.

Energy management in the network core

Adam Morsman, BT

The use of virtualised network functions for components such as the 5G mobile core means that these crucial network functions can now be run in cloud environments. BT have their own private cloud infrastructure which is used to run these mobile core functions amongst various others. This talk will introduce work being conducted by the BT Cloud Infrastructure research team into how the server hardware that makes up this private cloud platform can be optimised to reduce energy consumption whilst maintaining performance of the networking functions that are hosted on it.

Optimizing Primary Care Panel Sizes: A Simulation Approach

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Determining panel size—the number of patients assigned to a healthcare provider—is an important consideration in primary care capacity management. Panel size influences both the workload and wellbeing of providers, and quality and accessibility of care for clients. In Canada, panel size recommendations are often rooted in average population demand: this is challenging for Community Health Centers (CHCs) that cater for high complexity clients with high rates of homelessness, substance use and mental health issues. In CHCs, evidence-based approaches to determining appropriate panel sizes that consider the specific setting and complexity of the client population are needed.

I will present a data-driven modelling approach for determining panel size, customized to the models of care of CHCs in British Columbia, Canada. Our approach uses Discrete Event Simulation to model clinic bookings and appointments, informed by historical appointment data. This model captures stochasticity in client booking and behaviour and can thereby inform panel size management via exploring how choice of panel size impacts performance indicators reflecting care quality and access. As well as providing specific panel size recommendations for our health partners, this research highlights the value and adaptability of simulation modelling to inform frontline primary care capacity management.

An Analytical Framework for the Linear Best-Worst Method: Derivation, Optimization, and Sensitivity Analysis

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Abstract
The Best-Worst Method (BWM) is a prominent Multi-Criteria Decision-Making (MCDM) technique used to determine criteria weights through pairwise comparisons. This research focuses on the linear formulation of the BWM, which involves deriving optimal weights by solving an optimization problem. The accuracy of the obtained weights is measured using the optimal objective value, termed as optimal accuracy. This study introduces an analytical framework to solve the optimization problem associated with the linear BWM. The proposed framework enables the direct derivation of both optimal weights and optimal accuracy in terms of the comparison values, eliminating reliance on software tools and significantly enhancing computational efficiency. By doing so, it offers a more robust theoretical understanding of the linear BWM, while also improving practical usability.

Additionally, the framework facilitates sensitivity analysis, allowing a deeper exploration of how variations in comparison values influence the results. This capability provides valuable insights into the behavior and reliability of the model under different scenarios. To validate the efficacy of the proposed approach, numerical examples are presented. These examples demonstrate the framework's practical application and confirm its potential to advance the use of the linear BWM in MCDM problems.

Maintenance schedules by tree-structure rules: An empirical analysis in BT Fleet Solutions

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Abstract
Maintenance represents a large part of the total operational costs of vehicle fleets. We perform reliability analysis based on a unique dataset of maintenance records from the fleet of light commercial vehicles used by BT Fleet Solutions and their customers (Post Office, National Grid, etc.). We firstly verify that reliability deteriorates with age, mileage, and the number of historical maintenance activities, as we also find heterogeneous behavior associated with different geographic locations and vehicle makes. Drawing on this background, we propose a flexible maintenance policy at the garage level. We build it on a data-driven method, Conditional Inference Trees (CIT), which provides a good balance between applicability (with loose assumptions) and interpretability (being a "white-box" solution). Since there is no closed form for maintenance cost based on tree-structured reliability, we develop a simulation-based method to estimate the maintenance cost for the CIT-based maintenance policy, along with a newly proposed backward optimization on operational parameters. Based on cost analysis, we show the efficacy of the CIT-based maintenance policy in comparison to two prevalent maintenance policies. Finally, we identify opportunities for further improvements in the operations of the company, and for maintenance operations in general.

Keywords: Maintenance; Conditional Inference Trees; Empirical Data; Automotive Engines.

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Declarations of interest: none.

Student Centric University Timetabling: New Perspectives and a Case Study

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Timetabling problems are a subset of scheduling problems that focus on assigning specific events to available time slots to optimize a certain objective, while handling both hard and soft constraints. University course timetabling and exam timetabling are some of the most complex instances of these problems, not only because of its NP-hard nature, but also due to the number of stakeholders and their conflicting interests. Emerging needs due to sharing educational resources, online education, incorporating sustainability and inclusiveness factors make university timetabling an attractive and dynamic problem for researchers.

In this talk, we will discuss our implementation in Munster Technological University (MTU). We will first summarize results of our stakeholder engagement that helped us to formulate the problem: (1) nearly 800 student responses through a survey, with follow-up focus groups to understand the students' perspective and factors that influence lack of engagement/attendance, (2) discussions with different stakeholders and policy makers including the VP for research and operations that extend timetabling context to other dimensions such as transport, parking, accommodation and energy use in classrooms for heating and cooling. Then we will share our data analysis to identify bottlenecks in current timetables and timetabling procedure. Finally, we will present a novel integer programming model that formulate the problem by incorporating the soft constraints stated by students in the survey and focus groups as a prototype for a single department.

Setting attainable targets through Data Envelopment Analysis: a way to direct improvements towards the European Education Area objectives

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European education governance, by benchmarking, relies on defining indicators and goals as well as monitoring and evaluating progress with the European Education Area (EEA) strategic framework. The mechanism of governance refers to the non-binding agreement, which means that success in achieving common objectives depends on each country's efforts. Setting attainable targets for each
country (and region) that guide toward desired goals is essential in driving performance improvement towards the European Education Area objectives. This paper aims to propose a benchmarking approach to set attainable targets through Data Envelopment Analysis (DEA) that direct improvements towards the EEA objectives. As the selection of appropriate peers is a crucial step in setting attainable targets, the idea of integrating peer selection preferences is used. However, the EEA strategic framework aims to improve education performance and, at the same time, achieve strategic goals; this requires more than one objective under analysis to be optimized simultaneously. Our proposed DEA approach solves a bi-objective problem that imposes two objectives of closeness,
namely that between actual performances and targets and between targets and defined goals. The proposed approach, which incorporates information on strategic goals and is based on peer selection preferences, was employed with the most recent data at the regional level for 29 European countries. The practice of measuring performance at the regional level is beneficial for policy interventions
as it allows the reduction of structural disparities within a country.

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Evaluation of Indian Banks' Efficiency: Intuitionistic Fuzzy Dynamic Two-Stage Data Envelopment Analysis

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Abstract
The conventional dynamic two-stage data envelopment analysis (DEA) is not a strong tool for assessing decision-making units' (DMUs) efficiency when the data is uncertain/ambiguous. This study presents an intuitionistic fuzzy two-stage DEA model for situations involving negative, undesired, and uncertain/ambiguous data. Using an intuitionistic fuzzy two-stage DEA approach, the efficiency of the Indian banking industry is measured in this research. In order to solve issues such as ambiguous/uncertain data, negative data, and undesired data, the study intends to examine the internal operations of Indian banks. Premium acquisition and profit are the two successive stages of the bank's activities that account for the existence of ambiguous/uncertain, negative, and undesired data. To the best of our knowledge, no analogous study has been carried out in India.

Keywords: Data envelopment analysis; Intuitionistic fuzzy; Negative data; Undesirable data; Indian banks.
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Climate Change, Revenue Efficiency and Green Revenue Sources: A study of Indian cities using Bootstrap Data Envelopment Analysis, Slack Based Model and Meta Frontier Analysis

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A popular solution to climate change is providing additional earmarked grants to the cities. However, cities can mitigate climate change by reforming their existing finances and thus the behavior of population consuming local services. The paper, for the first time, explores how the existing revenue handles of the Urban Local Governments (ULGs) can be utilised to green the cities, using a case study of 20 big and mid-sized rapidly growing cities in India. The paper answers the following research questions: a) Are ULGs efficiently utilizing the potential green revenue sources to green the cities? b) Which green revenue sources can be leveraged further? c) How do big and mid-sized cities compare? We use a combination of Bootstrap Data Envelopment Analysis (DEA), Slack Based Analysis (SBA) and Meta- frontier Analysis.

Results indicate that with existing levels of expenditures, on an average, Indian cities can expand green revenue sources by as high as 52 percent. Furthermore, an overlap in 5% confidence intervals of bigger and mid-sized indicates no difference in their revenue efficiency. This is expected given a huge outflow of population to mid-sized cities in the wake of their rampant urbanisation. Using SBA, we find as high as 70 per cent of the ULGs can still expand their development charges, which can help curb urban sprawl and pressure on resources. Similarly, 60 per cent of the ULGs can still raise higher fees from solid waste management. The Meta Frontier Analysis suggests that the best practices in operations of ULGs are dominated by bigger cities, which is also concerning, given only a 50 percent revenue efficiency of big cities. Policy recommendations suggest for ULGs to revise upwards development charges, solid waste management fees, property taxes, water supply and sewerage charges and vehicle tax to mitigate climate change risks in Indian cities.

Noise-pollution analysis of European railways using A network DEA model

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Railway transportation is a crucial component of sustainable mobility, yet it poses significant environmental challenges, with noise pollution being one of the most pressing issues, particularly in Europe. This study assesses the environmental efficiency of railways across 22 European countries, focusing on two key factors: the extent to which countries have retrofitted their wagon fleets with quieter braking technologies and the number of people affected by railway noise pollution. To achieve this, we adopt a network Data Envelopment Analysis (NDEA) approach, specifically customizing an additive decomposition model to capture both intermediate and undesirable outputs. The railway transport process is analyzed through two dimensions—asset efficiency and service efficiency—allowing for a detailed examination of how effectively railway systems manage their infrastructure while minimizing negative environmental impacts.

Our findings indicate that Estonia, Germany, and Poland are the most environmentally efficient railway systems overall. Additionally, the results suggest that, apart from Finland, countries that perform well in asset efficiency also demonstrate strong service efficiency, but the reverse does not necessarily hold. This highlights the importance of comprehensive efficiency strategies that integrate both infrastructure management and service provision. A sensitivity analysis was conducted to test the robustness of efficiency rankings, revealing that the results remain stable under variations in decomposition weight restrictions. This underscores the reliability of our approach in evaluating railway environmental efficiency. Notably, this is the first study to apply DEA in incorporating noise pollution as a factor in railway efficiency assessment. By introducing this novel framework, our research provides valuable insights for policymakers and railway operators seeking to enhance the environmental sustainability of railway networks while mitigating noise-related externalities.

Conic Robust Multiobjective Optimization with Applications to Virtual Power Planning

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In this talk, we consider a conic multiobjective linear optimization problem, where the objective and constraint functions are involving affinely parameterized data uncertainties. We examine necessary and sufficient optimality criteria for robust weak/efficient solutions of the conic robust multiobjective problem. It is shown that the obtained optimality conditions can be expressed in terms of linear matrix inequalities or second-order cone conditions for the corresponding subclasses of conic robust multiobjective programs. We also show how efficient solutions of conic robust multiobjective problems can be found by way of conic programming reformulation problems including semidefinite programming or second-order cone programming problems. In addition, an application to modeling a virtual power plant problem in electricity markets is given.

A Multi-objective Hyper-Heuristic Algorithm for solving the Airport Slot Allocation Problem with efficiency, unaccommodated requests, and fairness considerations

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The Worldwide Airport Slot Guidelines (WASG) is the prevalent mechanism for managing demand-supply imbalance at overly congested airports (Level 3, slot coordinated airports). Single and multi-objective WASG based formulations have been proposed in the literature to optimize airport slot allocation decisions. These models result in large scale combinatorial optimization formulations that require the development of heuristic algorithms that can produce a good approximation of the efficient frontier.

In this paper we propose a Hyper-Heuristic Algorithmic framework that can approximate the efficient frontier of multi-objective slot allocation models when efficiency (total displacement), fairness, and unaccommodated requests (requests that can't be allocated slots within the airlines' flexibility limits), are considered. The proposed Hyper-Heuristic framework incorporates a large set of low-level heuristics able to handle the fairness objective. The proposed Hyper-Heuristic Algorithm is tested on a dataset of a European Level 3 (coordinated) airport, and the results generated by the proposed framework are compared with the results obtained by an exact approach. The scalability of the proposed framework is also demonstrated using a synthetic dataset.

Design Optimization of 2D-Mesh Network-on-Chip Systems: Energy Efficiency and Load Balancing with Multi-Objective and Bi-Level Approaches

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Network-on-chip (NoC) technology represents a sophisticated communication infrastructure designed to address the scalability and efficiency challenges posed by traditional bus-based interconnections in System-on-Chip architectures. Energy efficiency and load balancing are crucial for NoC design because they significantly influence overall performance and sustainability. However, these objectives often conflict, as improving energy efficiency can lead to imbalanced load distribution, posing a complex optimisation challenge. In this work, we explore two optimisation approaches, multi-objective and bi-level optimisation, to obtain a solution(s) to the problem. The first approach employs the Non-dominated Sorting Genetic Algorithm (NSGA-II), a state-of-the-art algorithm known for its ability to balance multiple conflicting objectives. In contrast, the second approach utilises a bi-level genetic algorithm (BiGA) to address the problem's inherent constraints. The hierarchical methodology enables bi-level optimisation to break down the complex problem into manageable sub-problems. Simulation results indicate that BiGA outperformed NSGA-II by 7.6% in optimising energy consumption. Although NSGA-II excels in load balancing, offering a 24.9% improvement, and produces a set of non-dominated solutions that balance energy consumption and load distribution, it requires approximately threefold the execution time. The experiments were carried out on six different NoC configurations. Approximated Pareto optimal solutions on one of the configurations between two objectives are shown in Figure 1.

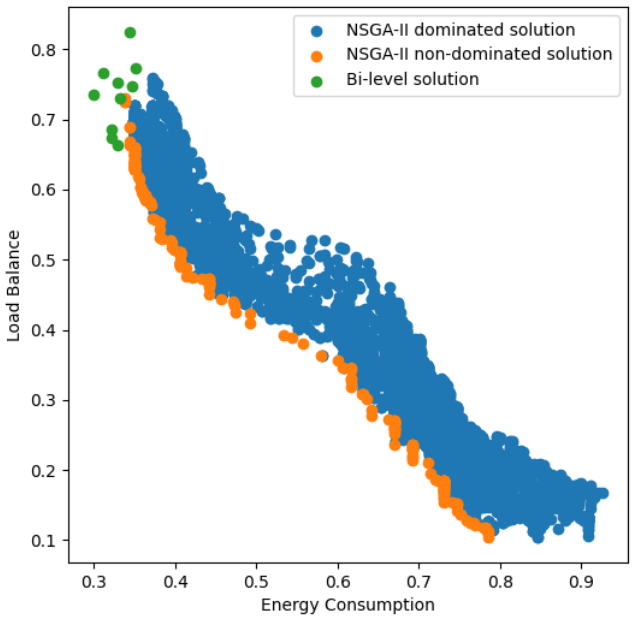

Figure 1: Solutions with NSGA-II and BiGA between energy consumption and load balancing

The diversity of solutions provided by NSGA-II can be valuable for chip designers to explore the trade-offs between objectives. To conclude, each problem formulation has its own merits. The multi-objective formulation offers a broad exploration of trade-offs and flexibility, whereas solving bi-level formulation is faster and provides more focused optimisation. The choice between them depends on the specific objectives and priorities of the decision-makers.

Keywords: Application mapping, Task routing, Load balancing, Multi-objective of NoC

The Split: Analysing Contest Design in the Scottish Premier League

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In this talk, we examine whether the policy to split the Scottish Premier League (SPL) into two after 33 games for post-season play generated negative externalities. Using a regression discontinuity (RD) design, we test whether the policy facilitated “tanking" by reducing the incentive to apply costly effort in a sporting contest. We also investigate whether it reduced attendance for teams finishing in the lower half of the standings. The analysis uses data from 23 seasons (2000/01 to 2023/24, excluding pandemic-impacted seasons) in which the league has operated under this structure. The results show weak evidence of mid-table teams tanking, but teams above and below this cut-off perform similarly Post-Split. However, teams just below The Split experience lower attendances compared to those just above, driven by the lost opportunity to play against the “top" teams such as Celtic and Rangers. This implies the new structure harmed a subset of clubs. Furthermore, this work highlights how large market teams subsidise smaller teams in sports leagues. Finally, we outline an open-source R-Shiny application that we developed to generate interactive visualisations of attendance data in the SPL.

The Role of Generalised Trust in Referee Appointment Decisions of European Football

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Appointment policies for referees in European football leagues vary significantly between countries, influenced by factors not made public by respective committees. Consequently, there are notable differences in the total number of referees used and the frequency of their appointments throughout a league season. We conjecture that high-trust countries distribute referee appointments more evenly across their talent pool, while low-trust countries tend to favour high-status referees to mitigate corruption allegations and minimise protests. Additionally, we hypothesise that high-trust countries maintain a smaller pool of referees, yet a higher number of higher-status referees, compared to low-trust countries. Using archival data from central referee appointments in European men's football leagues and international matches from 2017 to 2024, combined with generalised trust levels for the respective countries, we conduct statistical analyses to test these hypotheses. Our findings support the notion that trust at the societal level significantly influences referee appointment policies. We discuss the implications of these divergent policies for referee development, retention, and the perception of fairness, and argue for more uniform appointment practices to foster a sustainable pool of professional referees.

The Demand for Grassroots Football

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Analyses of the demand for attendance at football matches has almost exclusively focussed on high-level professional men's football. In contrast, in this paper we investigate the determinants of attendance at grassroots, semi-professional and amateur football. We examine the 6 levels of the English football system outside the Football League, and consider the different explanations provided for attendance demand in the literature, from the uncertainty of outcome hypothesis to the league standing effect, as well was the perception of quality. In addition, we investigate how grassroots attendance is affected by both spatial competition from top-flight rival clubs located nearby and temporal substitution due to this rival having a home match on the same day. Our analysis provides important evidence on the rationale for policies to protect grassroots football, which is arguably of vital importance for the local communities and serves as a breeding ground for players that move higher up the leagues.

Football from the elite down to grassroots

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Football is England's national sport, and overwhelmingly so. The game is, in its essence, the same in the Premier League as it is played on a public park on a weekend morning or afternoon. Of course, the nature of the product on offer has different characteristics as one moves from the very elite down to semi-professional, amateur and grassroots levels. In this paper we document some of these differences moving from England's professional leagues down into the very lower steps of the non-league game – we combine data sources to look at seventeen levels of football, with at each level below the fifth, an increasing number of regional leagues as the geographic breadth of competitions gets smaller. We document variations in match outcomes down the divisions, and more interestingly, variation in the predictability of matches using methods commonly used to evaluate elite football. We finally consider the extent to which these methods help over and above basic league table information when predicting attendances at these football matches.

Tackling Global Crises with OR: From Flood Mitigation to Healthcare

Abstract: The Sustainable Development Goals (SDGs), adopted by the United Nations in 2015, call for collective action to eliminate poverty, promote health and well-being, and address the climate crisis by 2030. Achieving these interconnected objectives demands innovative, data-driven strategies and robust interdisciplinary collaboration.

This talk showcases several research projects using Operational Research to tackle pressing development challenges in South East Asia and Sub-Saharan Africa. These include, for instance, the GCRF-OSIRIS project, which leverages optimisation modelling, stakeholder engagement, and cross-disciplinary methods to develop flood mitigation strategies for cities in Vietnam, contributing to SDG 11 (Sustainable Cities) and SDG 13 (Climate Action). Other examples focus on ongoing collaborations with CUAMM Doctors with Africa, to showcase how OR methodologies can be used to strengthen healthcare services in resource-constrained settings. These include health services in refugee camps in Ethiopia and mental health services for adolescents in Tanzania and Mozambique, contributing to SDG 3 (Good Health and Well-being) and SDG 10 (Reduced Inequalities).

The presentation will also discuss key lessons learned from these projects, offering practical insights for developing successful OR applications in developing countries.