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Transforming Emergency and Urgent Care Services with OR

Paul Harper

In this talk I will discuss several related research projects, broadly within emergency and urgent care services, both in the UK and with our partners in Indonesia. This includes game theoretic and queueing models at the interface of Emergency Medical Services (EMS) and Emergency Departments (EDs), and a research programme working with ambulance providers and the Indonesian Government to help them make critical decisions on the optimal types, capacities and geographical locations of response vehicles. Such factors directly impact on the probability of patient survival, ability to respond to major disasters, and the overall quality of care provided. There are however many challenges faced in Indonesia, including vast geographical areas, traffic congestion, inadequate numbers of ambulances and a lack of a co-ordinated service. I will share the findings to date, including an analysis of ED survey data that we undertook across Jakarta hospitals, and an approach to consider EMS allocations for both heterogeneous populations (multiple medical needs) using a heterogeneous fleet (consideration of multiple vehicle types each with differing travel speeds). This has been achieved via the creation of an optimisation and simulation decision-support framework.

Capacity management for a leasing system with different equipment and batch demands

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Abstract: This work explores the admission and capacity allocation for a leasing system with two types of equipment and three kinds of batch demands: elementary specified, premium specified, and unspecified demands. The demands arrive following mutually independent Poisson processes, and the rental duration of equipment follows a negative exponential distribution. The lessor can satisfy partially the specified demands with the required type of equipment and satisfy partially the unspecified demands with any type of equipment. The objective is to maximize the expected discounted revenue. We formulate this problem as a Markov decision process, prove the anti-multimodularity of the value function, and characterize the structure of the optimal policy. We show that the optimal policy has a simple structure and is characterized by state-dependent rationing and priority thresholds. Moreover, a solution algorithm is proposed to calculate the optimal policy. We study the impacts of the system state on the optimal action and find that the optimal action has limited sensitivity to the system state. Numerical studies are conducted to compare the performance of the optimal policy with that of two heuristic methods and to derive some managerial insights by analysis. We further discuss batch acceptance.

Shifting demands and sharing savings in service delivery to minimize emission cost

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We study a problem of scheduling technicians each driving a vehicle to perform service tasks at customer sites. Customers request services one day in advance. Each customer specifies a time window for the service to start and can also choose to participate in a green delivery program by indicating alternative time windows he/she can also accept. Travelling at different time slots of the day causes different amount of emission because of different congestion levels. The savings of emission cost due to time window flexibility will be shared by the customers allocated to their alternative time windows. Such a multiple time window VRP has not attracted much attention in the literature. The problem is formulated as a MILP model which schedules the service routes to minimize the emission cost. A self-adaptive simulated annealing algorithm is developed to solve the problem. Small instances which can be solved by optimization software are used to test the performance of self-adaptive SA heuristic. The results show that the objective value of the heuristic solution is close to optimal. Real-life sized instances are then randomly generated and solved by the SA heuristic. The operation is simulated for several working days. Results show that the proposed incentive sharing policy can help save emissions and improve the number of customers served when there is overbooking. Tests with different settings demonstrate that more flexible customers or more available time windows for each customer can further reduce emissions and increase the number of customers served.

Index Policies for Campaign Promotion Strategies in Reward-based Crowdfunding

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Abstract:
Reward-based crowdfunding plays a crucial role in fundraising for start-up entrepreneurs. Many crowdfunding platforms follow an all-or-nothing scheme, where a project is successful only if its pre-specified funding goal has been reached by the end of the campaign and the crowdfunding platform collects commission fees only from successful campaigns. This study considers crowdfunding platform's strategy of selecting and highlighting some projects on its homepage to boost the chance of success for these projects, and thus their contributions to revenue. We investigate the optimal promotion strategy to maximise the platform's revenue over a fixed time horizon. We characterize backers' investment decision by a Multinomial Logit model, and formulate this problem into a stochastic dynamic program which is however computationally intractable. We decompose the problem into a collection of single project problems through an extension to the Whittle's Restless Bandit approach. We show the indexability for each single project problem and demonstrate that the index values can directly be calculated from the value-to-go of each project under a non-promotion policy. To the best of our knowledge, this work is the first in the literature to provide indexability analysis of restless bandits coupled with state-dependent discrete choice models and modelled with bi-dimensional states (i.e. funds already raised and remaining time). Extensive numerical experiments show that the proposed index policy outperforms other benchmark heuristics in most scenarios considered.

Procedural bilevel programming: applications to the bin packing problem

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The assumption of a follower solving their optimization problem to optimality is key to bilevel optimization. In practical applications, though, where the follower's problem is typically solved by a human, it is arguably very rare that the follower would always find an optimal solution. Motivated by this observation, we introduce a new bilevel optimization paradigm, which we refer to as "procedural bilevel programming", where the follower, rather than seeking an optimal solution to their problem, applies a well-defined procedure (such as a constant-factor approximation algorithm) for its solution. Assuming the bin packing problem as the motivating example, we propose (and experiment with) exact single-level formulations for the problem where the leader affects the problem instance (modifying, e.g., the item weights and/or the bin capacity) in such a way that, by anticipating the procedure the follower would use to solve the resulting instance, the leader's objective function is maximized.

Keywords: bilevel programming, bin packing

Voxel-Based Solution Approaches to the Three-Dimensional Irregular Packing Problem

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Three-Dimensional Irregular Packing Problems consist in finding suitable non-overlapping placements for collections of irregular shapes inside one or various containers. They have a variety of applications that range from efficient transportation of cargo to additive manufacturing and 3D printing. In this talk we present solution methods for a variant of the problem where the aim is to place a set of 3D irregular items in a container, while minimizing the container height. We explore the potential of voxels, the 3D equivalent of pixels, as the geometric representation of the irregular items. In this discretised space, we develop a geometric tool that extends the concept of the nofit polygon to the 3D case. This enables us to tackle the problem from different angles, including an integer linear programming formulation and various metaheuristic optimisation approaches. Our computational tests, both on new benchmark datasets and existing literature instances, show that voxel-based metaheuristic algorithms can find best-known solutions for various instances in practical computation times.

Intelligent 3D Tire Packing Algorithm

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The container loading problem of packing the tires into a cuboid container has far-reaching applications in commercial and industrial applications. An increase in the number of tires in a container leads to a decrease in transportation cost. This paper studies the intelligent tire packing algorithm in various settings of new tires packing, second-hand tires packing and the combination of the two. Two solutions are developed in terms of orthogonal rotation and herringbone arrangement. The result of numerical analysis shows a significant improvement on its efficiency of space utilization.

Supply Chains

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This paper deals with scheduling in biopharmaceutical manufacturing involving uncertain process durations, dual-resource constraints, and no-wait constraints, i.e., once the production of a batch has been started, it must go through all tasks without delays. This is general practice for products with highly sensitive raw and work in progress materials. We address the problem of maximising throughput by assigning operators and equipment to a task whenever one is required for a biopharmaceutical firm that produces Chimeric Antigen Receptor T-cell therapies. This therapy is extremely expensive, thus even a slight increase in utilisation and throughput would significantly increase profits. The company produces the therapy using patients' own T-cells which are taken in an associated clinic. The cells are then modified to be re-injected into the patients. The underlying problem is formulated as a mixed-integer linear programming model and Gurobi is used as the solver. However, due to the complexity of the problem only solutions for small size instances are obtained. We develop a two-step lookahead heuristic to tackle real-world size instances. We test the proposed algorithm in a simulation considering the uncertainties in process durations and availability of the raw materials (T-cells from the patient). We illustrate how the proposed algorithm improves resource utilisation in the presence of uncertainties and how using Cryopreserved Leukapheresis materials impacts the throughput.

Decomposition of large-scale MILP supply chain models using convolutional neural networks

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Abstract
Chimeric Antigen Receptor (CAR) T cell therapies are an indicative example of personalised medicine products that owing to their promising clinical results have led the way for the approval of numerous cell and gene therapy products by the regulatory agencies (Young (2022). Personalised medicine products are often described by 1:1 business models that consider bespoke parallel manufacturing lines and dedicated distribution nodes. CAR T-cell therapies are based on the use of the patient's own T-cells as the starting material, which is then genetically engineered and administered back to the patient (Papathanasiou (2020)). Planning and scheduling the end-to-end supply chain of such therapeutics is a challenging task, presently relying on white-glove logistics. Operations Research tools can offer a methodical approach to aid informed decision-making.

In this work, we present a Mixed Integer Linear Programming (MILP) model that characterizes the supply chain of personalised therapeutics. For the first time, we track each patient's flow individually. The model combines strategic planning and scheduling decisions, resulting in 26,975,374 linear constraints and 6,190,134 binary variables when 2000 patients' samples per year are tracked simultaneously. To decrease the computational complexity of the MILP model, we utilise the potential of convolutional neural networks (CNNs) to decompose the problem. The data-driven part of the proposed framework accounts for strategic planning in the supply chain by forecasting the optimal supply chain network structure and hence the search space of the original MILP model is significantly reduced. The results indicate a reduction of up to 81% and 83% in the number of constraints and binary variables for all scenarios examined, respectively.

Keywords: supply chain optimisation, MILP, machine learning, personalised medicine

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Optimizing the Sustainable Energy Transition among SIDS

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Abstract

Trinidad and Tobago is one of the largest emitters of CO_2 per capita globally, with a significant reliance on oil and gas sectors. With the country's commitment, as a small island developing state (SIDS), to sustainable development goals and climate change agreements, rapid redesign of Trinidad and Tobago's power sector is critical to promoting a sustainable energy transition. Our study examines the minimisation of electricity costs (LCOE) and greenhouse gas emissions (GHG_{LC}), using a mixed-integer linear programming model (MILP) across 5 scenarios describing the national power generation system. Our results show an LCOE of $\$_{USD}$ 61.72 per MWh and GHG_{LC} of 756 $kgCO_{2eq}$ per MWh, attributed to current take-or-pay Power Purchasing Agreements (PPA) aligned to Scenario 1A. Coupled improvements in power generation technology and resource efficiency (Scenario 2), resulted in LCOE and GHG_{LC} reductions of up to 40% ($\$_{USD}$ 36.94 per MWh) and 24% (572 $kgCO_{2eq}$ per MWh), respectively. Furthermore, the incorporation of low carbon H_2, MeOH and NH_3 into the process system was infeasible at current prices, despite potential avoided emissions when compared to local business-as-usual operations. Lastly, looking ahead to 2030 shows a general increased LCOE of ($\$_{USD}$ 8.5 – 14) per MWh) and GHG_{LC} of 8 – 27 $kgCO_{2eq}$, attributed to higher grid demand and natural gas prices. Thus, our results support the need for active decarbonisation within the national energy sector and removal of current legislation that discourages the application of low carbon technologies towards sustainable development. Ultimately, multiple decision criteria must be integrated into public sector decision-making to ensure sustainability is met within current and future national projects and policies.

Keywords: Sustainable development goals, Power generation, Multiple decision criteria, Life cycle assessment, Small Island Developing States.

Downside Loss Management in Inventory Control: Minimization of Conditional Value-at-Risk via a Non-parametric Feature-based Approach with Adaptive Data Selection

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In modern corporate management, the risk of operation is just as important as profitability. In this research, we consider a very popular risk measure in financial risk management, conditional value at risk (CVaR), in an inventory control context.

We propose a feature-based non-parametric approach to Newsvendor CVaR minimisation under adaptive data selection (NPC). This proposed method is simple and general. NPC works directly with the data, not relying on any assumption of the demand distribution. It can handle minimisation with both linear and nonlinear profits and requires no prior knowledge of the demand distribution. Our main contribution is two-fold. Firstly, NPC uses a feature-based approach. The estimated parameters of NPC can be easily applied to prescriptive analytics to provide additional operational insights. Secondly, unlike common non-parametric methods, our NPC method uses an adaptive data selection criterion and requires only a small proportion of data (usually only 10-20% of data), significantly reducing the computational effort. Results from both numerical and real-life experiments confirm that NPC is robust with regards to difficult and large data structures. Using less data points, the computed order quantities from NPC lead to equal or less downside loss in extreme cases than competing methods.

Acknowledgments*: The work by Wenqi Zhu was supported by the Hong Kong Innovation and Technology Commission (InnoHK Project CIMDA).*

Working force planning with stochastic turn over

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We consider a workforce planning problem in which the employee turn over in each periodfollow a Binomial distribution. The objective is to minimize the total costs related to hiringand satisfy minimum employee requirement in each period. We apply discrete convexity andK-convexity to show that the optimal hiring policy is (s,S): hiring the employee to S whenthe employ number falls below s in each period and do not hire otherwise. We also propose apiece-wise approximation method to build a mixed-integer linear programming (MILP) modelfor the problem. This method can compute the problem fast with small optimality gaps.

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Problem-driven Scenario Generation for Stochastic Programming: Two Recent Approaches

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Stochastic programming is a tool for making decisions under uncertainty. Under this paradigm, uncertain parameters are modelled as a random vector, and one attempts to minimize the expectation or risk measure of some cost function which depends on the initial decision. However, typically to solve a stochastic program the underlying random vector needs to be finite and discrete.

The construction of such a discrete random vector is called *scenario generation*, and the individual mass points are *scenarios*. Typically, the more scenarios one uses, the more accurate the representation of the uncertainty, but the more computationally expensive the resulting stochastic program becomes to solve. Scenario generation should therefore aim to represent uncertainty with as few scenarios as possible.

Traditionally scenario generation approaches were *distribution-driven*. That is, they constructed scenarios in such a way to match some reference distribution without explicitly considering the underlying stochastic program. More recently *problem-driven* methods to scenario generation have been proposed which exploit problem structure to provide a more concise representation of uncertainty.

In this talk we present two recent problem-driven approaches to scenario generation. The first approach deals with general two-stage stochastic programs where one minimizes the expectation. The method aims to detect degeneracy in *output distributions* by analysing those belonging to a set of candidate solutions. Scenarios are then selected to preserve expectations in an as efficient a manner as possible. The approach is agnostic to problem and distribution type as it relies only on evaluating the cost function in different outcomes. The second method is for problems which involve minimizing tail risk measures such as conditional value-at-risk. For these problems we identify *risk regions* of distributions, which are the areas which determine the value of a tail risk measure. We then propose scenario generation approaches which prioritise the generation of scenarios in these areas.

Optimising In-Store Price Reductions

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When selling products, demand for each product does not remain consistent throughout its lifetime. As time progresses a product is deemed less desirable by customers due to factors such as declining quality or newer improved products being released. We often wish to maximise revenue and keeping prices consistent while demand is decreasing is not likely to achieve this. Therefore, we need to use historic sales data to determine a discount pricing strategy for products towards the end of their saleable lifetime, known as markdowns. We can use this data to model the relationship between demand and price which we can use to determine what set of discounts will be most profitable.

Within available historic sales data, there are often only a limited number of discount percentages that have been applied to products. Additionally, some products have much more sparse data than others. Consequently, we can have a large amount of uncertainty in our demand.

To tackle this, we can group products to enable data sharing among similar products. Here rather than grouping by physical characteristics, as is commonly done, we determine similar products are those that have similar demand behaviour. We cannot assume the demand for a luxury and a basic version of the same product follows the same demand function but grouping by physical characteristics can accidentally do this.

We propose a hierarchical Gaussian process model and present some numerical results based on this. The model takes advantage of data sharing which also can capture the demand behaviour without a known underlying demand function. The model also gives a measure of uncertainty based on data availability. This work was undertaken in collaboration with Tesco.

Intermittent Demand Forecasting for Final Purchase Decisions

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Across a number of sectors, after-sales services constitute a billion-dollar business. Final purchases are high stake decisions of particular importance for the aftermarket business. They are often made towards the end of the spare part life cycle and need to balance shortages and over-ordering so as to sustain demand for the rest of a part's life. In the automotive industry, among others, this period can extend for as long as ten years.

Forecasting in order to make effective final purchase decisions is made difficult by the nature of the demand. A large majority of spare part inventories consist of items with intermittent demand structures, where in some periods no demand is observed at all. As a result, standard forecasting methods provide inaccurate forecasts for intermittent items. As final purchase decisions are frequently made to sustain demand several years into the future, modelling procedures should also be designed to include the decay in demand as time passes. A forecasting model that accounts for aspects of both decline and the intermittency of demand are the subject of this talk.

Capacity planning of healthcare outsourcing network under uncertainty

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This talk concerns the capacity planning problem of a healthcare outsourcing network with uncertain patient arrivals and service times. The healthcare outsourcing network consists of several hospitals sharing a patient population based on contracting. A central authority with a fixed budget distributes patients among service providers by ensuring certain performance targets while each service provider offers a limited capacity with fixed price.
We formulate the problem as a nonlinear integer programming model where each service provider is modelled as a queueing system with the service and inter-arrival times following general distributions. Moreover, the maximum waiting time in each queue is approximated by a worst-case approach. An alternating optimization algorithm is proposed to solve the underlying non-linear mixed-integer optimization model. Computational experiments are designed to illustrate performance of the proposed approaches and some managerial insights are discussed.

A two-time-level model for mission and flight planning of an inhomogeneous fleet of unmanned aerial vehicles

Johannes Schmidt, Armin Fu¨genschuh

Due to their high savings potential of time and resources, unmanned aerial vehicles (UAVs) are considered a promising alternative to human-operated machines in a vast number of applications. To ensure their mostefficient and economical deployment, detailed information about their cho-sen trajectory is advantageous already in a strategic planning stage. Thus,we consider the mission and flight planning problem for aninhomogeneousfleet of UAVs. Therein, a set of waypoints with givenscore values andtime windows represents different tasks, while bydeploying the UAVs, thetotal score of the visited waypoints should bemaximized. This variant ofthe team orienteering problem with timewindows (TOPTW) combines twosubproblems have to be tackledsimultaneously. On the one side, there isthe combinatorial missionplanning problem of assigning waypoints to par-ticular UAVs. On theother side, there is the flight planning problem offinding optimal flighttrajectories for each of them regarding their respec-tive set of waypoints.For its solution, we derive a mixed-integer problemwith differentialequation constraints (MIPDECO) incorporating two cou-pled timediscretizations. These allow the computation of trajectories ina greaterlevel of detail while the number of variables increases less com-pared toa single time discretization scheme. For every UAV, Newton'sequationof motion, detailed physics of flight with mass-dependent tech-nicalparameters, and an altitude-dependent operating range yield accurateflighttrajectories. Convex-shaped areas are used to describe wind zones andrestricted airspaces as environmental restrictions. Furthermore, safety dis-tances between all UAVs are established to allow safe operations. Applyingseveral linearization techniques, we achieve a mixed-integer linear problemand demonstrate its applicability to GUROBI as a state-of-the-art numer-ical solver in different numerical experiments. Next to its computational performance, the effects of the two-time level discretization on the aspectsof the model are discussed.

Polyhedral Structure of RLT Relaxations of Nonconvex Quadratic Programs with Implications on Exact and Inexact Relaxations

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In this talk, we focus on nonconvex quadratic programs which involve minimizing a nonconvex quadratic function over a polyhedron. We study the polyhedral properties of RLT (Reformulation-Linearization Technique) relaxations. We establish several relations between the vertices and the recession cones of the feasible region of the original problem and that of the RLT relaxation. In particular, our results lead to a description of the sets of instances of quadratic programs that admit exact and inexact RLT relaxations. We propose an algorithmic procedure to construct instances with exact and inexact RLT relaxations.

Restaurant Meal Delivery Problem with Order Bundling Allocation and Fairness

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Online food ordering is well developed nowadays, with many people choosing to order their meal online and waiting at home instead of going to a restaurant. We consider a dynamic restaurant meal delivery problem (RMDP) where a pool of drivers deliver food from multiple restaurants to ordering customers. The objectives are to reduce both delivery delays and unfairness for drivers. In practice, order delays increase significantly when the demand for orders is high relative to the number of available drivers. To address this issue, we consider the RMDP as two sub-problems, order bundling and order allocation. First, we implement an order bundling policy (OBP) that gathers orders with similar characteristics into a single group within drivers' capacity. This group is then assigned to a driver instead of assigning each individual order to a driver, respectively. Second, we propose an order allocation rule to allocate the groups to drivers considering both delay reduction and fairness to drivers. Finally, we build simulation models with both single and multiple restaurants to test our method using synthetic data. The experimental results show that order bundling allocation improves the delivery service in RMDP.

A Generic Approach for Conference Scheduling with Integer Programming

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Conferences are a key aspect of academia, and their schedule plays a vital role in meeting the expectations of participants. Given that many conferences have different constraints and objectives, different mathematical models and heuristic methods that tackle a specific conference scheduling problem have been developed. We present a penalty system that allows organisers to set up scheduling preferences for tracks and submissions regarding sessions and rooms, and regarding the utilisation of rooms within sessions. In addition, we also consider hybrid and online conferences where submissions need to be scheduled in appropriate sessions based on time zone information. This makes the problem multi-objective where each type of preferences is an objective. By following a weighted sum approach, we convert the problem from multi-objective into single objective. A generic scheduling tool is presented that schedules tracks into sessions and rooms, and submissions into time slots by minimising the violations of each objective subject to certain hard constraints. Three integer programming models following the weighted sum approach are presented: an exact model, an approximation model, and an extended model. The models were tested on five real instances from three different conferences, namely the OR Society's 60th Annual Conference, the New to OR Conference, and the Genetic and Evolutionary Computation Conference. Additionally, the models were tested on two artificial instances to evaluate their performance on larger instances. The results showed that the exact model achieves optimal solutions and near-optimal solutions within the time limit for small to medium sized instances, the approximation model performs well for large instances, and the extended model handles more complex and additional constraints for small to medium sized instances. Overall, this work demonstrates the suitability of the proposed generic approach to optimise schedules for in-person, hybrid, and online conferences.

Modelling and Solving the Two-Echelon Location-Routing Problem with Different Intermediate Facilities

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This work proposes a variation of the location-routing problem (LRP), a problem that interconnects two NP-hard optimisation problems: the vehicle routing problem (VRP) and facility location problem (FLP). There are many mathematical formulations and solution methods for a number of variations within the literature. Within our two-echelon problem, we include intermediate facilities, which receive products from suppliers to combine into a truckload to deliver to the next step of the network. However, the inclusion of both existing and new intermediate facilities within a static model makes this work unique. As a business expands, there will be a need for the business to add facilities to its distribution network. Considering both new and existing intermediate facilities within the model will allow a business to use their current distribution network and grow it efficiently.

Our primary objective is to minimize the total distance travelled by vehicles. We use this as a proxy for the efficiency of the network. For our solutions to be practical in a real-life business model, they must satisfy a number of constraints, such as time constraints, capacity constraints, meeting demand, maximum number of new facilities, which may be opened and minimum throughput needed for a new facility to open. By including these constraints, we fragment the space of feasible solutions, increasing the difficulty of finding a feasible solution. We instead quantify the infeasibility of these constraints and penalize constraint violations in the objective function. Thus, we can treat minimizing constraint violations as a secondary objective. We use a weighting of our two objectives to solve our problem. In this work, we propose selection hyper-heuristic methods for our LRP, considering constructing sequences of low-level heuristics and selecting them based on their performance. Low-level heuristics are changes, which can be made to a solution to produce a new solution.

Solving MINLPs to Global Optimality with FICO Xpress Global

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FICO Xpress Global was recently added to the FICO Xpress solver suite as a global solver for general MINLPs as part of the FICO Xpress 9.0 release. In this talk we will present the features and internal workings of the solver and how it integrates with the existing solvers within the FICO Xpress suite.

How I Learned to Stop Worrying and Love Parameters

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A variety of theoretical frameworks, e.g. the Lasserre hierarchy of relaxations, basic steps in generalized disjunctive programming, and the reformulation linearization technique, offer discrete levels for optimization formulations and relaxations. These discrete choices, for instance picking the first versus the second level of the Lasserre hierarchy, may be problematic for computational optimization strategies. For example, the first order Lasserre relaxation may be too loose but solving the second order Lasserre relaxation may be too computationally expensive. This presentation considers developing intermediates between theoretical optimization frameworks that classically come with discrete levels. We explore the tradeoff between possibly better computational performance with these between formulations versus the possibly explosive number of parameters these formulations introduce.

This is joint work with Juan Campos, Jan Kronqvist, Panos Parpas, Alexander Thebelt, and Calvin Tsay.

Reduced-space formulation for deterministic global optimization in process engineering

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Nonlinearity in the numerical representation of many operational and design problems requires global optimization methods for optimal decision making. Unlike stochastic approaches, deterministic global optimization guarantees global solution in finite number of iterations. However, the computational cost associated with it largely limits its use to small problem sizes. Our open-source deterministic global optimization solver MAiNGO [1] relying on McCormick relaxations [2, 3] and their subgradient propagation [4], enables reformulating the problems in a reduced-space formulation. Therefore, it allows for extensive computational savings. Particularly for integration of data-driven models into optimization problems, we have developed the open-source MeLOn toolbox [5]. We present theory, algorithms and applications that demonstrate the benefits of our proposed approach process systems engineering problems, in particular flowsheet optimization and various types of hybrid mechanistic/data-driven models.

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Historical Analysis in U.K. Defence

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Historical Analysis within Dstl is defined as: 'The use of mathematical, statistical, qualitative and other forms of analysis to understand historical engagements, operations, campaigns and conflicts for the purpose of providing impartial analysis and sensitive decision support to policy makers.'

In this respect, 'Historical Analysis' is not the same as 'Historical Research' - the study of primary source material to construct understandings and interpretations of past events. Historical Analysis, however, does draw upon such historical – including modern - source material to enable quantitative analysis. This uses a range of mathematical, statistical and other analytical techniques to draw out insights and factors which can be applicable to current day situations – ranging from tactical combat to strategic international relations.

As part of Dstl's suite of Operational Research techniques, Historical Analysis also provides real-world empirical evidence to inform and underpin other analysis and modelling.

This paper briefly outlines the origins and history of Historical Analysis within the UK Ministry of Defence and provides an overview of some recent applications of the approach.

Human Factors for Human-in-the-Loop Tactical Engagement

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The Combat Model is a multivariate analysis of the battlefield and it has been used to successfully reproduce momentous historical battles including the Somme, Gettysburg and the Arab-Israeli War. From a complex dynamic arises the tactical implementation of suppression of one's opponent, a control mechanism that impedes freedom of movement and affects human entities and supply-chain logistics. The suppression of troops is also a significant factor in the rate of casualties suffered as a consequence of the ongoing psychological strictures from witnessing physical trauma to allies; undeniably affecting actions, as evidenced by RARDE (1976), DOAE (1990). Scarce data and the ethical implausibility of experimentations that invoke horror, distress and fearfulness are acknowledged, but their importance is no less diminished.

Recent research has examined procedural complexities for human-beings who operate remote systems in combat, while the psychological factors inherent to this newly configured technological battleground are still uncertain. Taking Tilley, Sawtell and Watson's (2007) 16 [influential] factors associated with achieving objectives in tactical level engagements as a starting point, this work aims to infiltrate the human-machine collaboration to examine the relevance of those factors to users of a single, simulated operator command post. A synthetic representation built onto a VBS3 platform was designed to study eight participants interactions in three scenarios. A basic multivariate analysis of a system's users' performance was analyzed for comparative purposes to identify change; for example, timeliness, accuracy, resource efficiency. The study also implements path-finder algorithms that simulate land maneuvers across simple terrains whilst under suppression; one demonstrable advantage is the avoidance of fratricide. The model uses pattern recognition techniques from machine learning to consider the behavioral interactions of combatants in a game environment, imposed onto pathfinder algorithms, and considers distinctive competencies amongst groups as well as the lone wolf.

The resultant conclusion is that the precedence of certain human factors to attain tactical advantages requires reconsideration when using digital platform systems. In fact, it is a requirement that new impediments to human behavior are considered and the optimal engagement strategies can accommodate them. The discussion includes recommendations to avoid negative outcomes of decision-making under enemy bombardment.

Abstracts must be submitted via MyIMA by the session chair, Sarah Jane Stapleton, sstapleton@dstl.gov.uk Abstract submission is free, however by submitting an abstract you are confirming that you will register and pay to present a full presentation (poster or oral) at the Conference if your Abstract is accepted.

Analytical Strategic Wargaming – A Developing Method

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Over the past three years, wargamers within Dstl's Defence Wargaming Centre have been grappling with the challenge of how to conduct strategic wargames that can produce robust, evidenced, and auditable insights to help policy makers. This new approach represents a departure from much of the strategic gaming that has been done previously, that primarily relied on participant's opinions and observational data capture to generate findings.

Building on the work done by wargamers at the US Naval War College, as well as theoretical work done within Dstl, the analysts within the Strategic Gaming and Historical Analysis team have begun to formalise a method for the design, execution, and analysis of strategic games.

This presentation will explain the development of this method, outline how it has been used within games run for the Ministry of Defence, and provide an overview of the challenges that still surround analytical strategic gaming.

Abstracts must be submitted via MyIMA by the session chair, Sarah Jane Stapleton, sstapleton@dstl.gov.uk Abstract submission is free, however by submitting an abstract you are confirming that you will register and pay to present a full presentation (poster or oral) at the Conference if your Abstract is accepted.

Merging tree-based rules and discretizations for intrinsically interpretable credit scoring.

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Balancing predictive performance and interpretability has recently become an emerging issue in applications of Machine Learning (ML) to credit scoring. In this research, we present a novel intrinsically interpretable classification model for credit scoring, which we refer to as Penalised Ensemble for Region Merging (PERM). The proposed approach is able to enhance interpretability of ensemble-based classifiers by merging discretized regions or tree nodes.

Existing methods in literature are either explainable without the consideration of a nonlinear structure, e.g., Logistic Regression, or nonlinear without explanations, e.g., Random Forest and Gradient Boosting. In contrast our proposed PERM model is intrinsically interpretable and can well capture the possible nonlinearity in data. This is done by adopting an ensemble structure to convert a series of weak learners into a strong learner as to enhance the performance. The challenge of interpreting a high number of weak learners is overcome by using a recently developed regularization term, namely the SCOPE. Originally proposed for nominal data, this regularization term pushes similar coefficients to have the same value. In our model this has the effect of merging tree-based rules or discretization regions in the weak learners, with a high benefit in interpretability.

The modelling framework of PERM is rather flexible for extension if needed to cope with the legislation requirements, which further increases the resilience. Extensive empirical analyses are conducted on credit default datasets with comparison to popular credit scoring models. The results show that PERM can predict credit risk competitively and consistently, while providing valuable insights for the decision makers.

Bandit Procedures for Designing Patient-Centric Clinical Trials

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Multi-armed bandit problems (MABPs) are a special type of optimal control problem that has been studied in the fields of operations research, statistics, machine learning, economics, and others. It is a framework well suited to model resource allocation under uncertainty in a wide variety of contexts. The use of bandit models to optimally design clinical trials is one of the typical motivating application, for designing the so-called patient-centric trials, which would take into account the benefit of the in-trial patients. Nevertheless, the resulting theory has had little influence on the actual design of clinical trials. Contrary to similar learning problems arising for instance in digital marketing where interventions can be tested on millions of users at negligible cost, clinical trials are about "small data", as recruiting patients is remarkably expensive and (in many cases) ethically challenging. Due to the focus on small sizes, we do not resort to the use of the normal distribution to approximate a binomial distribution which is a common practice for large samples either "for simplicity" or "for ease of computation". We evaluate and compare the performance of a variety of operations research and machine learning procedures for the finite-horizon MABP, including the traditional and still dominant clinical trial design choice – equal fixed randomization – and interpret them in the context of designing clinical trials. Our results illustrate how bandit approaches could offer significant advantages, mainly in terms of allocating more patients to better interventions, but still pose important inferential challenges, particularly in terms of their resulting lower statistical power, potential for bias in estimation and existence of closed-form test distributions or asymptotic theory. We illustrate some promising modifications to bandit procedures to address power and bias issues, and we reflect upon the open challenges that remain for an increased uptake of bandit models in clinical trials.

Keywords: bandit problem, dynamic resource allocation, index rules, clinical trials

Online optimisation for ambulance routing in disaster response with partial or no information on victim conditions

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In response to mass casualty incidents, medical aid must be provided to numerous victims synchronously under challenging circumstances including uncertainty about the condition of victims. Therefore, it is essential to have decision support tools which can generate fast solutions under uncertainty and utilise the available medical resources efficiently to provide victims with the needed treatments. We introduce an online optimisation problem for routing and scheduling of the ambulances under uncertainty about the triage levels and required treatment times of the victims in mass casualty incidents. Due to the lack of information in the initial emergency response phase, we assume that the triage level and treatment time of each victim can be disclosed online only once the condition of a victim is closely assessed by the medical team on one of the ambulances at the casualty location. We investigate this problem under two different scenarios with partial and no information about the conditions of victims. We follow the theoretical competitive analysis framework for online optimisation and prove the lower bounds on the competitive ratio of deterministic and randomised online solutions for both cases of partial and no prior information. Next, we introduce three novel online heuristics to solve this problem. We verify the quality of our online solutions against the offline optimal solutions that are provided under complete information on a comprehensive set of 1296 instances from the literature. Finally, we draw our conclusions in regard to the suitability of each of our solutions in various scenarios with different numbers of victims and the ratio of available information.

Keywords: Ambulance routing; mass emergency incident; online optimisation; competitive ratio; partial information; disaster relief

On exact and inexact RTL and SDP-RLT relaxations of nonconvex box constrained quadractic programs

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We study the problem of minimizing a nonconvex quadratic function over a polytope defined by box constraints. This fundamental problem arises in various applications and also as a subproblem in some general nonlinear programming algorithms. Despite its very special structure, this is an NP-hard problem. In fact, it is NP-hard to even approximate a local minimizer. On the other hand, the problem admits various tractable convex relaxations that yield lower bounds on the optimal value. A convex relaxation is said to be exact if the lower bound is equal to the optimal value. We focus on the well-known Reformulation Linearization Technique (RLT) relaxations and RLT with semidefinite (SDP-RLT) relaxations of box-constrained quadratic programs (BoxQPs). We present complete descriptions of the set of instances that admit exact RLT and SDP-RLT relaxations. We show that our descriptions can be converted into algorithms for efficiently constructing instances of BoxQPs with exact and/or inexact relaxations.

Matching markets with middlemen

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We study matching markets in the presence of middlemen. In our framework, a buyer-seller pair may either trade directly or use the services of a middleman; and a middleman may serve multiple buyer-seller pairs. For each such market, we examine an associated transferable utility cooperative game.

We first show that, in our context, an optimal matching can be obtained by considering the two-sided assignment market where each buyer-seller pair is allowed to use the mediation services of any middleman free of charge. Second, we prove that matching markets with middlemen are totally balanced: in particular, we show the existence of a buyer-optimal and a seller-optimal core allocations where each buyer or each seller receives her marginal contribution to the grand coalition. In general, the core does not exhibit a middleman-optimal allocation, not even when there are only two buyers and two sellers. We prove, however, that in these small markets the maximum core payoff to each middleman is her marginal contribution. Finally, we establish the coincidence between the core and the set of competitive equilibrium payoff vectors.

Computing Balanced Solutions for Large International Kidney Exchange Schemes

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To overcome incompatibility issues, kidney patients may swap their donors. In international kidney exchange programmes (IKEPs), countries merge their national patient-donor pools. We consider a recently introduced credit system. In each round, countries are given an initial ``fair" allocation of the total number of kidney transplants. This allocation is adjusted by a credit function yielding a target allocation. The goal is to find a solution that approaches the target allocation as closely as possible, to ensure long-term stability of the international pool.

As solutions, we use maximum matchings that lexicographically minimize the country deviations from the target allocation. We perform, for the first time, a computational study for a *large* number of countries.

For the initial allocations we use two easy-to-compute solution concepts, the benefit value and the contribution value, and four classical but hard-to-compute concepts, the Shapley value, nucleolus, Banzhaf value and tau value. By using state-of-the-art software, we show that the latter four concepts are now within reach for IKEPs of up to fifteen countries.

Our experiments show that using lexicographically minimal maximum matchings instead of ones that only minimize the largest deviation from the target allocation (as previously done) may make an IKEP up to 54% more balanced.

Mathematical Programming for Scheduling Telemedicine Appointments

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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. In this paper, we consider the scheduling of patients' GP and hospital follow-up clinic appointments via three different modes of delivery: traditional face-to-face appointments, video conferencing platforms, and telephone. The solution of the model not only has an impact on satisfying patients and clinicians' preferences, but also could potentially reduce travel for patients and staff.

We present a multi-mode resource constrained project scheduling problem formulation to solve the problem. Our aim is to schedule appointments, while maximising how often the patients' and clinicians' preferences for delivery method are met. We also consider uncertainty in the number of emergency appointments which are added to the set of planned appointments to be scheduled with no associated patient preference.

Once a schedule is generated, we import this into a simulation model which allows for no-shows and lateness to test how well the schedule performs. Performance indicators including clinician idle time, clinician overtime, and patient waiting time are evaluated. These models will then be evaluated with data from a partner organisation in the UK.

A flow-shop problem with a batch processing machine and transportation

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We consider a flow-shop scheduling problem where the first machine is a standard machine and the second machine is a batch processing machine. The jobs are transported from the first machine to the second by a robot. The first machine can run only one job at a time, but the second machine can run a batch of jobs simultaneously. Once batch execution has started, no work can be removed from the secondg machine until the batch is fully treated. The processing time of a batch on the second machine is a constant P, independent of the jobs it contains. The capacity of the batch processing machine is equal to c; that is, it is not possible to combine more than c jobs in a single batch. The execution time of job j on the simple machine in t_j. The capacity of the robot is equal to c; i.e., the robot cannot transport more than c jobs in a single shipment. When the robot arrives at the second machine, all jobs contained in the same sequence define the delivered batch. Several variations of this model have been used in industry and in theoretical studies. Practice has shown, however, that the travel time between machines should be taken into consideration, given its importance in the industry of today. We formulate the problem as a mixed-integer linear program and solve it using the CPLEX solver. Since the problem is NP-hard, we have also proposed two heuristics to solve large instances. Computational results are given to assess the performance of the developed methods.

Strategic Modelling: The Challenges of OR in an Increasingly Data-Driven World.

Professor Nira Chamberlain OBE

With the increase of AI, Machine Learning, Data Science one can argue, the world is becoming more Data-Driven. However, as good as this sounds, there are also challenges. In this Data-Driven World, will there still be room for OR? Will OR become obsolete? In this talk, we will examine lessons from scientific history, where the rise of one discipline does not necessarily lead to the decline of another. It will be argued that it is never right to “throw the baby out with the bath water!” The future bright, the future is OR strategic modelling!

Some mathematical perspectives on microinsurance

Corina Constantinescu

We model the capital of a household from a ruin-theoretic perspective to measure the impact of microinsurance on poverty dynamics and the governmental cost of social protection. We analyse the model under four frameworks: uninsured, insured (without subsidies), insured with subsidised constant premiums and insured with subsidised flexible premiums. Although insurance alone (without subsidies) may not be sufficient to reduce the likelihood of falling into the area of poverty for specific groups of households, our analysis suggests that subsidised schemes can provide maximum social benefits while reducing governmental costs..

Stochastic Runway Scheduling using Simheuristics

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Runway scheduling (also known as "aircraft sequencing") problems involve micromanaging the sequences of landings and take-offs at an airport in order to reduce costly flight delays. The earliest versions of these problems were both static and deterministic, with all relevant information assumed known and unchanging. Under such assumptions one obtains an NP-hard combinatorial optimisation problem, in which the optimal runway sequences depend on required time separations between different aircraft weight classes. In reality, though, the problem is both stochastic and dynamic, as air traffic controllers make decisions based on the latest estimated times of arrival (ETA) for enroute aircraft, weather conditions and other factors that evolve in unpredictable ways over time. In recent years, some progress has been made in applying stochastic programming methods to these problems, but even these methods are usually based on highly simplified problem formulations. In this talk we consider a new problem formulation in which the "system state" at any given time includes hundreds of variables evolving via continuous-time stochastic processes. With conventional dynamic programming methods being out of the question, we consider an approach based on the emerging field of "simheuristics" and demonstrate the advantages of using this approach as opposed to an alternative based on deterministic forecasts.

Approximate Dynamic Programming for the Maintenance of Controlled Network Infrastructure

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When maintaining infrastructure given any potential state of disrepair, we must prioritise the allocation of resources such that the long-run cost of both using and maintaining the network is minimised. This presents us with a sequential decision making problem, where given the current state of the network, we want to decide which links should be under repair. These decisions must incorporate our understanding of the dynamics of the system, such as the rates of breakages and the times for repairs to be completed, and the uncertainty surrounding occurrences of these events. We formulate this problem as a continuous-time Markov decision process with a high-dimensional state space and consider the application of heuristics and approximate dynamic programming methods. Our first approach is based on approximate value iteration using a linear value function approximation architecture, and our second approach is based on a one-step policy improvement heuristic. We evaluate the performances of these methods in a simplified setting with one source node, one destination node, and any number of links connecting the two. Results indicate that our methods yield similar performance to exact solutions found using dynamic programming.

This research is being conducted in collaboration with the STOR-i Centre for Doctoral Training at Lancaster University, and the Naval Postgraduate School, Monterey, California.

Dynamic Allocation of Mobile Servers in a Network

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We consider a problem in which mobile "servers" are sent dynamically around the nodes in a network in order to serve demands from customers appearing at random times and locations in the network, with the objective being to minimise congestion-related costs. This type of problem can have many possible applications; for example, in a machine scheduling context, the time needed for a server to travel between two nodes could represent the "set-up time" needed to switch from processing one type of job to another. By using a network formulation, we can model complex relationships in switching times between different types of activity. The problem can be formulated as a Markov decision process, but exact solutions using dynamic programming are not possible due to the complexity of the state space. Heuristics for certain special cases of the problem have been proposed in the literature and in this talk we discuss how to adapt these heuristics to our problem. We also discuss how reinforcement learning can be used to develop improved heuristics and show the results obtained by applying these methods to networks of various different configurations.

Title: A Stackelberg Game for Empty Container Sharing under a Carbon Tax Policy

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Abstract: In the container shipping industry, container sharing between different shipping carriers have been considered as an effective way to reduce the movements of empty containers. Meanwhile, due to rising concerns about climate change and global warming, governments propose to levy the carbon emission tax that may suppress the demands for container shipping. This research develops a Stackelberg game model to investigate how container sharing in the maritime industry may be affected by the carbon tax imposed by governments. In the game, as the leader, the government's decision is to maximise social benefit by setting up the best carbon tax rate; while, as the followers, shipping carriers aim to design a mechanism of sharing containers to achieve container supply chain coordination under the government's carbon tax rate. It has been found that the carbon tax can affect carriers' profits positively or negatively and thus it is the dominant factor affecting the system coordination. However, even if the government introduces a carbon tax rate, a revenue sharing contract still can make a container sharing supply chain coordinated as long as the parameter in the contract is appropriately set.

Keywords: Stackelberg game; Carbon tax; Coordination; Revenue-sharing contract

An Introduction to Semiparametric Choice Models

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Discrete choice models play an important role in numerous applications such as route choice modelling in traffic research, product assortment and pricing in revenue management, and policy planning in health care. In this talk, we will discuss semiparametric choice models which can be built without specifying the full distribution of product utilities. We observe that semiparametric models provide good alternatives in many ways to the traditional approach that use random utility theory.

Utilising SimPy and Process Mining to Develop an Automated Symbiotic Simulation

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Significant improvements in computing power has led to the application of simulation models being used for short-term, operational decision making, known as symbiotic simulation. Unlike traditional simulation methods, symbiotic simulation is designed to be run by decision makers, without the presence of the modeller. Furthermore, these models are to be used indefinitely. However, the system that is being modelled can change over time, potentially leading to the simulation model becoming inaccurate and thus redundant. The research presented proposes a method to address this problem through constructing a generalised simulation model and using process mining techniques on the system data to structure the pathways of the simulation. Instead of using specialised simulation software, where models explicitly define the routes of entities in the system, the Python simulation package SimPy is used, and the model is structured on the processes resources in the system can perform. This allows for the entities' pathways to be separated from the main simulation model, and instead be included as parameters, determined through process mining. This method is applied to an emergency department of a hospital, which changed structure significantly to accommodate the COVID-19 pandemic.

Pricing Optimisation for Car Share Schemes

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Shared car services are one of the solutions being developed in the move towards a more sustainable transport system. The aim of car share schemes is to maintain the accessibility and flexibility of privately owned cars while reducing the overall number of cars in service, hence going some way towards reducing the carbon footprint of driving. We consider the problem of how much to charge users for hiring cars, using optimisation of both queueing and simulation models to develop dynamic pricing strategies for car share providers. The aim is to develop a pricing scheme for car sharing that allows it to be financially sustainable but still attractive to consumers.

Empirical Evaluation of Simulation-based Digital Twin Decisions

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A digital twin is a model of a system that uses real-time data to keep up-to-date with the real system it is modelling. They can be used for real-time decision making and have a wide variety of applications. Some digital twins make use of stochastic simulation, in areas including port operations and supply chain management. The research is usually from an applied or computational stance, with statistical considerations largely ignored. An example of the problems that arise is whether we can actually say if the digital twin is leading to better decisions being made. There are (at least) two issues that make this problem hard. Firstly, for random systems, one may make the "optimal" decision but still end up with a poor result, or vice versa. Secondly, as the digital twin adapts to the current circumstances, each problem it is asked to solve may be unique. So, can we come up with a statistically sound method for evaluation? This presentation will introduce this issue and describe a statistical method for to approach it.

TWO-ECHELON DISTRIBUTION NETWORK DESIGN WITH COLLABORATION AMONG CARRIERS

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Keywords: distribution network design, two-echelon supply chain, collaborative supply chain, location-routing, mixed integer programming, cut-generation

Globalization, exponential growth of e-commerce and q-commerce industries, changing market habits and increased need of logistics services result in high competition among supply chain pillars. Collaboration is an effective strategy to pursue in this endeavor. We define a two-echelon distribution network design problem in which parties can collaborate to complete the last-mile delivery requests in the lower echelon. The objective is to minimize costs which arise from facility opening, transportation and transfer of goods between regional depots. In the upper echelon, goods are transferred from plants to regional depots via direct transportation. In the lower echelon, goods are delivered to the customers in a milk-run fashion from regional depots. We develop three mixed-integer linear programming models which differ in terms of modelling outbound routing decisions. Several valid inequalities are proposed to strengthen formulations. To solve a traditional vehicle-based formulation, a cut-generation based method is developed. For the path-based formulation, a heuristic route pool generation procedure which promotes collaboration is developed. Proposed models are tested with different problem sizes to examine solution qualities and computational times. Moreover, models are tested under different collaborative network settings in which main parameters of the problem such as number of common customers, demand amounts and number of common depots are varied in order to explore managerial insights such as savings due to collaboration.

Mobility as a Service: Personalised multi-modal journey planning and optimisation

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Mobility as a Service (MaaS) is a term coined for the development and implementation of multi-modal trip planner recommendation systems. Most current trip recommendation systems provide lists of single mode trips, often including, just walking, just buses or by rail. Things become more complicated when trips can include multiple transportation modes, and customer preferences and budgets are considered. Multi-modal journeys can include both fixed schedule transport and on demand transport (e.g., car followed by a bus, as in park and ride). MaaS has the potential to make public transport more convenient and attractive, and as a result, reduce negative externalities, such as emissions and congestion. In this research, we propose an exact journey planning algorithm, namely an enumeration algorithm with pruning and a fast constructive heuristic, which is augmented with a range of diversification and intensification mechanisms. The exact and heuristic procedures are compared using a series of Manhattan and random structure transport networks, and the results are evaluated in terms of solution time, optimality gap, shortest paths, Pareto set size, and the range of multi-modal journeys generated for commuter queries.

Handling User-based Relocations in One-way Carsharing Systems Considering User Acceptance Rates

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Although one-way carsharing systems allow users the flexibility to use the different pick-up and drop-off stations, these systems experience serious mismatches between vehicle supply and trip demands at stations during their operations. Therefore, vehicles are relocated among the stations to accommodate the spatial and temporal characteristics of the demand. As relocation operations require personnel involvement, having vehicles (and available parking spots) at the right place at the right time comes with a considerable cost. One other way to reduce the relocation activities and the associated cost with them is by giving incentives to the users to make alterations in their original trip requests and manage the spatio-temporal demand asymmetries.

In this paper, we introduce a reservation-decision framework that determines the offer (both incentives and route) made to the users at each request. The framework consists of a simulator and a mixed integer linear programming (MILP) model, which aims to maximize the expected profit while considering the acceptance probabilities of the offers. Due to the computational complexity of the proposed MILP, we present graph spanner-based heuristic algorithms that efficiently solve large-size problems. We have conducted a case study using real-life system data from Nice, France. The results suggest that incorporating user flexibility can significantly reduce the need for relocation and improve profitability.

A Construction Heuristic for a Time-Constrained Mixed-Mode Two-Echelon Vehicle Routing Problem With Scheduling

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Pathology sample collections in the UK's National Health Service (NHS) are typically fulfilled by a fleet of traditional light goods vehicles (vans/trucks), but there is growing interest in improving both (i) the environmental impact of deliveries, under the NHS's net zero plan; and (ii) the quality of patient care, as a result of collection-to-delivery times.
Vehicles currently operate in fixed periods (e.g., a morning shift, an afternoon shift), collecting samples from a given set of surgeries before delivering them to a central hospital laboratory for analysis; however, operations result in significant greenhouse gas emissions and improvement opportunities in terms of delivery times.
By introducing in-vehicle time constraints (suggested in literature), and multiple modes over two-echelons, this paper explores the use of an adaptation of the Clarke and Wright Savings Algorithm to construct solutions that leverage the benefits of different modes, including vans, drones, and cargo cycles. Optimising to cost, routes are constructed based on an upper bound of travel times before then being scheduled into fixed-length shifts using an adapted bin packing algorithm in each iteration.
Presented using a case study in the Solent region of the UK, where investigations into drone deliveries are being conducted, the algorithm produces reasonable solutions quickly to allow planners to understand how different scenarios might perform.
Furthermore, potential developments of the construction heuristic are discussed, including its use in different scale use cases/problems, or as part of into an online routing problem in which issues that can disrupt plans, such as traffic or weather, can be quickly integrated into the solution.

The Role of Direct Cash Transfers Towards Extreme Poverty Alleviation - An Omega Risk Process

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Abstract: Trapping refers to the event when a household falls into the area of poverty. Households that live or fall into the area of poverty are said to be in a poverty trap, where a poverty trap is a state of poverty from which it is difficult to escape without external help. Similarly, extreme poverty is considered as the most severe type of poverty, in which households experience severe deprivation of basic human needs. In this article, we consider an Omega risk process with deterministic growth and a multiplicative jump (collapse) structure to model the capital of a household. It is assumed that, when a household is not trapped, its capital surplus grows exponentially, whereas once trapped, the capital grows linearly only due to the external support of direct transfers (cash transfers) of money provided by donors or governments. Under this model, we derive closed-form expressions for the probability of extreme poverty, which only depends on the value of the capital at that time given by some extreme poverty rate function. For different extreme poverty rate functions, we present numerical examples to illustrate the role of cash transfers on extreme poverty dynamics.

Understanding the demand for inclusive insurance: a pilot study in Canada

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Abstract: In this paper, we examine survey data from low- to mid-income households residing in Canada on (i) risks and risk-management strategies, (ii) insurance knowledge and use, (iii) financial practices, (iv) health information, and (v) socio-demographics. Our goal is to assess gaps between the risks faced by low-income individuals and the risk-mitigation mechanisms available to them to ascertain the potential benefit of microinsurance or inclusive insurance in Canada.

Based on some of the key messages of our empirical analysis, comprising the estimation of the probability of buying insurance as well as the estimation of the willingness to pay (WTP) for insurance, risk comfort and trust are two important factors. Specifically, the risk comfort index, which combines the belief that the probability that a risk event occurs is low with the perception that the consequences of risk events are manageable, is a critical factor in both the decision to buy insurance and the WTP decision. However, other factors are at play in the WTP decision, most importantly how people feel about insurance: a benign view of insurance, which reflects an appreciation for and trust in insurance, tends to increase WTP, while a malign view of insurance, which reflects distrust in insurance, tends to decrease WTP.

The main implication of the WTP analysis as to the benefit of microinsurance options lies in the prospect that they promote a more positive view of insurance companies, appealing to concepts such as social business, a consumer-centred approach, and corporate social responsibility.

A Machine Learning Approach for Micro-Credit Scoring

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Abstract: Mathematical modelling of loan cashflows in microfinance is more involved than modelling comparable defaultable cashflows in traditional financial markets. Microloan customers often have no credit history recorded with a third party and no collateral. Hence pricing these loans fairly, determining correct interest rates, assessing customer creditworthiness and the resulting segmentation of customers is quite challenging. The research presented here compares various machine learning algorithms on real micro-lending data to test their efficacy at classifying borrowers into various credit classes. We pose credit scoring as a multiclass classification problem, using readily available data about customers (such as their age, loan amount, charged interest rate and marital status) as inputs and using arrears information to define the credit classes. We demonstrate that off-the-shelf multi-class classifiers such as random forest algorithms can perform this classification task very well, yielding about 80% classification accuracy on validation data. Our results present an inexpensive and reliable means to microlending institutions around the developing world with which to assess the creditworthiness of customers in the absence of credit history or central credit databases.

Microfinance interest rates: Using mutually excited processes to determine microfinance loan and portfolio risk

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Our work addresses a gap in the academic literature regarding modelling problems of non-collateralized defaultable cash flows where a default is defined as multiple missed repayments (as in a microfinance loan). We propose a theoretical framework to study the impact of self and cross-excitation shocks of missed repayments within a portfolio of microfinance loans. We adopt a multivariate setting where the credit default intensity is driven by a mutually exciting jump process, commonly referred to as the Hawkes process. This allows us to capture the clustering effect of missed repayments across time.

We implement the Hawkes process to derive the credit default spread for each individual loan. This methodology offers the tractability to price individual loans under a risk measure adapted to incorporate a repayment feedback mechanism in which the probability of default is affected by missed repayments.

To our knowledge, ours is the first rigorous approach focused on pricing defaultable cash flows specific to microfinance, with dependencies in repayment behavior (both across time and customer classes). Our research provides theoretical groundwork for a detailed simulation model of cashflows for a microfinance institution (MFI), with potential applications in measurement and mitigation of risk arising from a portfolio of microfinance loans.

Smart products and R&D: effects of the option to update

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This paper considers the problem of a monopolist that can invest in R&D to improve the quality of a smart product (e.g., AVs). A higher quality directly results in a lower frequency of incidents caused by the AVs. The R&D process is uncertain both in terms of duration and outcome. In addition, the firm holds two (nested) options: the option to launch the product on the market and the option to update the product after launch. The firm chooses not only the timing to exercise its options, it also chooses its R&D intensity and production capacity size. We analyze the problem of the firm as well as the impact of measures by a regulator. In particular, we are interested in the impact of the option to update, and safety regulation, on the firm's R&D and investment strategy as well as the impact on the accident rate.

Game options under proportional transaction costs

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A game option is a contract between an option buyer and seller, which allows the buyer the right to exercise the option, and the seller the right to cancel the option at any time up to expiry. The payoff associated with this option is due at the earliest of the exercise and cancellation times. If the option is cancelled before it is exercised, then the buyer also receives additional compensation from the seller. Game options is an application of Dynkin stopping games to finance.

In this talk we will consider game options in a technically simple discrete-time model. We will discuss efficient ways of determining optimal hedging, cancellation and exercise strategies, as well as computing option prices.

When proportional transaction costs on trading in stock is introduced, the probabilistic dual representations for the bid and ask prices, curiously, involve probabilistic dual representations involve randomised (or mixed) stopping times. This leads to the study of a variant of game options where gradual exercise and cancellation is allowed, with increased flexibility in hedging, and hence tighter bounds on the option price as compared to the classic case.

Strategic Investment under Uncertainty: Second Mover Advantage in Duopoly

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We study a strategic duopoly investment game. Initially the firms are potential entrants. The decision to enter implies choosing the optimal timing and size of a capacity investment. The literature until now typically admits a linear demand structure, and then finds that a preemption equilibrium exists. Our main message is that, when replacing the linear demand function by an iso-elastic one, a second mover advantage can arise. This especially occurs in case of high demand uncertainty, a low discount rate, a high market trend and a high demand elasticity. The second mover advantage could imply inefficiently long waiting with investment.

The Impact of Ambiguity over Signal Quality on Optimal Investment Timing and Welfare

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A decision maker has the opportunity to invest in a venture and, prior to investing, she receives signals pertaining to the likely outcome. However, she is ambiguous over how reflective they are over the true outcome; i.e., their quality. The decision maker is averse to this ambiguity and determines her optimal investment strategy over the worst possible outcome. I show that, while the investment threshold decreases in the extent of ambiguity, so too does the probability of investment. I further show that the investor's welfare also decreases in the extent of ambiguity and, to that end, ambiguity should be reduced to improve welfare. To address this, I adapt the model to account for learning about ambiguity over signal quality and derive a threshold on the ambiguity level over when to stop learning so that for all levels of ambiguity above this threshold, the decision maker should not invest irrespective of her belief in the expected outcome.

Unmanned Aerial Vehicles: Opportunities for Operational Research

Joerg Fliege

Swarms of unmanned aerial vehicles often operate in dynamic environments in which given information changes over time and new information only becomes available locally. This necessitates the use of distributed computational frameworks and optimisation models that take uncertainty into account. In addition, most UAVs do not operate fully autonomously: they have to communicate with each other or with a group of remote pilots. This increased complexity is reflected in additional decisions that have to be taken with respect to the usage of the electromagnetic spectrum (EM) for communication by the UAVs. In this talk we discuss the corresponding challenges and opportunities and provide examples for such OR problems in the realm of defense. In defense, judicious use of EM resources is particularly important, as adversaries and own forces will attempt to intercept, spoof, and jam electronic communications in a highly dynamic and rapidly evolving environment.

A Mathematical Programming Formulation for the Walking School Bus: Bradford Case Study

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School commuting is crucial in modern societies, considering its impact on the travel choices for parents, and the travel behavior of the young generation. It is important to use sustainable transport modes for school commuting, in order to reduce traffic and engage children in active travelling. The Walk to School Bus (WSB) has been recognised as means to achieve this goal. The WSB involves a group of children lead by adults walking on defined routes with pre-determined stops for picking-up children and walk them to the school destination. This problem has recently attracted the research community.

The WSB is a difficult routing problem with multiple conflicting objectives. It comprises several sub-problems that are also hard such as the route design and leaders rostering and scheduling. This makes it an interesting real-world problem for optimisation research. Our goal is to design an optimisation tool to find the optimal route set based on multiple criteria on targeted areas for applying the WSB.

Our focus on this study will be on the route design aspect and allocating potential stops for picking up/dropping children. We develop a mathematical model that aims to find the optimal walking routes based on the following objectives: travel time, pollution dose, and walkability, where we define the walkability as the factors that affect the quality and comfort of the walking experience. Our work is pioneer in proposing an in-depth description for the WSB mathematically, defining its constraints, and developing mathematical formulations for modelling a realistic version of a WSB.

Our preliminary results are given based on road network data from the city of Bradford in the UK. We convert the road network to a walking network on which the routes are defined. We prove that our implementation is general and can adapt to any case of city or school.

Exploring the Optimal Camera Placement Problem and its Relationship with the Set Covering Problem

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Optimal Camera Placement (OCP) is the process of finding the optimal locations and orientations of a set of cameras, where the objective can be to maximize the coverage of a given surveillance area or to minimize the total cost of the selected cameras. This should be achieved while ensuring that a given set of constraints such as specific point coverage, camera budget, camera quantity, and other case-specific restrictions, are satisfied. In some studies, this problem has been formulated in a way that resembles the formulation of the Set Covering Problem (SCP). This similarity has not been explicitly discussed in the literature until recently. Therefore, this paper studies the OCP problem by exploring its literature and understanding its relationship with the SCP. Furthermore, the aim of this study is to find techniques from the SCP literature that can be used to deal with the OCP problem. More specifically, this study focuses on exploring a variety of instance reduction techniques that were studied in the SCP literature to reduce the size of a problem. Since OCP is an NP-hard problem, which means it can be time consuming to solve some large instances using exact methods, reducing its size can significantly reduce the amount of time needed to provide optimal solutions. This study proves this by providing a comparison between the results of some instances and the reduced version of these instances.

Walking School Bus Line Routing for Efficiency, Health and Walkability: A Multi-objective Optimisation Approach

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Walking School Bus (WSB) has been recognised as an innovative solution to promote walking to school, bringing a wide spectrum of benefits, including: health benefits from the physical exercise, social skills and traffic reduction. To facilitate the success of WSBs, one vital element is its route planning, which directly affects the catchment for the service and the realisation of all the potential benefits. Previously, time has been the only factor that has been considered in WSB routing problems. Important factors including air quality, safety and comfort will also be considered in this paper. Air quality along a WSB route is important to help realise the health benefits of walking. Traffic safety has been the biggest barrier to walking to school and must be addressed in planning a WSB route. Ensuring children have an enjoyable and comfortable experience is vital for the sustainability and success of WSB.

A walking network is introduced to enable modelling pedestrian movements in detail, including walking movements on different sides of the road and crossing movements. This approach enables detailed route-based analysis to assess the localised effect of air quality on pollutant dose. We define walkability as a measure of children's needs in safety and comfort, which can also be assessed in detail on each route. We propose a multi-objective optimisation model to generate *efficient* WSB routes with three objectives representing the potential benefits of WSB:~(1) to minimise time;~(2)~to minimise pollutant dose;~and~(3)~to maximise walkability.

We apply our model to a selected school in Bradford in the UK, generating three WSB lines following *efficient* routes. These lines go through a predetermined sequence of ``WSB Stops", with the final stop as the school. All children within the catchment area will be able to join a WSB within 1--2 minutes' walk from their home to the nearest stop.

Augmentation search for integer programmes defined on polyhedra

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This talk will describe a primal search algorithm to optimise an integer programme defined over a polyhedron. The search is conducted on the lattice described by the linear constraints of the model, where search directions are derived in the spirit of Graver bases and are extracted dynamically using a feasibility-seeking black-box. The algorithm is conceptually different to branch-and-bound-type algorithms as it does not need to resort to branching. Computational results will be presented to show the potential of the algorithm, particularly on 0-1 programming formulations with complex objective functions.

On Upper Bounds for the Multiple Knapsack Assignment Problem

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The *Multiple Knapsack Assignment Problem* (MKAP) was introduced by Kataoka and Yamada [1]. In the MKAP, we have m knapsacks and n items. The i-th knapsack has a capacity c_i. The j-th item has a profit p_j and a weight w_j. Moreover, the set of items is partitioned into r subsets or classes. Each knapsack can contain items from at most one class. The task is to assign each knapsack to a class, and to select a set of items of maximum total profit, such that the total weight of the items assigned to any given knapsack does not exceed the capacity of that knapsack.

The MKAP has applications in the purchasing of goods and their subsequent transportation by air, rail or water. It includes the *Multiple Knapsack Problem* (MKP) as a special case. Since the MKP is strongly *NP*-hard [3], the same is true of the MKAP.

We prove three results concerned with *upper bounds* for the MKAP. First, we show that a bound due to Kataoka and Yamada can be computed in linear time. Second, we show that some bounds due to Martello and Monaci [2] dominate the Kataoka-Yamada bound. Third, we define two even stronger bounds, and show that they can be computed in pseudo-polynomial time.

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Approximating integer programs with monomial orders

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We consider the problem of maximizing a function over integer points in a compact set. Inner- and outer-approximations of the integer feasible set are obtained using families of monomial orders over the integer lattice. The convex hull is characterized when the monomial orders satisfy some properties. When the objective function is submodular or subadditive, we provide a theoretical guarantee on the quality of the inner-approximations in terms of their gap to the optimal value. An algorithm is proposed to generate feasible solutions, and it is competitive with a commercial solver in numerical experiments on benchmark test instances for integer LPs.

Rostering staff with network design models

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Processing of multiple different materials is often done at sequential sorting facilities. In these facilities, different types of commodities need to pass through multiple different work areas in order to be sorted. Miss-setting staff levels in these facilities is a big problem, due to upstream delays affecting downstream processing times. The deterministic case of these problems can readily be modelled as network design problems. However, often the staffing decisions need to be made before all information is known. Here we present out work on using network design problems to staff these facilities. We show results from the deterministic case, as well as our work using stochastic programming to deal with the uncertainty. In addition, we talk about the different techniques we use to reduce the computational complexity of these models. We demonstrate our findings, using a mail sorting centre as an example facility.

Integrated forecasting and inventory management for perishable products in retailing

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Recent studies have caught attention to the large amounts of food wasted in retailing. Food waste can be reduced by better matching supply and demand. We investigate a retail chain that owns several stores and keeps inventory at the stores and at a central warehouse.

The inventory policy must include order quantities for the warehouse and stores, and an inventory allocation policy between stores when stocks are limited. Demand is stochastic and non-stationary.

We propose a data-driven approach that integrates demand forecasting and inventory optimization by determining the optimal policy parameters as a function of exogenous variables such as price, weekday, and weather. Using historical demand and feature data, we formulate a mixed integer linear program and test its performance when relaxing different constraints. We then use a Retrospective Optimization and Gradient Search algorithm to solve the full problem.

We test our approach with generated data for different cost parameters and levels of demand variance. We also collected hourly and daily sales data from a large European retail chain over a time horizon of more than six years. We show that our approach outperforms the standard constant basestock inventory policy by 8.9% on average.

Packing and routing: an integrated model

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In real-world distribution problems, the "packing" and "routing" decisions are usually required to be considered simultaneously, and the overall cost is more of interest to the decision maker than the individual costs. However, in early works in the field of OR, these two procedures are often treated independently. We argue that, since the packing is normally considered a priori the routing, it is difficult to take destination information into account during packing. As consequence, poor packing decisions might impact the routing in an unexpected way, possibly leading to sub-optimal solutions. To overcome it, we propose a rich and realistic formulation of an integrated packing and routing model. We show analytically that the solution of our integrated model is different from that of the traditional separated packing and routing model, achieving lower overall cost in most cases. Moreover, we propose a set of constructive heuristic algorithms as solution methods. Each algorithm is tested separately under extensive experiments. Finally, we consider the possibility of selecting algorithms in an automated fashion.

Solution approaches to the three-index assignment problem

Mohamed Mehbali

Abstract

The axial three-index assignment problem (3IAP), also called the axial multidimensional assignment problem, consists of allocating *n* jobs to *n* machines in *n* factories such that exactly one job is executed by one machine in one factory at a minimum total cost. This combinatorial optimisation problem is an extended version of the classical two-dimensional assignment problem. Kadhem (2017) developed the diagonals method (DM) as a heuristic for solving 3IAP.

This paper builds on the DM heuristic and considers tie-cases in the form of three variants. Furthermore, by exploring some characteristics of the cost matrices, two new classes of heuristics for solving 3IAP are devised. Numerical experiments show that the proposed heuristics outperform DM and always guarantee in polynomial time good feasible solutions. Further, two efficient methods are suggested to achieve optimal solutions for 3IAP in competitive computational times.

Keywords: *Multi-index assignment problem, Hungarian algorithm, heuristic, branch-and-bound method.*

Distributed Algorithms for U-statistics-based Empirical Risk Minimization

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Empirical risk minimization, where the underlying loss function depends on a pair of data points, covers a wide range of application areas in statistics including pairwise ranking and survival analysis. The common empirical risk estimator obtained by averaging values of a loss function over all possible pairs of observations is essentially a U-statistic. One well-known problem with minimizing U-statistic type empirical risks, is that the computational complexity of U-statistics increases quadratically with the sample size. When faced with big data, this poses computational challenges as the colossal number of observation pairs virtually prohibits centralized computing to be performed on a single machine. This paper addresses this problem by developing two computationally and statistically efficient methods based on the divide-and-conquer strategy on a decentralized computing system, whereby the data are distributed among machines to perform the tasks. One of these methods is based on a surrogate of the empirical risk, while the other method extends the one-step updating scheme in classical M-estimation to the case of pairwise loss. We show that the proposed estimators are as asymptotically efficient as the benchmark global U-estimator obtained under centralized computing. As well, we introduce two distributed iterative algorithms to facilitate the implementation of the proposed methods and conduct extensive numerical experiments to demonstrate their merit.

A Multi-Target Dynamic Scheduling Approach for VTOLs Involving Piecewise Linearization of Value Functions

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Originally developed in the middle of the past century, vertical take-off and landing vehicles (VTOLs) have recently gained new momentum thanks to progressive concepts newly developed in various scientific fields. These aircraft possess unique properties: they are comparatively small, highly maneuverable and can be universally deployed since they do not require any runways for take-off and landing. Integration of electric motors instead of conventional ones implies in additiontheir environment-friendliness. Due to these characteristics, VTOLs are extensively used in severalindustries. Urban air mobility, agricultural sector, logistics, supply chain management or search-and-rescue scenarios are only a few examples where unmanned aircraft play a key role.

Because of a growing number of VTOLs in use, their safe and efficient management becomes a crucial issue. We propose a technique for dynamic scheduling of multiple VTOLs (up to eight) heading to many different target regions. Each VTOL is hereby supposed to fly to exactly one region. The whole setting is mathematically described by a mixed-integer bilevel optimization problem. The upper level problem is in charge of scheduling all VTOLs, while the lower level one provides the shortest path for each of them. To solve the latter problem, we exploit a value functionapproach originating from dynamic programming and the Kruzkov transformation. The bileveloptimization problem is then recast into a nonlinear single-level one, linearized using an advancedpiecewise-linearization technique and numerically solved by a robust and fast mixed-integer linearsolver.

Based on our previous research work, we extended the previously developed numerical framework for tackling scheduling and optimal path planning tasks for multiple VTOLs and multiple target regions. Preliminary results show the feasibility of this sophisticated approach. Nevertheless, the model can be still improved to reduce the number of binary variables and therefore the computational time.

An evolutionary heuristic for solving the robust single airport slot allocation problem

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We propose an evolutionary heuristic method for solving the robust single airport slot allocation problem. The proposed method aims to discover a new solution by applying one or several mutation procedures to the current best solution. The best solution is defined by a fitness value that covers constraints violation parameters and allocation properties. Constraints' violation parameters control the feasibility of the solution. Such structural aspects allow us to move towards acceptable results after each evolutionary iteration. Allocation properties work in a similar manner but defining a solution quality via indicators measuring slot allocation objectives used in the literature, such as, total displacement, maximum displacement, number of rejections, and number of displaced requests.

The method's implementation has a flexible design providing the range of parameters that can be set to change the algorithm's way of work. The benchmarking is done for different number of iterations, different weights of fitness function components, list of allowed mutations (for both equivalent and different mutation probabilities), and number of mutations per iteration. The efficiency of the method is analyzed from both computational complexity and direct performance comparison to the exact method. The results show that heuristic methods adjusted for the problem structure could be used as a general replacement for exact approaches which require an enormous amount of time to solve even some small size instances.

A Hyper-Heuristic Algorithm for Airport Slot Allocation

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In this work we propose a selection perturbative Hyper-Heuristic (HH) algorithm for solving the single airport slot allocation problem considering the optimization of the efficiency of the allocation of slots, i.e. minimization of the sum of the absolute differences between the requested and allocated time intervals of all requests. The proposed HH method adheres to the WASG (2022) regarding the prioritization of the satisfaction of different types of slot requests and considers the season wide scheduling of series of slots. The proposed approach consists of a constructive and a perturbative phase. We propose and implement a pool of constructive heuristics that produce an initial feasible slot allocation in short computational times. The perturbative phase improves iteratively the efficiency objective by utilizing a pool of low-level heuristics grounded in the 'Destroy and Repair' rationale. We provide utilization analysis of the incorporated low-level heuristics to demonstrate their contributions during the solution process. Real world data from a coordinated airport are used to demonstrate the use of the proposed algorithm.

Survey of Some Subdivisions and Triangulations of Polytopes

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Abstract: The set of solutions to a *Linear Program* (LP) is a convex polyhedron that is formed by a given system of linear equations and inequalities. *Vertex Enumeration* (VE) algorithms are used to determine some or all of the vertices of such polyhedra. These algorithms have several applications, such as computing near-optimal LP solutions, performing parametric analysis of LPs, solving bilinear or concave minimization problems, and analysing two-person bi-matrix games. Moreover, by duality, VE algorithms can be used to compute the convex hull of a given set of points in R^n, a problem which has applications in integer programming and combinatorial optimisation.

For general polyhedra, the problem of enumerating all vertices has been shown to be NP-hard (Khachiyan et al., 2008). Nevertheless, there exists some reasonably effective algorithms, and several useful software packages (cdd, PORTA, Polymake and so on). Our goal is to find even faster algorithms. To this end, we review some properties of *subdivisions* and *triangulations*. (A subdivision is a partition of a polytope into a finite number of smaller polytopes of the same dimension. A triangulation is a subdivision in which each of the smaller polytopes is a simplex.) We present some new results on triangulations, and show some results that can be used for VE (in the dual version). In particular, we establish that all regular subdivisions are “shellable”. Our algorithms have been implemented in FORTRAN and we hope to compare them with PORTA, Polymake and so on, using Travelling Salesman and cut polytopes as examples.

Keywords: Convex Polytopes, Convex Hull, Triangulations

Notes on the use of data transformations in DEA

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Data transformation refers to the modification of any point in a data set by a mathematical function. When applying transformations, the measurement scale of the data is modified. Data transformations are commonly employed to turn data into the appropriate form, which can serve various functions in the quantitative analysis of the data. This study addresses the investigation of the use of data transformations in Data Envelopment Analysis (DEA). Although data transformations are important options for analysis, they do fundamentally alter the nature of the variable, making the interpretation of the results somewhat more complex.

Keywords: Data transformation; data envelopment analysis; undesirable data; negative data; interval scale; ratio scale

Mathematical models for irregular packing problems

[1]*Julia Bennell

Cutting and packing has been a recognised research area in OR for over 60 years. Many problems can be solve to optimality efficiently and at a reasonable scale, while other problems remain challenging. In some cases, the challenge resides in certain problem instances, for others it is more critically that problem types cannot be solved at any useful scale. One particular class of problem that this applies to is packing arbitrary shaped items. Models that address these problems are strongly defined by how the geometric properties of the items are represented. Among the adopted approaches, models either compromise the fidelity of the item, or contain non-linear constraints, or can only model part of the solution space. This is an open problem with lots of opportunity for research. In this talk, I hope to encourage optimisation researchers to engage with these problems.

Survey of Some Subdivisions and Triangulations of Polytopes:

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We review some subdivisions which are triangulations of finite sets of points V_i of the convex hull of set V of vertices into polytopes $\{P_1, P_2, \ldots\ldots\ldots\ldots, P_n\}$. We present properties and results of some triangulations of convex polytopes.

***Key words*:** *Affine Space, Convex Hull, Subdivisions, Triangulations, Convex Polytopes*

Online Restaurant Meal Delivery Problem with Order Bundling and Assignment Fairness

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Online food ordering is well-developed nowadays, with many people choosing to order their meal online and waiting at home instead of going to a restaurant. We consider a dynamic online restaurant meal delivery problem (ORMDP) where a pool of drivers deliver food from multiple restaurants to ordering customers. The objectives are to reduce both delivery delays and unfairness for drivers. In practice, order delays increase significantly when the demand for orders is high relative to the number of available drivers. To address this issue, we consider the ORMDP as two sub-problems, order bundling and order assignment. First, we implement an order bundling policy (OBP) that gathers orders with similar characteristics into a single group within drivers' capacity which is then assigned to a driver instead of assigning each individual order to a driver, respectively. Second, we propose an order assignment rule to allocate the groups to drivers considering both delay reduction and fairness to drivers. Finally, we develop a discrete-time simulation model with single and multiple restaurants to test our method using both synthetic data and public data. The experimental results show that order bundling and fairly assignment improves the delivery service in ORMDP.

How hybrid learning increases the size of educational timetabling problems but not the difficulty.

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Before the invention of the internet, the standard university experience only involved in-person teaching. In 2023, events can be held completely online. These events can also be held in a hybrid format where participants of the meeting can be at a designated physical location or access the meeting remotely.

In educational timetabling, there is a problem known as the University Course Timetabling Problem (UCTTP) which involves assigning events and people to resources. These resources typically include fixed timeslots when events can happen and spaces where events can happen.

Allowing one of these spaces to be the online setting increases the size of the UCTTP by increasing the number of decisions that need to be made as well as further constraining the resulting assignment.

We first formulate an MIP representing a simplified version of the UCTTP based on common features in the literature. Then we show one way that this simplified model can be modified to include the new decisions and constraints introduced by considering hybrid learning. This second step producing a new MIP model.

It is difficult to assess to what extent including a new feature in a timetabling model will change the size and complexity of the problem. By comparing these two simplified models we can for the first time gain some insight on how incorporating hybrid learning impacts the timetabling problem. We find that the hybrid problem has more variables and constraints. When using a modification of popular benchmark data, we also find the hybrid problem takes longer to solve.

We show these increases in size and solution time are small compared to the size of the non-hybrid UCTTP concluding that incorporating hybrid learning results in a model that better represents the real-world problem without being much harder to solve.

Insertion Heuristics for a Class of Dynamic Vehicle Routing Problems

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We consider a simple family of dynamic vehicle routing problems, in which we have a fixed fleet of identical vehicles, and customer requests arrive during the route-planning process. For this kind of problem, it is natural to use an insertion heuristic. We test several such heuristics computationally, on two different variants of the problem. It turns out that a parallel heuristic, based on a certain "sum-of-squares" insertion criterion, significantly outperforms the others.

A new data-driven uncertainty set using clustering

Alireza Yazdani Esfidvajani
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We propose a new data-driven technique for constructing uncertainty sets for robust optimization problems. The technique captures the underlying structure of sparse data through volume-based clustering, resulting in less conservative solutions than most commonly used robust optimization approaches. This can aid management in making informed decisions under uncertainty, allowing a better understanding of the potential outcomes and risks associated with possible decisions. The paper demonstrates how clustering can be performed using any desired geometry and provides a mathematical optimization formulation for generating clusters and constructing the uncertainty set. In order to find an efficient solution to the problem, we explore different approaches since the method may be computationally expensive. This contribution to the field provides a novel data-driven approach to uncertainty set construction for robust optimization that can be applied to real-world scenarios.

Crime-oriented Directional Distances for Measuring and Redistributing Police Production Capacity

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Measuring the productive capacity of public authorities is essential to outline the best strategies for providing efficient services. Planning public security resources from a perspective of maximum efficiency is essential to seek police service provisions with minimal impact on the public budget and infrastructure. This work uses the advances in Data Envelopment Analysis (DEA) and Multiple Criteria Decision Analysis (MCDA) to measure and prioritize police resource allocations over the urban space and time.

The technical efficiency of the police decision-making units is investigated through crime-oriented non-parametric frontier estimations for the evaluation of the police production capacity in the state of Pernambuco, Brazil. The considered discretionary inputs are the number of sworn officers (police officers, deputy sheriffs, and state troopers) and police vehicles. The outputs are firearm apprehensions and red-handed arrests (violent crimes, property crimes, drugs, and illegal weapon possessions). The crime-oriented criteria used for defining directions are violent crime (CVLI), property crimes (CVP), and illegal weapons in each area based on ROC weights in three dimensions (0.6111, 0.2778 and 0.1111).

The results provide police-based measures of police efficiency that can support redistributions on units operating at full capacity. In addition, police ranks according to their production capacity (technical efficiency) on different criminal perspectives, benchmarks for best practices, potentials for improvement, and officers and vehicle resources that can be spared and reallocated are provided as results of this application.

Robust return-risk optimization models with proportional transaction costs

Ebenezer Fifi Emire Atta Mills

This study proposes min-max portfolio optimization models with proportional transaction costs under the worst-case (robust) entropic value-at-risk. The models are reduced to solvable mathematical problems using the duality theorem with the underlying random variables following discrete box and ellipsoidal distributions. Numerical application discusses the impact of transaction costs on the optimal portfolio under the proposed robust return-risk strategies.

Keywords: portfolio optimization, entropic value-at-risk, transaction costs, uncertainty, robust return-risk

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Lower bounds for the permutation flowshop scheduling problem

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The permutation flowshop problem with makespan objective is a classic machine scheduling problem, known to be *NP*-hard in the strong sense. We analyse some of the existing lower bounds for the problem, including the "job-based" and "machine-based" bounds, a bound from linear programming (LP), and a recent bound of Kumar and co-authors. We show that the Kumar *et al.* bound dominates the machine-based bound, but the LP bound is stronger still. On the other hand, the LP bound does not, in general, dominate the job-based bound. Based on this, we devise simple iterative procedures for strengthening the Kumar *et al.* and LP bounds. Computational results are encouraging. In particular, we are able to obtain improved lower bounds for the "hard, small" instances of Vallada, Ruiz and Framinan.

Sergey Sergeev (University of Birmingham, School of Mathematics)

Title: Signed tropicalization of polars and application to matrix cones

Abstract:

We study the tropical analogue of the notion of polar of a cone, working over the semiring of tropical numbers with signs. We show that the tropical polars of sets of nonnegative tropical vectors are precisely sets of signed vectors that are closed and that are stable by an operation of linear combination. We relate tropical polars with images by the nonarchimedean valuation of classical polars over real closed nonarchimedean fields. We show in particular that for semi-algebraic sets over such a field, the operation of taking the polar commutes with the nonarchimedean valuation. We apply these results to characterize images by the nonarchimedean valuation of classical cones of matrices, including the cones of positive semidefinite matrices, completely positive, completely positive semidefinite matrices, and their polars, including the cone of co-positive matrices. We show in particular that hierarchies of classical cones collapse under tropicalization. We finally discuss a simple application of these ideas to optimization with signed tropical numbers.

Joint work with: Xavier Allamigeon, Marianne Akian and Stephane Gaubert (INRIA and CMAP Ecole Polytechnique, France)

Understanding overcrowding

Prof. Dr. G. Keith Still FIMA FICPEM SFIIRSM FIPM FHEA MAE
Visiting Professor of Crowd Science at the University of Suffolk

Recent events (Itaewon, Seoul, South Korea, 156 dead, hundreds injured and O2 Brixton, 2 dead and many injured) highlight the significant risk to life and limb of overcrowding in places of public assembly. For over 30 years, the author has studied the fundamental causes of overcrowding incidents around the world, and how to avoid crowd crushing in places of public assembly. In his work, as a consultant to major events (Hajj, Olympics, Canada Day, Royal Events. New Year Events, as an expert witness in cases involving crowd related injury and death (UK, Europe, and USA) he has a unique insight to facilitate his teaching/training programmes. This short talk covers all aspects, causes, prevention and liabilities for overcrowding and the significant risk to life and limb.

By breaking the risks into a fundamental model of influences on crowd behaviour and phases of crowd behaviour, and using simple mapping and flow diagrams, you can produce a predictive overcrowding model. With this model you can understand the risks of high-density crowds from the site geometry before the crowd enters the environment.

One crucial factor to understand is the limits of crowd density (what is safe or dangerous) and crowd flow. Specifically, exposure to high-density, is the main cause of injury, as the enormous forces involved are life threatening. By showing examples of small, medium, and large crowds we can both educate planners and manage/mitigate high density crowd risks.

Using example video clips, models and simulations, this talk explores the issues of managing crowds in places of public assembly.

Autonomous Navigation of Unmanned Aerial Vehicles (UAVs) for Border Patrolling:A Stochastic Approach

Busra Biskin

Unmanned Aerial Vehicles (UAVs) have become essential tools in modern defence & security operations, offering advantages such as increased mission speed, success rate, and reduced risk to human personnel. This study focuses on employing UAVs in internal safety operations, specifically border patrolling, where rapid information flow, precise navigation, and accurate decision-making are critical. We propose an algorithm for fully autonomous UAV navigation within given constraints and test its effectiveness through simulations of border violation incidents.

In real-life scenarios, border invasions often occur repetitively from the same borderline, making deterministic strategies ineffective for UAVs and intruders. Thus, our main objective is to develop a stochastic strategy for UAV navigation that minimises the mission completion time while simultaneously maximising the probability of mission success, considering the uncertainty in the intruder's movement. We model the movement of UAVs and intruders via simulations in various scenarios and solve the resulting optimisation problem using a response surface methodology employing radial basis functions.

The developed algorithm and mathematical model have broad applicability in real-life situations where little or partial information about intruders' movement is available, such as disaster management and defence. Our research contributes to the field of mathematics in defence and security by providing a novel approach to the autonomous navigation of UAVs for border patrol, enhancing the capabilities of UAVs in safeguarding national borders and ensuring internal safety.