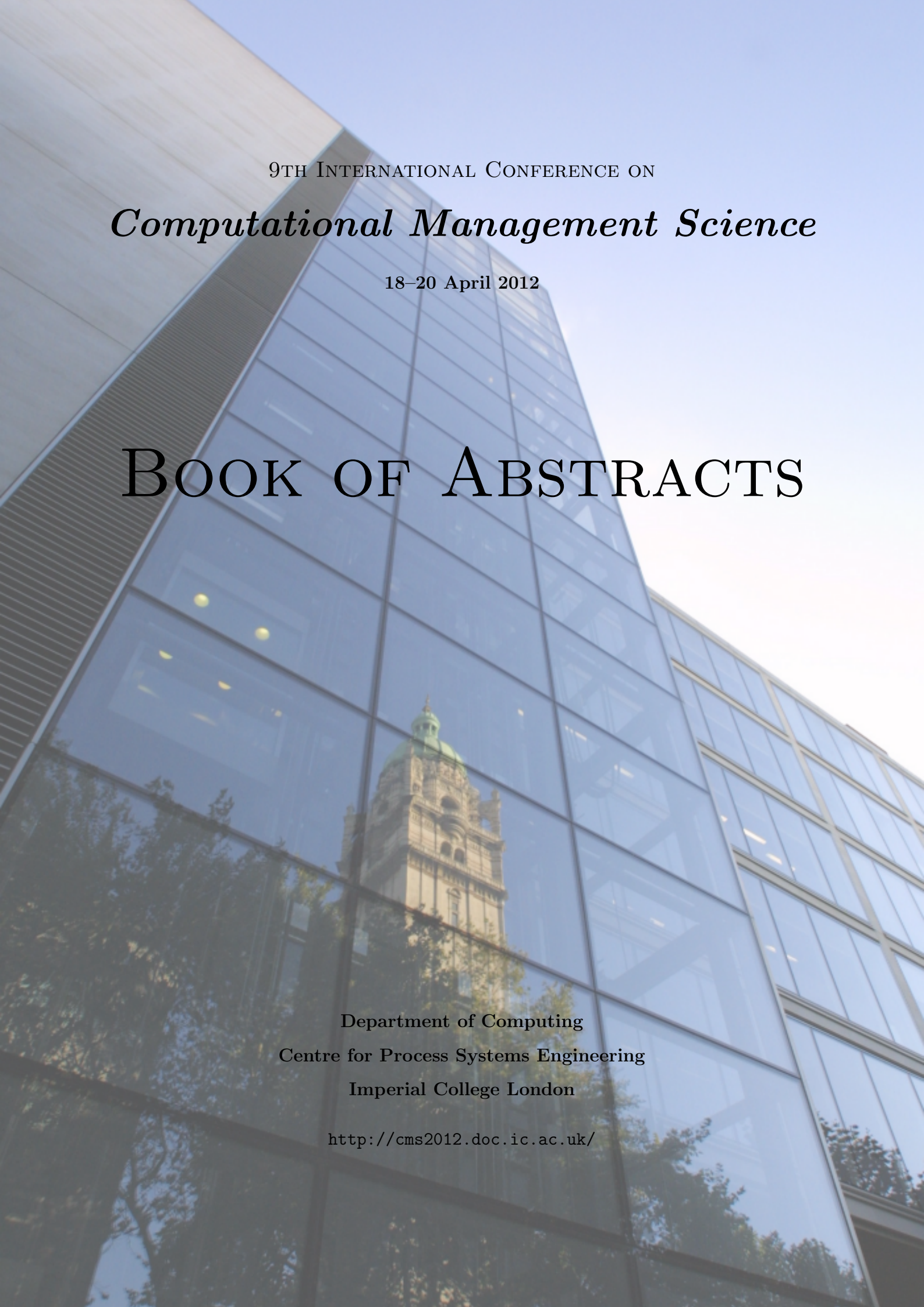

9th International Conference on

Computational Management Science

18–20 April 2012

Book of Abstracts

Department of Computing

Centre for Process Systems Engineering

Imperial College London

http://cms2012.doc.ic.ac.uk/

Organising Committee

We would like to express our appreciation to all the members of the organising committee:

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Dear Conference Participants,

Welcome to the 9th International Conference on *Computational Management Science* taking place at Imperial College London.

The Computational Management Science conference is an annual meeting associated with the journal of Computational Management Science, published by Springer. The aim of this conference is to provide a forum for theoreticians and practitioners from academia and industry to exchange knowledge, ideas and results in a broad range of topics relevant to the theory and practice of computational methods, models and empirical analysis for decision making in economics, finance, management, and engineering.

The conference focus is on all computational aspects of management science: theoretical and empirical studies of computational methods, models and empirical analysis for decision making in economics, finance, management, and related aspects of engineering. These include theoretical and empirical analysis of computational models; computational statistics; analysis and applications of constrained, unconstrained, robust, stochastic and combinatorial optimisation algorithms; dynamic models, such as dynamic programming and decision trees; new search tools and algorithms for global optimisation, modelling, learning and forecasting; models and tools of knowledge acquisition.

We hope you enjoy the conference and we wish you a pleasant stay in London.

With our compliments,

Daniel Kuhn

Panos Parpas

Stratos Pistikopoulos

Berç Rustem

Wolfram Wiesemann

General Information

Venue and Registration

The conference is hosted by the Department of Computing at Imperial College London. The main entrance to the Department of Computing is located on the second floor of the Huxley Building at 180 Queen's Gate. For further guidance, please consult the map on page 106. Huxley building marked number thirteen on this map.

The registration can be found on level three of Huxley building near the main stairs.

Lecture Rooms

The Rooms 144, 145 are on the first floor while the lecture theatres 311, 342, 343 are on the third floor of Huxley building. Please see the floor maps on pages 107 and 108.

Presentation Instructions

Plenary talks last one hour including set up and questions. All presentations that are part of an invited or contributed session last thirty minutes including set up and questions. Please bring a copy of your presentation on a USB stick and in PDF format in order to avoid compatibility problems. In case you bring your own laptop, please make sure you also bring the appropriate adapter since UK power sockets are different from those in the rest of Europe and the US.

Paper Publication

Papers presented at the conference are invited to be considered for publication in a special peer-reviewed, or regular, issue of the journal of Computational Management Science. The Guest Editors of the special issue are Panos Parpas and Wolfram Wiesemann. Papers will go through the usual review process. The deadline for paper submissions is the 31st of July 2012.

Internet Access

Registering your laptop for wireless network

- Select Imperial as the WiFi network and visit: `https://guestaccess.imperial.ac.uk/`
- Then click on Guest Login Page
  `https://guestaccess.imperial.ac.uk/GuestLogin/GuestLogin.aspx`
  Use **conf41426** as the Unique ID, and supply any additional details necessary.
- You will then be able to create a guest account. The account will be valid throughout the conference.

CMS Prize

Best Student Paper Prize A prize of 250 British pounds will be awarded at the conference for the best student paper. In addition, the winning paper will be published in the journal of Computational Management Science after a basic review procedure. Candidate papers are to be nominated by the supervisors of the students and the winning paper will be announced in the closing ceremony.

Social Events & Additional Information

Welcome reception The welcome reception will take place in the Physics Common Room on Wednesday the 18th of April from 6:30pm to 8:30pm. The Physics Common Room is located on the 8th floor of the Blackett Building, that is the building with number six on the map on page 106. The Blackett Building is connected to the Huxley Building via an indoor corridor on the third floor. Please walk through that corridor to enter the Blackett Building and then take the elevators to the 8th floor. The reception room is on your left. It is advisable to enter the College through the Huxley Building.

Conference dinner The conference dinner takes place in the 170 Queen's Gate restaurant on Thursday the 19th of April at 7pm. The restaurant is located on 170 Queen's Gate, which is 100m south of the conference venue. Please turn left as you leave the Huxley Building.

Lunch Lunch is available from a large number of very diverse restaurants in the immediate vicinity of Imperial College, e.g., on Gloucester Road, around the South Kensington underground station and on Cromwell Road towards Knightsbridge. A list of recommended restaurants in walking distance from the conference venue is available on page 109.

Participants who prefer to stay on site during the lunch breaks are advised to use the culinary offerings of the Senior Common Room cafeteria, which is located in Sherfield Building (number 21 on the map on page 106) just a few meters away from the Department of Computing. Please leave the Huxley Building through the glass door on the third floor and walk along the walkway (marked with pink colour on the map). You will find the Senior Common Room on your right.

Coffee breaks During the coffee breaks light refreshments will be served in front of Room 344 on the third floor of Huxley building – just next to the registration desk.

Toilets Men's and women's toilets are located just next to the Lecture theaters 144 and 145 on Level 1 and in front of the main stairs on Level 3 of Huxley Building. Additional toilets can be found on the third floor of the Blackett Building (number six on the map on page 106), which is accessible from Huxley Building via an indoor corridor.

Wednesday 18th April 2012

08:30-09:30	Registration
09:30-09:45	Opening Ceremony (Room 311)
09:45-10:45	**Plenary I: Stein W. Wallace (Room 311)** Chair: Daniel Kuhn
10:45-11:15	Coffee

	Sessions I				
	Room 144	Room 145	Room 342	Room 343	Room 311
	Energy Systems I Chair: Michel Gendreau	**Option Pricing and Calibration** Organiser: Paolo Foschi Chair: Paolo Foschi	**Modelling and Optimisation for the Process Industry I** Organisers: Vivek Dua, Lazaros Papageorgiou Chair: Lazaros Papageorgiou	**Combinatorial Optimisation** Organiser: Houyuan Jiang Chair: Houyuan Jiang	**Large Scale Optimisation** Chair: Amir Beck
11:15-11:45	Vitor de Matos	Diego Ronchetti	Iqbal Mujtaba	Giovanna Miglionico	Duy Luong
11:45-12:15	Milica Vranesevic	Nicos Koussis	Songsong Liu	Francesca Maggioni	Georgios Kopanos
12:15-12:45	Michel Gendreau	Paolo Foschi	Alexandros Adam	Houyuan Jiang	Amir Beck

12:45-14:15	Lunch

	Sessions II				
	Room 144	Room 145	Room 342	Room 343	Room 311
	Energy Systems II Chair: David Fuller	**Stochastic Finance** Organiser: Paolo Foschi Chair: Paolo Foschi	**Modelling and Optimisation for the Process Industry II** Organisers: Vivek Dua, Lazaros Papageorgiou Chair: Vivek Dua	**Risk Analysis I** Chair: Michalis Kapsos	**New Trends in Operations Research I** Chair: Vladimir Roitch
14:15-14:45	David Wozabal	Candia Riga	Romain Lambert	João Telhada	Laura McLay
14:45-15:15	Joseph Warrington	Pirmin Meier	Georgios Kopanos	Sergey Sosnovskiy	Jesco Humpola
15:15-15:45	David Fuller	Nuria Ruiz-Fuentes	Edith Ejikeme-Ugwu	Michalis Kapsos	Vladimir Roitch

15:45-16:15	Coffee

	Sessions III				
	Room 144	Room 145	Room 342	Room 343	Room 311
	Robust Optimisation I Chair: Dick den Hertog	**Financial Optimisation I** Chair: Valery Kalyagin	**Risk Analysis II** Chair: Ana-Maria Fuertes	**Portfolio Selection and Econometrics I** Organiser: Alessandra Amendola Chair: Alessandra Amendola	**Stochastic Optimisation I** Organisers: Rudabeh Meskarian, Huifu Xu Chair: Huifu Xu
16:15-16:45	Bart P. G. Van Parys	Fang He	Dimitra Bampou	Giorgia Rivieccio	Rudabeh Meskarian
16:45-17:15	Mikhail Zhelonkin	Arsenii Vizgunov	Florian Löcker	Maria Lucia Parrella	Arash Gourtani
17:15-17:45	Bram Gorissen	Gautam Mitra	David Song	Valeria D'Amato	Georg Pflug
17:45-18:15	Dick den Hertog	Valery Kalyagin	Ana-Maria Fuertes	Alessandra Amendola	Huifu Xu

18:30-20:00	Reception (Physics Common Room, Level 8)

Thursday 19th April 2012

	Sessions IV				
	Room 144	Room 145	Room 342	Room 343	Room 311
	Energy Systems III Organiser: Afzal Siddiqui Chair: Afzal Siddiqui	**Financial Optimisation II** Chair: Christoforos Charalambous	**Inventory Problems** Chair: Maria Grazia Speranza	**Networks and Graphs** Organiser: Leonidas Pitsoulis Chair: Leonidas Pitsoulis	**Stochastic Optimisation II** Chair: Wolfram Wiesemann
08:30-09:00	Lajos Maurovich Horvat	Mickaël Sahnoun	Grani Adiwena Hanasusanto	Konstantinos Papalamprou	Teemu Pennanen
09:00-09:30	Michal Kaut	Raghu Sengupta	Sepideh Alavi	Panos Pardalos	Alexei Gaivoronski
09:30-10:00	Javier M. Moguerza	Iakovos Kakouris	Samira Mirzaei	Katerina Papadaki	Werner Römisch
10:00-10:30	Afzal Siddiqui	Christoforos Charalambous	Maria Grazia Speranza	Leonidas Pitsoulis	Ruediger Schultz

10:30-11:00	Coffee
11:00-12:00	**Plenary II: Yves Smeers (Room 311)** Chair: Panos Parpas
12:00-13:30	CMS Editorial Meeting (by invitation, Room 217, Level 2, Huxley Building)
12:00-13:30	Lunch

	Sessions V				
	Room 144	Room 145	Room 342	Room 343	Room 311
	Energy Systems IV Organiser: Andres Ramos Chair: Andres Ramos	**Portfolio Selection and Econometrics II** Organiser: Peter Winker Chair: Bjoern Fastrich	**Modelling and Optimisation for the Process Industry III** Organisers: Vivek Dua, Lazaros Papageorgiou Chair: Lazaros Papageorgiou	**Resource Allocation** Chair: Stefan Pickl	**Estimation and Relaxation Strategies for Global Optimisation I** Organisers: Alexander Mitsos, Benoit Chachuat Chair: Benoit Chachuat
13:30-14:00	Pedro Sánchez Martín	Ivan Savin	Pedro Rivotti	Sophia Parker	Angelos Georghiou
14:00-14:30	Gerardo Perez Valdes	Susan Kriete-Dodds	Eleftheria Polykarpou	Zsolt Ercsey	Alexander Mitsos
14:30-15:00	Ricardo Fernández-Blanco	Bjoern Fastrich	Iqbal Mujtaba	Stefan Pickl	Benoit Chachuat

15:00-15:30	Coffee
15:30-16:30	**Plenary III: Ignacio E. Grossmann (Room 311)** Chair: Stratos Pistikopoulos

	Sessions VI				
	Room 144	Room 145	Room 342	Room 343	Room 311
	Robust Optimisation II Organiser: Nalan Gulpinar Chair: Nalan Gulpinar	**Financial Optimisation III** Organisers: Alex Weissensteiner, Michael Hanke Chair: Alex Weissensteiner	**Supply Chain Management** Chair: Henry Thille	**Stochastic Optimisation III** Chair: Maria Teresa Vespucci	**Surrogate and Derivative-Free Optimization: Algorithms and Applications** Organiser: Nick Sahinidis Chair: Nick Sahinidis
16:30-17:00	Xuan Vinh Doan	Kourosh Marjani Rasmussen	Ozlem Akgul	Anna Timonina	Francesco Rinaldi
17:00-17:30	Xiang Yu	Sonja Huber	Mark G. Jennings	Gloria Pérez	Erik Santiso
17:30-18:00	Ihsan Yanikoglu	Alex Weissensteiner	Fereshteh Mafakheri	Bita Analui	Nick Sahinidis
18:00-18:30	Nalan Gulpinar	Michael Hanke	Henry Thille	Maria Teresa Vespucci	

19:00	Conference Dinner (170 Queen's Gate)

Friday 20th April 2012

	Sessions VII				
	Room 144	Room 145	Room 342	Room 343	Room 311
	Energy Systems V Chair: Paula Rocha	**Financial Optimisation IV** Chair: Hatem Ben Ameur	**Computational Statistics and Data Analysis I** Organiser: Ana Colubi Chair: Ana Colubi	**New Trends in Operations Research II** Chair: Iakovos Kakouris	**Global Optimisation in Process Design** Organiser: Claire Adjiman Chair: Claire Adjiman
08:30-09:00	Dorea Chin	Paresh Date	Christophe Ley	Bosko Blagojevic	Gonzalo Guillén-Gosálbez
09:00-09:30	Teck Hao Tan	Jonela Lula	Jochen Einbeck	Mariem Baazaoui	Alexander Mitsos
09:30-10:00	Paula Rocha	Hatem Ben Ameur	Stefano Favaro	Elif Mac	Cheng Seong Khor

10:00-10:30	Coffee

	Sessions VIII				
	Room 144	Room 145	Room 342	Room 343	Room 311
	Energy Systems VI Organiser: Andres Ramos Chair: Andres Ramos	**Algorithms for Routing \& Location Problems** Organiser: Eleni Hadjiconstantinou Chair: Eleni Hadjiconstantinou	**Computational Statistics and Data Analysis II** Organiser: Erricos Kontoghiorghes Chair: Erricos Kontoghiorghes	**Electricity Markets** Chair: F.-Javier Heredia	**Stochastic Optimisation IV** Organisers: Rudabeh Meskarian, Huifu Xu Chair: Rudabeh Meskarian
10:30-11:00	Nidhi Santen	Laura Galli	Stephen David Pollock	Paul Sabloniere	Ronald Hochreiter
11:00-11:30	Sara Lumbreras	Mahdi Noorizadegan	Quang Phan	Bratislav Svetozarevic	Diana Roman
11:30-12:00	Dario Siface	Said Salhi	Bahar Ghezelayagh	Michail Chronopoulos	Martin Branda
12:00-12:30	Andres Ramos	Pairoj Chaichiratikul	Ana Colubi	F.-Javier Heredia	Milos Kopa

12:30-14:00	Lunch

	Sessions IX				
	Room 144	Room 145	Room 342	Room 343	Room 311
	Electric Vehicles Chair: Angelos Georghiou	**Portfolio Selection and Econometrics III** Organiser: Victor DeMiguel Chair: Victor DeMiguel	**Credit Risk** Chair: Duc Pham-Hi	**Scheduling** Chair: Mauricio de Souza	**Estimation and Relaxation Strategies for Global Optimisation~II** Organisers: Alexander Mitsos, Benoit Chachuat Chair: Alexander Mitsos
14:00-14:30	Fernando Báñez Chicharro	Michael Wolf	Thierry Lavoix	Sündüs Dag	Boris Houska
14:30-15:00	Ilan Momber	Alberto Martin-Utrera	Magdalena Pisa	Robin Vujanic	Polyxeni-Margarita Kleniati
15:00-15:30	Jonathan Donadee	Victor DeMiguel	Duc Pham-Hi	Mauricio de Souza	Ignacio Grossmann

15:30-16:00	Coffee
16:00-17:00	**Plenary IV: Melvyn Sim (Room 311)** Chair: Wolfram Wiesemann
17:00-17:15	Closing Ceremony (Room 311)

Contents

Plenary Talks

Understanding Stochastic (Mixed) Integer Programs

Speaker: **Stein W. Wallace** (Lancaster University, UK)
Chair: **Daniel Kuhn** (Imperial College London)
Time: Wednesday 18th April 09:45-10:45, Room 311

On one hand, most cases of industrial-sized stochastic (mixed) integer programs are numerically unsolvable. On the other hand, the problems exist and deserve our attention. This talk focuses on a series of papers investigating different network design problems. We investigate the relationship between the stochastic and deterministic versions of the design problems, and in particular ask if the deterministic solutions can be useful even if the Value of the Stochastic Solution is high. The goal is to understand what stochastics does to these problems and how it affects the optimal solutions. By better understanding what stochastics does we are in a position to develop better heuristics and also to communicate better with users, even when we do not solve the relevant models.

From Stochastic Programming to Stochastic Equilibrium for Capacity Expansion Analysis: The Example of Power Generation

Speaker: **Yves Smeers** (Université Catholique de Louvain, Belgium)
Chair: **Panos Parpas** (Imperial College London)
Time: Thursday 19th April 11:00-12:00, Room 311

Capacity expansion in power generation was first formulated as an optimization model aimed at satisfying demand at overall minimal discounted cost. Uncertainty justifies extending the formulation to a stochastic environment and hence to resort to a stochastic programming version of the model. The primal-dual optimality conditions can be interpreted in term of a competitive market where different agents invest in order to maximize their expected profit discounted at a single cost of capital. Competitive markets are not always perfect and one finds situations were risk exposure depends on technology and plant owner and hence assets need to be valued at different costs of capital. A first extension of the standard capacity expansion model is to insert these technology and company dependent costs of capital in the model. We explain how a particular stochastic version of the equilibrium model permits this extension and discuss computational approaches. The follow-up question is to go beyond exogenous differentiated costs of capital and to make them endogenous. This means that cost of capital can depend on exogenous factors such as fuel cost or demand evolution, but also on the endogenous development of the generation system (different generation structures imply different risk exposures: just think of wind penetration). We first take the problem in the usual CAPM context and show that the introduction of stochastic discount rates allows one to endogenize the cost of capital in a CAPM compatible way at least as long as we only deal with systematic risk. The model can be stated as a stochastic programming problem. Things become more complicated if one wants to deal with idiosyncratic risk. The principle of the CAPM is that this risk is priced at zero. But the notion of incomplete market suggests to go beyond that usual model and to account for non-zero idiosyncratic risk in the equilibrium model. One then extends the CAPM based equilibrium model to one where systematic risk is represented by a linear stochastic discount factor and idiosyncratic risk is modelled through a non-linear stochastic risk factor. This calls upon using convex or coherent risk functions. The model is of the stochastic equilibrium type and can become non convex. Non-convex stochastic equilibrium problems are as annoying as non-convex optimization problems. It is thus interesting to explore the origin of the non-convexity. The CAPM with its zero pricing of idiosyncratic risk is a convex stochastic equilibrium model. A more general situation that does not rely on the CAPM assumes full risk trading (a complete market) where the price of risk is determined endogenously from a capacity optimization problem with risk function. The crucial remaining question is then to explore how incomplete risk trading can affect investment in a stochastic equilibrium model. We sketch a possible way to handle that problem using a (simpler) stochastic equilibrium model with an incomplete market for risk hedging when capacities are fixed. This is joint work with Gauthier de Maere d'Aertrycke, Andreas Ehrenmann and Daniel Ralph.

Modelling and Computational Strategies for Optimal Offshore Oilfield Development Planning under Complex Fiscal Rules

Speaker: **Ignacio E. Grossmann** (Carnegie Mellon University, USA)
Chair: **Stratos Pistikopoulos** (Imperial College London)
Time: Thursday 19th April 15:30-16:30, Room 311

Offshore oil and gas field development planning has received significant attention in recent years given the new discoveries of large oil and gas reserves in the last decade around the world. Therefore, there is currently a strong focus on exploration and development activities for new oil fields all around the world, specifically at offshore locations. These projects involve capital intensive decisions pertaining to the installation of exploration and production facilities, subsea structures, pipeline connections, well drilling, that must be made at the early stages of the project. However, there is a very large number of alternatives that is usually available to make these decisions under the given physical and practical restrictions. This motivates the need for optimizing the investment and operations decisions to ensure the highest return on the large investments over the given time horizon. The optimization of investment and operations planning of offshore oil and gas field infrastructure is traditionally modeled using the net present value (NPV) as the objective function, without considering the effect of fiscal rules that are associated to these development sites. These rules determine the share of the oil company and host government in the total oil produced in a given year. Therefore, the models with simple NPV objective functions may yield solutions that are optimistic, which can in fact be suboptimal after considering the impact of fiscal terms. The main goal of this paper is to extend a mixed-integer nonlinear programming (MINLP) model for NPV-based oilfield development planning to include complex fiscal rules. In particular, we consider a recently proposed multi-field site strategic planning model for offshore oil and gas fields as a basis to include generic fiscal rules with ring-fencing provisions. The proposed MINLP model is rather large as it includes many new discrete variables and additional constraints. We show that this model can be reduced to a variety of specific contracts models. Results on realistic instances show improved investment and operations decisions due to the explicit consideration of the fiscal terms during planning. Since the model becomes computationally very expensive to solve with the extension to fiscal rules, we provide several reformulation/approximation techniques and solution strategies that yield orders of magnitude reduction in the solution time. Finally, we briefly discuss the extension of the proposed model to handle uncertainties in the reservoir size and its productivity using a framework based on multi-sage stochastic programming. This is joint work with Vijay Gupta.

Aspirational Preferences and Their Representation by Risk Measures

Speaker: **Melvyn Sim** (National University of Singapore, Singapore)
Chair: **Wolfram Wiesemann** (Imperial College London)
Time: Friday 20th April 16:00-17:00, Room 311

We consider choice over uncertain, monetary payoffs and study a general class of preferences. These preferences favor diversification, except perhaps on a subset of sufficiently disliked acts, over which concentration is instead preferred. This structure encompasses a number of known models (e.g., expected utility and several variants under a concave utility function). We show that such preferences share a representation in terms of a family of measures of risk and targets. Specifically, the choice function is equivalent to selection of a maximum index level such that the risk of beating the target at that level is acceptable. This representation may help to uncover new models of choice.One that we explore in detail is the special case when the targets are bounded. This case corresponds to a type of satisficing and has descriptive relevance. Moreover, the model is amenable to large-scale optimization. This is joint work with David Brown and Enrico De Giorgi.

Sessions

Algorithms for Routing & Location Problems

Organiser: Eleni Hadjiconstantinou
Chair: Eleni Hadjiconstantinou

A Branch-and-Cut Approach for some Heterogeneous Routing Problems under Demand Uncertainty

Slot: Friday 20th 10:30-11:00, Room 145
Presenter: **Laura Galli** (University of Warwick, United Kingdom)
Coauthors: **Mahdi Noorizadegan** (Warwick University, United Kingdom) **Bo Chen** (Warwick University, United Kingdom)

The Capacitated Vehicle Routing Problem (CVRP), with its many variants, is one of the most widely studied NP-Hard problems in combinatorial optimisation due to its wide practical applications and tough computational challenges. An important generalisation of the classical CVRP is the so-called Heterogeneous Vehicle Routing Problem (HVRP), where a heterogeneous fleet of finite vehicles is stationed at the depot and is used to serve the customers. In this study, we first consider the stochastic HVRP, and then move to a new and even more general variant known as (stochastic) Capacitated Multi-Depot Heterogeneous VRP, which has never been presented in the literature before. In the stochastic versions it is assumed that customer demands are not known for certain. There are many ways to deal with uncertainty. We present three models: two robust counterparts according to Ben-Tal & Nemirovski (1999) and Bertsimas & Sim (2004) and one chance-constrained. Our first step is to formulate the (deterministic) problems in such a way that the corresponding stochastic ones, according to the three frameworks mentioned above, remain tractable via Mix Integer Linear Programming (MILP). The second step is to solve the resulting models using a Branch-and-Cut approach. We present heuristic separation algorithms for some classes of valid inequalities.

Keywords heterogeneous vehicle routing problem, optimisation under uncertainty.

A Disjunctive Decomposition Approach for the Stochastic Location Routing Problem

Slot: Friday 20th 11:00-11:30, Room 145
Presenter: **Mahdi Noorizadegan** (University of Warwick, United Kingdom)
Coauthors: **Laura Galli** (Warwick University, United Kingdom) **Bo Chen** (Warwick University, United Kingdom)

We address a two-echelon Stochastic Location Routing Problem (SLRP) with suppliers, depots and customers by designing a distribution system between two adjacent echelons under demand uncertainty. The echelons interact in a two-tiered system, where in the upper level suppliers are assigned to depots, and in the lower level depots are assigned to customers together with the routing of vehicles. We decompose the problem into two stages. In the first stage, we decide which depots to open and the amount of product to be delivered from each supplier to each of the opened depots. In the second stage, we consider a Multi-Depot Vehicle Routing Problem (MDVRP) and design optimal routes between the opened depots and the customers. This problem can be modelled as a two-stage stochastic mixed integer programme (SMIP), where the number of scenarios is finite. Our solution approach is based on a Disjunctive Decomposition framework (D^2). The standard D^2 provides us with cut functions valid for all scenarios to approximate the convex hull. Given the complex polyhedral structure of the MDVRP, we customise the method by using valid inequalities from the classical vehicle routing problem.

Keywords stochastic location routing problem, two-stage stochastic mixed integer programming, disjunctive decomposition.

A Set Partitioning-based Approach for the Fleet Size and Mix Vehicle Routing Problem with Backhauls

Slot: Friday 20th 11:30-12:00, Room 145
Presenter: **Said Salhi** (University of Kent, United Kingdom)
Coauthors: **Mutaz Hajarat** (University of Kent, United Kingdom) **Niaz Wassan** (University of Kent, United Kingdom)

In this talk we present a new variant of the classical Vehicle Routing Problem - the Fleet Size and Mix Vehicle Routing Problem with Backhauls (FSMVRPB). This variant involves two kinds of customers, deliveries (linehauls) and pickups (backhauls) with known demands. In this backhauling version the delivery customers are served before any pickups are made, and a fleet of heterogeneous vehicles is utilized that start and end their journey at a single depot. The aim is to find the minimum cost heterogeneous fleet set of routes while respecting problem constraints. An ILP formulation of the FSMVRPB is put forwarded and optimal solutions for small size instances (up to n=20) are produced. We also propose an efficient hybrid heuristic method to solve this routing problem. First, a Set Partitioning Problem (SPP) based on a set of routes generated through giant tours and partitioned accordingly into a pool of routes. Several implementations of the SPP-based method are tested and the most promising one is then used with TS and a hybrid VN-TS meta-heuristics acting as post-optimizers. The proposed approach is tested on a set of FSMVRPB data instances adapted from those originally used for the vehicle fleet mix. New results are presented which can be used for future benchmarking.

Keywords vehicle routing, set partitioning.

An Adaptive Memetic Algorithm using Large Neighbourhood Search for the Multi-Depot Pickup and Delivery Problem

Slot: Friday 20th 12:00-12:30, Room 145
Presenter: **Pairoj Chaichiratikul** (Imperial College London, United Kingdom)
Coauthors: **Eleni Hadjiconstantinou** (Imperial College London, United Kingdom)

At operational level, Third-Party Logistics Providers typically have to deal with variants of the Multi-Depot Pickup and Delivery Problem with Time Windows (MDPDPTW). The objective is to minimise the routing cost of the fleet of vehicles serving transportation requests in a large geographical coverage, subject to customer requirements. The MDPDPTW is an NP-Hard problem. In the published literature, Adaptive Large Neighbourhood Search (ALNS) has been identified as one of the-state-of-art meta-heuristics for solving variants of Vehicle Routing Problems such as the MDPDPTW. The ALNS applies the large neighbourhood search in an adaptive manner, embedded in Simulated Annealing. As a single-solution approach, the ALNS may locate false peaks while population-based approaches, such as Genetic Algorithms, climb many peaks in parallel. The latter are good at identifying promising areas of the search space while less efficient at refining near-optimal solutions. Hence, several genetic algorithms are hybridised with local search operators, called Memetic Algorithms. In this paper, we propose a new heuristic approach that involves hybridisation between ALNS and Adaptive Memetic Algorithm (AMA) with the view to combining the strengths of both and counteract their limitations. This heuristic evolves in a number of stages. We initialise diverse and greedy population for reproduction. The recombination operator is designed to exchange good building blocks between two parents. The ALNS is then applied to each offspring for improvement. The population management is done following the steady-state approach without duplicates, associated with the adaptive replacement. The new proposed heuristic, using AMA instead of simulated annealing in ALNS, is computationally tested on standard benchmark test instances of MDPDPTW from the literature. The preliminary computational results are promising; the proposed heuristic is capable of obtaining improved feasible solutions for some instances.

Keywords multi-depot pick-up and delivery, adaptive memetic algorithm, large neighbourhood search.

Combinatorial Optimisation

Organiser: Houyuan Jiang
Chair: Houyuan Jiang

New Formulations for the Conflict Resolution Problem in the Scheduling of TV commercials

Slot: Wednesday 18th 11:15-11:45, Room 343
Presenter: **Giovanna Miglionico** (University of Calabria, Italy)
Coauthors: **Giovanni Giallombardo** (University of Calabria, Italy) **Houyuan Jiang** (University of Cambridge, United Kingdom)

Selling commercial air time to clients represents a critical task for television network companies, as advertising revenues represent a relevant part of their income. Several problems arise in this context, at different decisional levels, like negotiating advertising contracts, assigning commercials to breaks of each TV program, and eventually scheduling commercials within each break. Typical constraints are related to the budget available for the advertising campaign, to the desired audience demographics to be reached, to the number and length of commercials allowed per break, to the preferred positions of commercials in a break, and to possible conflicts among commercials of competing advertisers assigned to the same break. We focus on the conflict-resolution problem arising in the allocation of commercial advertisements to television program breaks. Given a set of commercials and a set of program breaks, the problem consists in assigning each commercial to (at most) one break, so that a total measure of the conflicts among commercials assigned to the same break is minimized. In particular, the conflict-resolution problem arises from several competition-avoidance requirements typically issued by advertisers. In fact, it is easy to understand that highly competing firms do not appreciate to see their advertisements placed too close one to each other, and that this is true also for different brands of the same manufacturer, and obviously for multiple copies of the same advertisement. We introduce new integer programming formulations of the problem, and we report on computational results for several small- to large-sized instances, in order to evaluate performance of the proposed models.

Keywords TV commercial scheduling, combinatorial optimization, assignment problems.

A Stochastic Second Order Cone Model for a Stochastic Capacitated Travelling Salesmen Location Problem with Recourse

Slot: Wednesday 18th 11:45-12:15, Room 343
Presenter: **Francesca Maggioni** (University of Bergamo, Italy)
Coauthors: **Luca Bertazzi** (University of Brescia, Italy)

In this talk we present a Stochastic Capacitated Traveling Salesmen Location Problem with Recourse (SCTSLP–R) in which a single facility (typically a service station) has to be located in a given area. This facility is used to serve a given number of customers with unknown position. The service to the customers is carried out by several traveling salesmen, with capacity in terms of the maximum number of customers that can be served in any tour. The aim is to determine the service zone (in a shape of a circle) that minimizes the expected cost of the traveled routes. The center of the circle is the location of the facility. Once the position of the customers is revealed, the customers located outside the service zone are served with a recourse action at a greater unit cost computed according to Daganzo (1984) . We propose a two-stage stochastic second order cone programming model (see Alizadeh and Goldfarb, 2003) as a solution methodology to solve the SCTSLP–R, where scenarios are represented by different sets of customers and of corresponding ellipses. Each ellipse represents the area covered by a traveling salesman to supply her/his set of customers, randomly generated by uniform and normal distributions in a neighborhood of her/his starting position inside a given region. Optimal solutions in terms of center and radius of the service zone are compared with the corresponding Capacitated Traveling Salesmen Location Problem heuristic solution proposed by Simchi-Levi (1991) and the advantages of the second order stochastic cone formulation are shown.

Keywords stochastic capacitated traveling salesmen location problem, second order cone programming.

Exact Computational Approaches to a Stochastic Uncapacitated Single Allocation p-Hub Centre Problem

Slot: Wednesday 18th 12:15-12:45, Room 343
Presenter: **Houyuan Jiang** (University of Cambridge, United Kingdom)
Coauthors: **Edward Hult** (EF, USA) **Daniel Ralph** (University of Cambridge, United Kingdom)

The stochastic uncapacitated single allocation p-hub center problem is an extension of the deterministic version which aims to minimize the longest origin-destination path in a hub and spoke network. Considering the stochastic nature of travel times on links is important when designing a network to guarantee the quality of service measured by a maximum delivery time for a proportion of all deliveries. We propose an efficient reformulation for a stochastic p-hub center problem and develop exact solution approaches based on preprocessing and constraint generation. We report numerical results to show effectiveness of our new reformulations and approaches by finding global solutions of small-medium sized problems.

Keywords hub location, uncertainty, integer programming.

Computational Statistics and Data Analysis I

Organiser: Ana Colubi
Chair: Ana Colubi

Optimal R-Estimation of a Spherical Location

Slot: Friday 20th 08:30-09:00, Room 342
Presenter: **Christophe Ley** (Université Libre de Bruxelles, Belgium)

Spherical data arise in a broad range of natural sciences such as astrophysics, biology or geology, as well as in studies of animal behavior and even in medicine and neurosciences. It is common practice to view such data as realizations of random vectors X taking values on the surface of the unit sphere $\mathcal{S}^{k-1}$ of $\mathbb{R}^k$, $k \geq 2$, the distribution of X depending only on its distance from a fixed point $\theta \in \mathcal{S}^{k-1}$. This parameter θ, which can be viewed as a "north pole" (or "mean direction") for the problem under study, is then a location parameter for the distribution. An interesting class of such spherical distributions are the rotationally symmetric distributions, containing in particular the celebrated Fisher-von Mises-Langevin distribution.

In this talk, we provide R-estimators of the location parameter of rotationally symmetric distributions on the unit sphere of $\mathbb{R}^k$. In order to do so we first prove the local asymptotic normality property of a sequence of rotationally symmetric models; this is a non standard result due to the curved nature of the unit sphere. We then construct our estimators by adapting the Le Cam one-step methodology to spherical statistics and ranks. We show that they are asymptotically normal under any rotationally symmetric distribution and achieve the efficiency bound under a specific density. Their small sample behavior is studied via a Monte Carlo simulation and our methodology is illustrated on geological data.

Keywords local asymptotic normality, rank-based methods, R-estimation, spherical statistics.

Principal Manifolds: A Versatile Tool for Data Visualisation and Beyond

Slot: Friday 20th 09:00-09:30, Room 342
Presenter: **Jochen Einbeck** (Durham University, United Kingdom)
Coauthors: **Ludger Evers** (University of Glasgow, United Kingdom)

For multivariate data structures featuring strong and non-linear dependency patterns between the involved variables, an attractive tool for non-linear dimension reduction is provided by principal manifolds, which can be considered as the nonparametric counterpart to linear principal components.

Their one- and two- dimensional representatives, known as principal curves and surfaces, respectively, have been proposed in the literature about two decades ago. Though many algorithms for their estimation have been suggested since then, most of this research, rather surprisingly, stops here, and does not consider exploiting the fitted object once it is established.

Using a localized approach to the construction of principal manifolds, we attempt to go this "next step". We present some applications, stemming from current collaborative work with applied natural scientists, which illustrate how principal surfaces do not only provide highly insightful visual data representations, but also enable further statistical analysis, such as multivariate nonparametric regression, based on the fitted principal object.

Keywords dimension reduction, smoothing, regression.

On the Stick-breaking Representation for Gibbs-type Priors

Slot: Friday 20th 09:30-10:00, Room 342
Presenter: **Stefano Favaro** (University of Torino, Italy)
Coauthors: **Antonio Lijoi** (University of Pavia, Italy) **Igor Pruenster** (University of Torino, Italy) **Stephen Walker** (University of Kent, United Kingdom)

Random probability measures are the main tool for Bayesian nonparametric inference, given their law

acts as a prior distribution. Many well-known priors used in practice admit different, though (in distribution) equivalent, representations. Some of these are convenient if one wishes to thoroughly analyze the theoretical properties of the priors being used, others are more useful in terms of modeling and computation As for the latter purpose, the so-called stick-breaking constructions certainly stand out. In this talk we focus on the recently introduced class of Gibbs-type priors and provide a stick-breaking representation for it.

Keywords Bayesian nonparametrics, Dirichlet process, normalized inverse Gaussian process, random probability measures, stick–breaking representation.

Computational Statistics and Data Analysis II

Organiser: Erricos Kontoghiorghes
Chair: Erricos Kontoghiorghes

Cycles, Syllogisms and Semantics: Examining the Idea of Spurious Cycles

Slot: Friday 20th 10:30-11:00, Room 342
Presenter: **Stephen David Pollock** (University of Leicester, United Kingdom)

The claim that linear filters are liable to induce spurious fluctuations has been repeated many times of late. However, there are good reasons for asserting that this cannot be the case for the filters that, nowadays, are commonly employed by econometricians. If these filters cannot have the effects that have been attributed to them, then one must ask what effects the filters do have that could have led to the aspersions that have been made against them.

Keywords linear filtering, spurious fluctuations, Wiener processes.

Estimating the Covariance Matrix of Idiosyncratic Errors

Slot: Friday 20th 11:00-11:30, Room 342
Presenter: **Quang Phan** (University of Warwick, United Kingdom)

Estimating the covariance matrix plays a central role in Finance and Economics. Recently, applying the factor models to asset returns before estimating the covariance matrix has been an effective method when the dimension of the portfolio is very high. After choosing a suitable factor model, the main problem is to provide good estimator for the covariance matrix of the errors term (the idiosyncratic errors). There are many approaches to make this task easier, including the very well-known assumption that this matrix is sparse. Another approach proposed by the author is to exploit the prior belief in the structure of this covariance matrix. We can improve our estimator and reduce the noise of the sample covariance matrix by shrinking it toward a specific matrix reflecting our prior belief before even collecting the data. This shrinkage method was first developed by Ledoit and Wolf (2003), but the direct application to the idiosyncratic errors covariance estimator is not widely considered. This paper discusses how this method can be used and compares it with the vastly popular sparse covariance matrix estimator. Simulation and empirical study with data from FTSE100 will then be used to demonstrate the results.

Keywords covariance matrix, sparsity, shrinkage.

Predicting Asset Returns: New Evidence from the Wavelet Multiscaling Approach

Slot: Friday 20th 11:30-12:00, Room 342
Presenter: **Bahar Ghezelayagh** (University of East Anglia, United Kingdom)

The traditional Capital Asset Pricing Model (CAPM), though playing an important role in Finance, has rarely been an empirical success. We address this failure by combining two lines of arguments. On one side of the argument the size and book-to-market factors (the so called Fama-French factors) are used, whereas, the other line of the argument incorporates higher-order systematic co-moments between the stock returns and market return. We contribute to the literature by combining these two lines and add a new dimension to it via wavelet technique, a technique that decomposes a given return series into different timescales enabling the investigation both at time and at frequency domain. We first investigate the relationship between stock returns and Fama-French risk factors: SMB ("Small Minus Big", the difference between the average returns of the small-stock portfolios and big-stock portfolios) and HML ("High Minus Low", the difference in returns between the high-BM portfolios and low-BM portfolios) at different time-scales. We then go one step further and examine the association between portfolio returns and higher order systematic co-moments of order 3 through 10 at different timescales. Our analysis shows that first, SMB and HML play a smaller role in spotting investment opportunities in

the short run, but they play a significant role in the long run; and second, the explanatory power of the Fama-French factors diminishes at certain timescales when higher co-moments are included. Our paper suggests that risk as measured by co-moments is timescale dependent, implying that investors operating at timescales should evaluate their portfolios with the risk levels estimated at such timescales.

Keywords wavelet multi-scaling, higher-order systematic co-moments, investment horizon, risk factor.

On the Trimmed Mean in Hilbert Spaces: Applications to Fuzzy and Functional Data

Slot: Friday 20th 12:00-12:30, Room 342
Presenter: **Ana Colubi** (University of Oviedo, Spain)
Coauthors: **Gil González-Rodríguez** (University of Oviedo, Spain) **Stefan Van Aelst** (Ghent University, Belgium)

Robust estimation in Hilbert spaces is specially relevant for its applications in the treatment of contaminated functional data. Specifically, the trimmed mean was already defined and analyzed under ideal conditions. However its estimation has not been efficiently implemented. An algorithm to compute the sample trimmed mean in Hilbert spaces is presented and its robust properties are briefly discussed. To show the performance of the algorithm some case studies concerning functional and fuzzy data will be presented.

Keywords robust statistics, sample trimmed mean, fuzzy data, functional data.

Credit Risk

Chair: Duc Pham-Hi

CDS Price Shock in Banks

Slot: Friday 20th 14:00-14:30, Room 342
Presenter: **Thierry Lavoix** (ECE Paris, France)
Coauthors: **Brian Lemoine** (ECE Paris, France) **Anthony Osmar** (ECE Paris, France) **Matthieu Degraeve** (ECE Paris, France) **Jean-Baptiste Bassani** (ECE Paris, France) **Duc Pham-Hi** (ECE Paris, France)

This paper describes the simulation of a propagation mechanism of counterparty risk through banks, as a "domino effect" via Credit Default Swap (CDS). For this purpose, a model that uses Markov and Monte Carlo methods is developed. It creates a typical set of borrowing companies and lending banks in order to analyze interactions between these economic agents. In the first part, samples of companies' initial assets sizes are uniformly chosen over a given interval. To estimate probability of default (PD), the structural model of Merton, which uses a Geometric Brownian Motion to simulate the net asset values of the firms through time, is implemented. Depending on these PDs, a "first rank" bank chooses whether it will keep the loan in its portfolio or sell its risk through securitization to another bank. For this second option, a CDS is priced and sold to a "second rank" bank and banks are thus linked with each other. As the assets and the liabilities of the firms are made to evolve, the number of defaults and the amount of loss that propagate to other banks are determined. Default may happen to a bank of first rank, or of second rank, or the ultimate banker, the central national bank. The model developed explores this "domino effect" through several years. Thousands of iterations are run for different scenarios of macroeconomic and microeconomic sets of parameters. We try to illustrate by approximation how banks' portfolios react to interbank CDS. The result sought is: -That a bank should not exceed a certain ratio of CDS of a given risk level in its portfolio in order to ensure strong capacities to meet its financial commitments; -And that this ratio, and speed of propagation are dependent on the concentration ratio of the banking system and initial balance sheet structures.

Keywords credit default swap, contagion mechanism, simulation, domino effect, counterparty credit risk, Merton, Markov, Monte Carlo.

Modelling Default Correlation in a US Retail Portfolio

Slot: Friday 20th 14:30-15:00, Room 342
Presenter: **Magdalena Pisa** (University of Luxembourg, Luxembourg)
Coauthors: **Dennis Bams** (Maastricht University, The Netherlands) **Christian Wolff** (Luxembourg School of Finance, Luxembourg)

The aim of the paper is twofold. First, the authors construct a framework to model and estimate default correlations in a retail loan portfolio. The general method of moments is here at hand. This approach fosters a flexible way to decompose the portfolio credit risk into systematic and idiosyncratic elements. This in turn reveals the dependency structure of defaults between different types of homogenous obligors. A common factor model of default timing serves here as a starting point to derive the joint default probability distribution for default times. The model builds on concept of event risk from insurance industry and the idea of latent variable in multinomial response models.

Second, the authors perform an empirical study on a unique dataset of US private firms from 2005 to 2011. The model captures macroeconomic conditions that each company is facing. To that end it extracts information contained in the default rate co-movements in the domain of US economy. This information subsequently is translated into a default correlation measure.

Moreover the study investigates patterns with which a concentration risk spreads from one economic sector to the other in the pre-, during and post-crisis periods. The results of that study have an important implication on the regulatory capital hold by financial institutions since it introduces a sophisticated measure of interdependencies between obligors and enhances the accuracy of risk measurement in a retail loan portfolio.

Keywords credit risk, default dependencies, multiple defaults, common factor model.

A Simulated Systemic Contagion Process in Banks with Corrective Control From a Central Bank

Slot: Friday 20th 15:00-15:30, Room 342
Presenter: **Duc Pham-Hi** (ECE Paris, France)

This paper reports the experimental application of combined forward looking methods, filtering techniques, Sequential Monte Carlo, or Interactive Particles systems, with stress testing causal scenarios in systemic context. We first show how the current regulatory framework and models leave out temporal dynamics in risk management processes in banks. Next, we suggest how to introduce stochastic equations to solve deficiencies of existing, risk non-sensitive, models. The new models are proposed as value-based, time varying, functions of rare catastrophic scenarios allowing arbitrage between risk mitigation decisions. As an illustration, we examine the impact of exogenous shocks on a toy model of a banking system under central bank control. Local banks, characterized by their stylized balance sheet reduced to a vector of ratios, have interbank borrowing and lending and also securitization relationships. This mechanism for spreads risks of default and liquidity among a hierarchy leading up to a "Rest-of-the-world" bank. Propagation is simulated through random markov chains processes. We observe the consequences of stressed perturbations in 2 directions: credit default (counterparty risk) and liquidity (lack of confidence and lending) risk. We then introduce a prediction process in a Bayesian framework, to model economic forecast and rationalized control (e.g. by a Central bank). Some parts of this framework also borrow from Hidden Markov Model and Interactive particle systems filters. We show how a model can evolve from a dynamic framework as previously shown, to one that also encompasses adaptive learning (by establishing a common mutual interbank fund at an optimal level as buffer capital). We conclude by showing how Basel II and Basel III regulations on macroprudential systemic risks (liquidity and default) can benefit from this new, exploratory, rather than statistical, approach to Risk Capital.

Keywords banking system, default risk, liquidity risk, random process, propagation of systemic risk, sequential Monte Carlo.

Electric Vehicles

Chair: Angelos Georghiou

Smart Charging Profiles for Electric Vehicles

Slot: Friday 20th 14:00-14:30, Room 144
Presenter: **Fernando Báñez Chicharro** (Comillas Pontifical University, Spain)
Coauthors: **Jesús M. Latorre** (Comillas Pontifical University, Spain)

Plug-in electric vehicles (PEVs) can help decarbonise the transportation sector, which is responsible for a great share of GHG emissions. Although different measures have been introduced to foster the penetration of PEVs in the society, they have not been deployed in a large scale yet. Electric utilities are concerned about the effects of introducing PEVs into the grid, especially for large amounts. The charging pattern of PEVs is the main factor that determines these effects. Unregulated charging (probably when returning home) would have undesirable consequences (e.g. increase in costs, emissions, reduction of reliability), it is therefore necessary to develop an "intelligent" strategy. Nonetheless, there are different parties (e.g. generators, distributors) and objectives (e.g. cost or emissions minimisation, demand valley-filling) to consider for an efficient integration of PEVs, which makes the problem even more difficult. These characteristics justify the existence of different smart charging profiles. It is also important to determine whether the use of real-time management systems is economically justified. This document compares different possible strategies for charging PEVs and their consequences in the power system. The impact on costs, emissions and RES integration will be obtained using the ROM model. This model determines the UC and daily economic dispatch of the system (optimization module), considering the uncertainty associated to the parameters in real-time operation (simulation module). The Spanish system for 2020 is analysed under different PEVs penetration levels and charging strategies. The results show the benefits of using a smart charging profile instead of an unregulated profile. The cost reduction for smart charging is about 4.1% (cost minimization) and 3.9% (valley-filling). Moreover, the benefits of using a real-time management system are also evaluated for the valley-filling profile, resulting in a cost reduction of 0.01% compared to the use of mean fixed charging profiles.

Keywords electric vehicles (EVs), smart charge, valley-filling, optimization, RES integration.

Plug-In Electric Vehicle Participation in Electricity Markets - A Stochastic Optimisation Approach

Slot: Friday 20th 14:30-15:00, Room 144
Presenter: **Ilan Momber** (Comillas Pontifical University, Spain)
Coauthors: **Afzal Siddiqui** (University College London, United Kingdom) **Tomás Gómez San Román** (CNE - National Energy Commission of Spain, Spain)

Abstract It is expected that government policies for energy efficiency in transportation systems will clear the way for alternative propulsion technologies, such as Plug-in Electric Vehicles (PEVs), to become widespread in automotive industry sales. However, integrating PEVs in electric power systems (EPSs), such that system-favorable charging schedules are facilitated, still poses regulatory and technical challenges for the entire spectrum of stakeholders, from policy makers to regulated distribution system operators and competitive fleet owners. To favor an EPS in question, i.e. a collection of producers, consumers represented by retailers/load aggregators that meet in the electricity market as well as network operators, a combination of competitive market prices as well as regulated use-of-system charges should govern the PEV charging. However, the value proposition, i.e. the value adding services that a Flexible Load Aggregator (FLA) is theoretically bringing to the EPS via participating in electricity markets with a contracted fleet of PEVs under Direct Load Control (DLC), remains unclear to this point.

Abstract This paper presents a methodology to approximate the economic impact of using a PEV fleet's aggregated battery as a resource in electricity markets, ignoring all network aspects. A stochastic profit optimization of the FLA's self-scheduling is formulated with price taker participation in day-ahead energy and ancillary service markets for capacity. Uncertainty in market prices as well as energy demand is addressed. Using the Conditional Value-at-Risk (CVaR) methodology, risk aversion of the

FLA is explicitly captured. The corresponding sensitivity of expected profits is analyzed with an efficient frontier. As a result, we obtain the optimal PEV charging schedule and according FLA market bids, subject to energy demand requirements for transportation of the final customers.

Keywords plug-in electric vehicles, electricity markets, stochastic programming.

Optimal Decision Making for EVs Providing Electric Grid Frequency Regulation: A Stochastic Dynamic Programming Approach

Slot: Friday 20th 15:00-15:30, Room 144
Presenter: **Jonathan Donadee** (Carnegie Mellon University, USA)
Coauthors: **Marija Ilic** (Carnegie Mellon University, USA)

Plug in electric drive vehicles (EVs) are expected to be adopted in large numbers in the coming decades. Meanwhile, electric grid operators are rolling out advanced metering infrastructure that will enable demand side participation in electrical energy and ancillary services markets. Many deterministic optimization models have been proposed for minimizing the cost of charging the batteries of individual EVs and aggregated fleets of EVs. These models also include revenues that EVs could earn by providing ancillary services to the grid, such as secondary frequency regulation. Providing frequency regulation would require altering the battery charge rate every 4 seconds to follow a control signal, causing the battery state of charge to take a biased random walk. Models in the literature do not accurately consider the risks of providing regulation. Hard constraints are imposed to avoid risky scenarios or the cost of such scenarios is ignored. We propose a stochastic dynamic programming approach to optimize EV charging while providing frequency regulation. Our model incorporates inconvenience costs to drivers and penalties for failing to provide regulation. Starting at the final charge rate decision time before the vehicle unplugs, a two stage stochastic MILP deterministic equivalent problem (DEP) is solved for many possible states of charge. Many hour-long samples of the regulation signal are used to create scenarios in the DEP. Binary variables indicate timesteps when a regulation contract has been broken, allowing for an accurate calculation of penalties. The resulting costs form a value function of the state of charge. Through backward recursion, an optimal decision can be made and implemented at the current time. We present our problem formulation and simulation results for a single EV in an idealized energy market.

Keywords smart electric grid, SDP, MILP, ancillary services, smart appliance, electric vehicles.

Electricity Markets

Chair: F.-Javier Heredia

Finance Optimisation Research on Solar Electricity

Slot: Friday 20th 10:30-11:00, Room 343
Presenter: **Paul Sabloniere** (ECE Paris, France)
Coauthors: **Cyrille Lamoureux** (ECE Paris, France) **Thomas Gutierrez** (ECE Paris, France) **Angelique Grauffel** (ECE Paris, France) **Alexandre De Gabriac** (ECE Paris, France) **Duc Pham-Hi** (ECE Paris, France)

The sun as a provider of renewable, free-of-charge, and limitless resources of energy, is an attractive and sustainable source for electricity production. Industrial solar plant projects are subject to market prices. Prices of KWh vary by a factor of three within a day in France, and create a profitable market for solar projects providing storage of energy versus solutions with no storage. Beyond photovoltaic technologies, solar power plants need significant investments and were in the past considered too costly.

In this paper, we present an optimization model to make profitable a molten salt solar power plant, by choosing optimal periods of electricity delivery. The problem of provisioning and dynamically optimizing such industrial projects requires implementing numerical methods that yield approximate solutions. The core of the problem is to solve a Hamilton-Jacobi-Bellman (HJB) partial derivatives equation in an infinite horizon dynamic optimal control problem, combined with a stochastic representation of solar incoming energy intensity. The system behavior is modeled by two sets of equations. The first set links the plant's specifications: the molten salt tank capacity, the total surface of mirrors, the power generator and their unit costs. The second set links the variables modeling sunlight random intensity, the price of the KWh of a given period with the molten salt tank level as a time dependent control variable $u(t)$. Solving HJB will compute the optimal $u^*(k)$ through a dynamic backward induction algorithm that combines the sunlight intensity with the expected $u(k)$ at the end of period k estimated from the one on period $k+1$.

The application of this technique, inspired from American derivative option pricing, can be extended to other areas where control problems are exposed to time dependent sets of price and return. It is a work-around for the curse of dimensionality in HJB problems.

Keywords infinite horizon optimal control, Hamilton-Jacobi-Bellman, Longstaff-Schwartz, molten salt solar tower power plant.

A Robust Bilevel Optimisation Approach to Generation Capacity Expansion in Liberalized Electricity Markets

Slot: Friday 20th 11:00-11:30, Room 343
Presenter: **Bratislav Svetozarevic** (ETH Zurich, Switzerland)
Coauthors: **Paul Goulart** (ETH Zurich, Switzerland) **John Lygeros** (ETH Zurich, Switzerland)

This paper provides a methodology to assist a strategic electricity producer in making informed decisions about investments in generation capacity, considering uncertainty in rivals' investment and offering decisions and demand growth. The strategic behavior of the producer is represented through a robust bilevel model whose upper level problem considers both investment and offering decisions to maximize the total expected profit and whose lower-level problems represent market clearing conditions for each demand block. Most of the current approaches characterize uncertainties in rivals' behavior and demand growth through scenarios, such that for each scenario a new lower-level program is defined. By replacing the lower-level programs by their Karush-Kuhn-Tucker (KKT) conditions, the complementarity constraints of the lower-level programs are replicated for each scenario. This results in a large-scale mathematical program with equilibrium constraints (MPEC). We instead propose to consider the convex hull of all possible scenarios and to treat the resulting collection of lower-level problems as a single robust program. If there exists a tractable convex counterpart of the robust lower-level program, as in the case of robust linear programs, than by taking the KKT conditions of the convex counterpart we obtain a smaller number of complementarity constraints in the final MPEC. Therefore, our approach leads to a

more tractable optimization problem. The MPEC is than transformed to a mixed-integer linear program (MILP) and solved using currently available solvers. Results from an illustrative example and a case study are reported and discussed. Moreover, a comparison of our approach with other approaches in the literature obtained on the case study is provided.

Keywords robust bilevel programming, generation expansion planning, mathematical programs with equilibrium constraints (MPEC).

Generation Capacity Expansion in Electricity Markets under Rivalry and Uncertainty

Slot: Friday 20th 11:30-12:00, Room 343
Presenter: **Michail Chronopoulos** (London Business School, United Kingdom)

We propose to extend the traditional real options approach to electricity capacity expansion by investigating game-theoretic issues emerging from the competition between agents, each with a portfolio of electricity production technologies. Such a framework will take into account not only the feedback effect of capacity expansion on the price of electricity and the dependence of the value of a generation unit on the presence of others (Gahungu and Smeers, 2011) but also the strategic aspects of capacity expansion in a quasi-analytical framework. We explore the application potential of real options theory in this new context of capacity expansion in the electricity sector by accounting not only for dependency between the cash flows of competing technologies but also for competition from a rival. Although market equilibrium can be determined analytically in stylised real options models, in a more general setting with asymmetric costs, multiple supply and demand nodes, and pipeline capacity restrictions, analytical solution of a system of equations is not possible. Therefore, a convex programming approach cannot be adopted to find the market equilibrium, while complementarity problems provide a viable modelling approach. Hence, in order to extend the framework of Gahungu and Smeers (2011) to account for competition, we will cast this problem as a mixed complementarity one. While Gahungu and Smeers (2011) indicate that the incentive to delay investment increases both with greater uncertainty and capital stock, whether a strategic context would promote a greater herding tendency or erode the option value of waiting is an important open research question, which becomes of even greater interest when considering the particular nature of the portfolios and the ability to diversify them.

Keywords electricity capacity expansion, competition, mixed complementarity.

Optimal Sale Bid for a Wind Producer in Spanish Electricity Market Through Stochastic Programming

Slot: Friday 20th 12:00-12:30, Room 343
Presenter: **F.-Javier Heredia** (Polytechnic University of Catalonia, Spain)
Coauthors: **Simona Scripante** (Universitat Politècnica de Catalunya, Spain) **Cristina Corchero** (Universitat Politècnica de Catalunya, Spain)

Wind power generation has a key role in Spanish electricity system since it is a native source of energy that could help Spain to reduce its dependency on the exterior for the production of electricity. Apart from the great environmental benefits produced, wind energy reduce considerably spot energy price, reaching to cover 16,6% of peninsular demand. Although, wind farms show high investment costs and need an efficient incentive scheme to be financed. If on one hand, Spain has been a leading country in Europe in developing a successful incentive scheme, nowadays tariff deficit and negative economic conjunctures asks for consistent reductions in the support mechanism and demand wind producers to be able to compete into the market with more mature technologies. The objective of this work is to find an optimal commercial strategy in the production market that would allow wind producer to maximize their daily profit. That can be achieved on one hand, increasing incomes in day-ahead and intraday markets, on the other hand, reducing deviation costs due to error in generation predictions. We will previously analyze market features and common practices in use and then develop our own sale strategy solving a two-stage linear stochastic optimization problem. The first stage variable will be the sale bid in the day–ahead market while second stage variables will be the offers to the six sessions of intraday

market. The model is implemented using real data from a wind producer leader in Spain.

Keywords stochastic programming.

Energy Systems I

Chair: Michel Gendreau

A Coherent Risk Measure Applied to the Brazilian Long Term Hydrothermal Scheduling

Slot: Wednesday 18th 11:15-11:45, Room 144
Presenter: **Vitor de Matos** (Universidade Federal de Santa Catarina, Brazil)
Coauthors: **Erlon Finardi** (Universidade Federal de Santa Catarina, Brazil) **Paulo Larroyd** (Universidade Federal de Santa Catarina, Brazil)

In power systems that rely heavily on hydroelectricity, such as those of Brazil and New Zealand, the hydrothermal scheduling problem plays an important role, given that if the water in the reservoirs is not used wisely throughout the operation, the system may present a high load shedding risk. The long-term hydrothermal scheduling (LTHS) problem aims to define the dispatch of each power plant in a power system in order to meet the demand for electricity over a long-term planning horizon (of years) at minimum expected operation cost (consisting of thermal fuel costs and penalties).

Although the dispatch at minimum expected operation cost is the most efficient from the economics point of view, there exist a small portion of scenario (tail of the cost probability distribution) in which the decision taken over the minimum expected cost incurs in a high risk of load shedding. Therefore, it is necessary to define an approach that deals with the risk of load shedding. In this sense, we use a Coherent Risk Measure (CRM), which is the convex combination of Expectation and Conditional Value-at-Risk (CVaR), as objective function.

The Brazilian LTHS problem is important because it is used to take decision that affects the operation and energy prices. The decisions aim at minimizing the expected total cost, but a minimum zone for stored energy is considered in order to reduce the risk of load shedding. In this paper we discuss the results of using the CRM to the Brazilian problem and no minimum zone is considered. We show that this approach yields a policy, computed by means of Stochastic Dual Dynamic Programming, that although it is more expensive on average, more thermal plants are dispatched, the reservoirs storage levels are higher, this increases the systems reliability by reducing the load shedding risk and depth.

Keywords hydrothermal scheduling, coherent risk measure, stochastic dual dynamic programming.

Stochastic Rainfall-Runoff Generators and Hydraulic Modelling in Optimisation of Drainage Pumping Station Regime

Slot: Wednesday 18th 11:45-12:15, Room 144
Presenter: **Milica Vranesevic** (University of Novi Sad, Serbia)
Coauthors: **Atila Bezdan** (University of Novi Sad, Serbia)

Agricultural drainage systems are designed to collect, convey and evacuate excess water in order to regulate the soil water-air regime to enhance agricultural crop production. The efficiency of drainage system largely depends on the condition of drainage network, primarily on the condition of the main canal but it also depends on the pumping regime.

This paper analyzes the effects of discontinuous and continuous pumping regime on the change in water level along the main canal based on stochastic rainfall-runoff generator and hydraulic modeling. The studies were conducted on the agricultural drainage system Plavna, located in the North West Serbia where agricultural production depends greatly on the efficiency of the drainage systems.

The continuous long term historical records from the four rainfall gauges in the study area were unavailable so the missing data were generated. Stochastic rainfall generators can provide precipitation input to hydrologic models whenever data are not available. Their parameters are calculated so that the long-term statistics of the synthetic rainfall time series match those of the rainfall records. In this study a non-homogeneous Markov model was used for generating daily rainfall. The Akaike information criterion and the Bayesian information criterion were used to determine the optimum order of the Markov

chains. A kernel estimator was used to estimate the transition probabilities through a weighted average of transition counts over a symmetric time interval centered at the day of interest.

Required input hydrographs for the hydraulic model were calculated. An unsteady HEC-RAS hydraulic model was created to simulate different pumping regimes. Simulations have shown that discontinuous pumping regime, which is usually applied in practice, has an adverse impact on the efficiency of removal of excess water and increases the risk of geomechanical instability of the inner canal bank.

Keywords stochastic rainfall generator, Markov chains, unsteady hydraulic modeling.

Midterm Hydro Generation Scheduling Under Inflow Uncertainty Using the Progressive Hedging Algorithm

Slot: Wednesday 18th 12:15-12:45, Room 144

Presenter: **Michel Gendreau** (École Polytechnique de Montréal, Canada)
Coauthors: **Pierre-Luc Carpentier** (École Polytechnique de Montréal, Canada) **Fabian Bastin** (Université de Montréal, Canada)

Hydro-Québec is among the largest electric utilities in North America. Virtually all of its power supply is generated using hydro plants. Its production is mostly sold on Quebec domestic market, but surpluses can be traded on wholesale markets.

A key problem faced by Hydro-Québec's planners is the midterm generation scheduling problem (MGSP), which is solved on a weekly basis. The aim is to set weekly generation targets for controllable hydro plants in order to manage reservoirs energy storage efficiently over the coming months.

Reservoir inflow intensity is generally unpredictable beyond a few days and this source of uncertainty must be taken into account in the decision-making process. At this time, deterministic decision-support tools are used for this task, but it seems natural to envision replacing them by stochastic optimization models.

In this paper, we consider the situation in which reservoir inflow uncertainty is modeled through scenario trees. This allows us to tackle the problem using a scenario decomposition scheme, as in the Progressive Hedging Algorithm (PHA) proposed by Rockafellar and Wets in 1991. We recently developed a stochastic optimization model based on the PHA to solve the MGSP. In this model, hydroelectric production functions are modeled by concave piecewise- linear functions of the upstream reservoir storage and of water release. A key feature of our implementation of the PHA is a new penalty parameter update formula.

Our main objective is to evaluate the model's performance on Hydro-Québec's power system over a 52-period planning horizon with several load levels. In this system, there are with 23 large reservoirs and 25 hydro plants. Reservoir inflow uncertainty is modeled by 1024-scenario trees. Computational results show that the PHA is capable of handling such a large power generation system and that our penalty parameter update formula greatly accelerates the convergence of the algorithm.

Keywords midterm hydro scheduling, multi-stage stochastic program, progressive hedging algorithm, scenario decomposition, multi-reservoir system operation, hydropower.

Energy Systems II

Chair: David Fuller

Optimizing Trading Decisions for Hydro Storage Systems Using Approximate Dual Dynamic Programming

Slot: Wednesday 18th 14:15-14:45, Room 144
Presenter: **David Wozabal** (University of Vienna, Austria)
Coauthors: **Nils Löhndorf** (University of Vienna, Austria) **Stefan Minner** (Technische Universität München, Germany)

We propose a new model formulation for the optimal operation of hydro storage systems in wholesale electricity markets. Our formulation integrates short-term intraday with long-term interday decisions. The intraday problem considers bidding decisions into the electricity market as well as storage operation during the day and is formulated as a stochastic program. The interday problem is modeled as a Markov decision process of managing storage operation over time, for which we propose integrating stochastic dual dynamic programming with approximate dynamic programming. We show that the approximate solution converges towards an upper bound of the optimal solution. We apply the approach along with an econometric electricity price model to a case study of an actual hydro storage system in Austria. Our results demonstrate that the gap between approximate and optimal solution is negligible and that the approach is tractable for real-world applications.

Keywords OR in energy, stochastic programming, Markov decision processes, simulation, approximate dynamic programming.

A Receding-horizon Approach to Short-term Electricity Markets

Slot: Wednesday 18th 14:45-15:15, Room 144
Presenter: **Joseph Warrington** (ETH Zurich, Switzerland)
Coauthors: **Paul Goulart** (ETH Zurich, Switzerland) **Sébastien Mariéthoz** (ETH Zurich, Switzerland) **Manfred Morari** (ETH Zurich, Switzerland)

The incorporation of uncertain and rapidly-changing quantities of intermittent renewable energy is arguably the major challenge of the coming decades for the operators of electrical grids in those countries where the renewable share is expanding. This is because ever greater flexibility from the other market participants is needed in order for power production and consumption to be shaped around the exogenous power infeed. The difficulty of ensuring this flexibility is provided efficiently is compounded by the need for the solution to be compatible with market-based operation of the power system.

A strategy explored in this work is the re-negotiation of prices and power volumes on a receding horizon basis, borrowing from predictive control principles. The aim of this approach is to ensure that the newest forecasts of exogenous power injections into the network are available at all times. This should improve efficiency by allowing market participants to adjust power consumption or production plans at the earliest possible stage.

We report on the application of Lagrangian relaxation techniques to finite horizon (multi-period) power flow problems with diverse market participants, such as generators, storage devices, aggregated household appliances, and other consumers. The methods are demonstrated in the presence of network constraints, firstly for linearised "DC-approximated" grid models, and then on full AC grid models via a tight semidefinite relaxation of the power flow problem. We discuss the computational issues arising from attempting to solve the multi-period optimization using distributed methods.

Finally, since these optimization techniques respect principles such as privacy of information and can therefore be interpreted as iterative market clearing mechanisms, their potential adaptation for use in real intraday electricity markets is discussed.

Keywords energy markets, distributed optimization, optimal power flow, Lagrangian relaxation, semidefinite programming, receding horizon control.

Equilibrium Prices from Models with Continuous and Binary Variables: Applications to Unit Commitment and Capacity Expansion for Electric Power

Slot: Wednesday 18th 15:15-15:45, Room 144
Presenter: **David Fuller** (University of Waterloo, Canada)

Market equilibrium models with continuous and binary variables often have no solutions if prices are related only to the continuous variable commodities. Two examples from the electric power industry take the form of mixed integer programs – unit commitment and some capacity expansion models. The definition of equilibrium prices for such models has not been fully resolved over several decades, but O'Neill et al. took a major step in a paper in EJOR in 2005. Their proposal has three major shortcomings: the possibility that some prices are negative; possibly unfair price discrimination; and an incomplete treatment of the fact that all revenues paid to producers must be collected from consumers. The first two shortcomings are resolved in this paper, by first extending the results of O'Neill et al. to allow for a much larger set of equilibrium prices. In particular, price discrimination is removed or limited in a controlled way by defining a "capacity price" that is to be paid whenever a binary variable takes the value one. A resolution of the third shortcoming is also explored. The results are illustrated with a unit commitment model, and with an electric power capacity expansion model.

Keywords equilibrium prices, non-convex models, unit commitment, capacity expansion, electric power.

Energy Systems III

Organiser: Afzal Siddiqui
Chair: Afzal Siddiqui

Optimal Technology Selection and Operation of Commercial-Building Microgrids Under Uncertainty and Risk Aversion

Slot: Thursday 19th 08:30-09:00, Room 144
Presenter: **Lajos Maurovich Horvat** (University College London, United Kingdom)

Technological advancements in small-scale distributed generations (DG) have made it possible for smaller institutional and industrial facilities to use on-site generations. Recent works on microgrids also indicate that DG with combined heat and power (CHP) applications can result in reduced energy cost and CO2 emissions (Siddiqui et al., 2005; Marnay et al., 2008; Siddiqui and Maribu, 2009).

While the EU and its member states as well have recognised the benefits of DG and CHP, the targets regarding the higher share of cogeneration and increased energy efficiency have rarely been achieved (Streckiene et al., 2009). One of the possible reasons for this is that the operator of the microgrid in deregulated markets would face considerably high risk due to uncertain electricity and fuel prices. This in turn results in insufficient investments for non-energy companies in energy-efficient technologies which often have lower risk tolerance for investments with undiversifiable risk, i.e., investments outside their core businesses (Heaton and Lucas, 2000; Schleich and Gruber, 2008; Wang et al., 2008).

We apply stochastic mixed-integer programming to find the optimal investment and operation of a cost-minimising microgrid and to assess its profitability and operational risk. We assume that the microgrid has to satisfy the electricity and heat loads at all time. To do so the microgrid can purchase electricity and gas from the spot and forward markets or can invest in DER technologies and produce electricity onsite. We investigate that under which circumstances it is optimal for the microgrid to use physical (DER technology) or financial (electricity and gas forwards) hedges or both. Finally, we examine the efficiency and the CO2 emissions of the microgrid and consider different policy options that can support investment in DG.

Keywords stochastic programming, risk aversion, microgrid, technology selection.

Scenario Generation for Building Operations and Investment

Slot: Thursday 19th 09:00-09:30, Room 144
Presenter: **Michal Kaut** (SINTEF Technology and Society, Norway)
Coauthors: **Kjetil Midthun** (SINTEF Technology and Society, Norway) **Adrian Werner** (SINTEF Technology and Society, Norway)

Following recent deregulation processes in the energy sector, consumers can take a more active role in controlling their energy usage and meeting energy needs. Daily operations can become more responsive to market situations. In order to achieve best possible economic and energy efficiency, investments into technology, including storage and generation equipment and passive measures, should be planned carefully. A decision support system helps building managers or operators in this process. Different time scales and contradictory goals require two modules: An operational module helps planning the operation of installed devices over a few days. An investment module helps finding long-term investment and de-installation strategies. In order to find properly cost- and energy-efficient measures, this module should evaluate the daily performance of the proposed infrastructure. Obviously, these planning processes are subject to substantial uncertainty: Operations are planned without precisely knowing demands, weather conditions, or, in the case of real-time pricing, energy prices. Investment strategies are found under imperfect knowledge about future technology prices and efficiencies. They should also create a flexible and robust infrastructure to cope with varying conditions. The uncertainty comes in various forms, some of which can be addressed by discretizing the underlying stochastic processes; that is, generating scenarios or, in the dynamic case, scenario trees. However, this task is not straight-forward for the investment module involving different time scales. We propose a "hybrid" structure addressing both long and short term uncertainty. Furthermore, we discuss the scenario-generation process itself. It starts with

a time-series analysis of the data, which gives us the historical forecast errors as our representations of uncertainty. Then we generate scenarios for the error terms and convert those to the target values using the fitted models. This way, the scenario generation framework provides the operations and investment decision support modules with data for the stochastic parameters.

Keywords scenario generation, stochastic programming.

Strategic Model for Robust Planning: Energy Efficiency and Risk Management in Public Buildings

Slot: Thursday 19th 09:30-10:00, Room 144
Presenter: **Javier M. Moguerza** (University Rey Juan Carlos, Spain)
Coauthors: **Emilio L. Cano** (University Rey Juan Carlos, Spain) **Tatiana Ermolieva** (International Institute for Applied Systems Analysis, Austria) **Yuri Ermoliev** (International Institute for Applied Systems Analysis, Austria)

Due to deregulations in energy sector and the setting of targets such as the 20/20/20 in the EU, operators of public buildings are now more exposed to instantaneous (short-term) market conditions. On the other hand, they gained the opportunity to play a more active role in securing long-term supply, managing demand, and hedging against risk while improving existing buildings infrastructures. Therefore, there are incentives for the operators to develop and use a Decision Support System to optimize their energy sub-systems in a more robust energy-efficient and cost-effective manner. In the presence of deregulations and uncertainties, there is a dilemma to choose an efficient technological portfolio in real time while pursuing long-term goals. The solution of the problem involves the so-called two-stage dynamic stochastic optimisation models with a rolling horizon. In this paper, a two-stage stochastic model is proposed, where some decisions (so-called first-stage decisions) regarding investments into new energy technologies have to be taken before uncertainties are resolved and some others (so-called second-stage decisions) will be taken once values for uncertain parameters become known, thereby providing a trade-off between long- and short-term decisions. Investment planning and operational optimization decisions concern demand and supply sides of different energy types (electricity, gas, heat, solar, etc.). The demand side is affected by old and new equipment and activities including such end uses as electricity only, heating, cooling, cooking, new types of windows and buildings, and energy saving technologies, etc. New activities may change peak loads whereas accumulators may considerably smooth energy demand–supply processes. The proposed stochastic model is capable of dealing with short- and long-term horizons. In particular, the model avoids unrealistic "end-of-the-world" effects of dynamic deterministic models. The model is illustrated with examples from simulated and real test sites.

Keywords energy efficiency, planning, risk management, stochastic programming.

Optimising Distributed Energy Operations in Buildings

Slot: Thursday 19th 10:00-10:30, Room 144
Presenter: **Afzal Siddiqui** (University College London, United Kingdom)
Coauthors: **Markus Groissböck** (Center for Energy and Innovative Technologies, Austria) **Somayeh Heydari** (University College London, United Kingdom) **Eugenio Perea** (Tecnalia Research and Innovation, Spain) **Ana Mera Vazquez** (Tecnalia Research and Innovation, Spain) **Michael Stadler** (Center for Energy and Innovative Technologies, Austria)

Deregulation of the energy sector has created new markets for producers as well as opportunities for consumers to meet their needs in a more customised way. However, in order to realise economic and energy efficiency gains, small-scale consumers at the building level require more tailored decision support. Indeed, deregulation also makes it necessary for decision makers to respond to market conditions, thereby becoming more active participants than in the regulated paradigm. Yet, traditional building energy management systems operate in a static fashion by adjusting air or water flow in heating and cooling systems in response to pre-determined triggers, viz., large deviations in the zone temperature from the setpoint temperature. In this paper, we provide decision support to operators of buildings via more active management of the installed equipment that seeks to minimise energy costs and/or maximise

energy efficiency. Assuming that the building's occupants have upper and lower limits for the temperature, we model the effect of active equipment control (via changes to either the setpoint or the valve flow) on the zone temperature taking into account the external temperature, solar gains, the building's shell, and internal loads. The energy required to change the zone temperature in each time period is then used to calculate the energy cost or efficiency in the objective function of an optimisation problem. Thus, we are able to find an optimal operating schedule for building equipment during each hour of a day given the occupants' preferences. By implementing our model for EU public buildings, we demonstrate the advantages of more active equipment management in terms of lower costs and higher efficiency. For both consumers and policymakers, the provision of such decision support is timely since recent years have emphasised tackling climate change by improving energy efficiency of existing building stock.

Keywords buildings, dynamic optimisation, energy systems.

Energy Systems IV

Organiser: Andres Ramos
Chair: Andres Ramos

Stochastic Programming Applied to Olive Husk Milling Process

Slot: Thursday 19th 13:30-14:00, Room 144
Presenter: **Pedro Sánchez Martín** (Comillas Pontifical University, Spain)

Olive husk is a by-product obtained from the industrial process for olive oil production containing oil, olive skin and stones. This olive husk is usually carried from presses to an Olive Waste Management Center where a mechanical milling extraction process is performed to obtain Olive Pomace Oil. The remaining oil in the husk is chemically extracted and finally, the residual husk is used as fuel for a cogeneration process to produce electricity. The olive Pomace Oil from mechanical milling has higher quality and price than the one extracted chemically. As the seasonal olive collection campaign is from October to March, husk usually is stored and processed along the year. Due to the own husk chemical degradation and the constrained milling capacity, not all received husk is milled mechanically but always chemically. Different pools are used to store and classify husk qualities. There are pools for short, medium and long term horizons. Short term pools have low storage capacity and contains high quality husk which is shortly milled mechanically. Medium term pools have higher storage capacity containing medium quality husk. These mid term pools provide husk to be milled mechanically when the collection rate decreases, or the husk quality coming from presses is poor. Long term pools have also high storage capacity and store husk with poor quality to be processed only chemically. The stochastic model is focused on optimal pouring decisions into different types of pools to improve the efficiency of the husk mechanical milling. Several probabilistic scenarios of weekly husk pouring from presses are included in the stochastic programming model. Blending husk with different qualities brings nonlinear constraints into the computation of milling efficiency. To cope with these nonlinearities, an accurate approximation has been developed. A real case study is analyzed for different weeks along the collection campaign.

Keywords stochastic programming, olive husk milling.

Parallel Computational Implementation of a Branch and Fix Coordination Algorithm

Slot: Thursday 19th 14:00-14:30, Room 144
Presenter: **Gerardo Perez Valdes** (Norwegian University of Science and Technology, Norway)
Coauthors: **Adela Pages-Bernaus** (Norwegian University of Science and Technology, Norway) **Asgeir Tomasgard** (Norwegian University of Science and Technology, Norway) **Marte Fodstad** (Norwegian University of Science and Technology, Norway) **Escudero Laureano** (University Rey Juan Carlos, Spain) **Perez Gloria** (University of the Basque Country, Spain)

Branch and Fix Coordination is an algorithm designed to solve large scale multi-stage stochastic mixed integer problems, based on the notion that the particular structure of such problems makes it so that they can be broken down into scenario clusters with smaller subproblems. With this in mind, it is possible to use parallel computing techniques to solve the subproblems created: each processor solves the subproblems pertaining to a particular cluster almost independently. Then To comply with the nonanticipativity constraints required for the global solution, the values of the binary variables in the subproblem solutions are coordinated by a master processor. Scenario clusters lend themselves particularly well to parallelization. Furthermore, smaller subproblems allow us to solve otherwise intractable instances, where the number of variables is too large to be efficiently computed in a single processor. In this work, we present details on the computational implementation of the Branch and Fix coordination algorithm; specifically, we have applied this method to natural gas infrastructure and similar energetic settings. Binary variables in the problem are investment decisions (pipelines, plants) while uncertainty is present in the form of unknown prices, demands, reserves, gas quality, and so on. Results on the experimentation over these conditions are presented and discussed, and areas of opportunity are also considered.

Keywords Branch-and-bound, stochastic, binary, parallel computing.

Network-Constrained Multiperiod Auction for a Pool-Based Electricity Market under Consumer Payment Minimisation

Slot: Thursday 19th 14:30-15:00, Room 144
Presenter: **Ricardo Fernández-Blanco** (Universidad de Castilla - La Mancha, Spain)
Coauthors: **José Arroyo** (Universidad de Castilla - La Mancha, Spain) **Natalia Alguacil** (Universidad de Castilla - La Mancha, Spain)

This paper examines a number of issues related to market-clearing procedures currently used in the operation of restructured power systems. We consider a pool-based electricity market for energy where producers and consumers respectively submit energy offers and bids to the independent system operator. Using a market-clearing procedure, this entity determines the market-clearing prices as well as the set of accepted offers and bids. Conventional market-clearing procedures are driven by declared social welfare maximization, which is a sound goal from an economic perspective under ideal conditions. However, declared social welfare maximization is characterized by several practical shortcomings thus yielding undesired distortion.

In order to overcome such deficiencies, this paper presents an alternative market-clearing procedure based on consumer payment minimization. This auction is an instance of price-based market clearing wherein market-clearing prices are explicitly modeled as decision variables of the optimization. This aspect further complicates the solution of the problem. The proposed auction design also takes into account the effect of the transmission network. Under a marginal pricing scheme, locational marginal prices are characterized by a bilevel programming approach. In the upper optimization level, generation scheduling is determined while taking into account that in the lower optimization level an optimal power flow is solved. In this bilevel programming setting, locational marginal prices are the Lagrange multipliers or dual variables associated with the power balance equations of the lower-level problem. The resulting mixed-integer linear bilevel program is transformed into an equivalent single-level mixed-integer linear program suitable for efficient off-the-shelf software.

The proposed methodology has been applied to small examples and the IEEE Reliability Test System. Numerical results show the effectiveness of the proposed tool to assess consumer payment minimization versus currently used social welfare maximization.

Keywords bi-level programming, consumer payment minimization, locational marginal pricing, transmission constraints.

Energy Systems V

Chair: Paula Rocha

Capacity Expansion under Uncertainty in the Power Sector

Slot: Friday 20th 08:30-09:00, Room 144
Presenter: **Dorea Chin** (University College London, United Kingdom)

The surge in demand for electricity in recent years requires that power companies ensure sufficient generation capacity to meet this increase. Yet at the same time, energy demand is subject to seasonal variation and peak hour factors that cause it to be extremely volatile and unpredictable, thus complicating the decision process. This project aims to investigate how power companies can optimise their expansion decisions whilst facing uncertainty, and examine how expansion and forward contracts can be used as suitable tools for hedging against risk. The CVaR is adopted as a coherent measure of risk. Instead of assuming price-taking behaviour, more realistic market conditions of monopolies and oligopolies are considered. The stochastic optimisation problem is solved using a mixed complementary approach. Scenario specific numerical results are analysed and conclusions drawn on how risk aversion, competition and uncertainty interplay in selling and expansion decisions of a power company. These conclusions can be further extended to more complicated and realistic models in future.

Keywords capacity expansion, energy markets, stochastic programming, risk, mixed complementary problem.

Investment in Solar Photovoltaic Technology: A Statistical Study on Risks and Support Schemes

Slot: Friday 20th 09:00-09:30, Room 144
Presenter: **Teck Hao Tan** (University College London, United Kingdom)

It has become common practice among energy companies, commercial entities, and domestic households to invest in renewable energy. Electricity prices in deregulated industries as well as meteorological conditions such as wind speed and solar irradiation, however, shroud such investments in risk and uncertainty. Statistical modelling provides a means by which these risks may be analysed. This will allow investment decisions to be better informed and also serve as an assessment tool for policymakers. We provide a detailed study conducted on the feasibility of investments in grid-connected solar photovoltaic (PV) systems in Singapore.

Through the Monte Carlo simulation method, both the mean-reverting (MR) and mean-reverting jump diffusion (MRJD) processes are used to model deseasonalised logarithms of electricity prices faced by investors. Annual power output from the PV system is modelled based on meteorological data. The price and energy output processes are then combined to simulate the annual revenue that the investment will yield. After this, the net present value (NPV) of the project is derived for each simulated path by differencing the appropriate revenue and the levelised cost of energy. With this information, the expected NPV and risks of investment can then be analysed.

This paper further explores the impact of existing economic support schemes for encouraging such investment in Singapore by studying the distribution of the NPV, the value-at-risk, and the conditional-value-at-risk. The support schemes discussed in detail are government subsidies on installation costs, feed-in tariffs (FITs), and special loans. The paper finally concludes with an analysis of the sensitivity of each support scheme and a discussion on its appeal to investors.

Keywords energy, renewable energy, statistical modelling.

A Decision Rule Approach to Medium-Term Hydropower Scheduling Under Uncertainty

Slot: Friday 20th 09:30-10:00, Room 144
Presenter: **Paula Rocha** (Imperial College London, United Kingdom)

Coauthors: **Wolfram Wiesemann** (Imperial College London, United Kingdom) **Daniel Kuhn** (Imperial College London, United Kingdom)

In this talk we address the scheduling of a cascaded hydropower system over a medium-term planning horizon. To this end, we present a multistage stochastic optimisation model which determines a generation and pumping schedule that maximises the expected profit from trading energy on the spot market. Electricity spot prices change on a much shorter time scale than the hydrological dynamics of the reservoirs in the cascade. We exploit this property to reduce the computational complexity of the model: we partition the planning horizon into hydrological macroperiods, each of which accommodates many trading microperiods, and we account for intra-stage price variability through the use of price duration curves. In addition, we restrict the space of recourse decisions to those affine in the history of the random parameters, thereby obtaining a tractable approximate problem. We evaluate the accuracy of these approximations and the scalability of the resulting optimisation problems in the context of a realistic case study.

Keywords hydropower scheduling, stochastic programming, linear decision rules.

Energy Systems VI

Organiser: Andres Ramos
Chair: Andres Ramos

Approximate Dynamic Programming for Environmental and Technology Policy Portfolio Optimisation under RD Uncertainty: The Case of the U.S. Electric Power Sector

Slot: Friday 20th 10:30-11:00, Room 144
Presenter: **Nidhi Santen** (Massachusetts Institute of Technology, USA)
Coauthors: **Mort Webster** (Massachusetts Institute of Technology, USA)

Managing carbon dioxide (CO2) emissions from fossil-based electric power generation is critical for successfully executing a global climate-protection and risk management plan. Unfortunately, many technologies for reducing CO2 emissions from the electricity sector are either still in early conceptual stages or available at high costs or small scales, requiring additional research and development (RD); the industry continues to meet increasing electricity demands with technologies that are both commercially available and economically viable.

To address the dilemma of resolving increasing energy demands with emission reduction goals, policymakers are interested in the dual role that environmental policy instruments can play in near-term carbon reductions by incentivizing existing low-carbon technology adoption, and long-term carbon reductions by inducing private RD. Likewise, the possibility that early and direct public RD can reduce the overall cost of mitigating future climate damages is enticing. However, identifying the best policies remains elusive due to the complexity with which different policy instruments affect existing technology adoption versus new technology RD, the magnitude of uncertainties associated with the outcomes to RD, and the long lifetimes of electric power capacity investments.

We present a stochastic modeling framework for comparing the relative impacts of environmental and RD policies on generation expansion under technological uncertainty, and optimize policy portfolios to guide low-carbon technological transformations in the power industry. We employ approximate dynamic programming (ADP) techniques to structure the model to make stochastic sequential decisions with learning and adaptation. The new model reveals how different policy instruments affect different evolutions of the power generation technology mix, and helps identify an optimal balance between them in the presence of uncertainty. In this presentation, we introduce the model, describe the ADP algorithm and its merits, and compare the stochastic and deterministic optimal policies for the case of the United States.

Keywords approximate dynamic programming, stochastic optimization, electricity, RD, technology change, portfolio optimization, decision-making under uncertainty, environmental policy.

Decomposition Strategies Applied to the Optimal Design of the Electrical Layout of an Offshore Wind Farm

Slot: Friday 20th 11:00-11:30, Room 144
Presenter: **Sara Lumbreras** (Comillas Pontifical University, Spain)
Coauthors: **Andres Ramos** (Comillas Pontifical University, Spain)

Electrical layout design is a critical element for offshore wind farms, and one of the main drivers of both cost and reliability. The model OWL (Offshore Windfarm Layout optimizer) produces optimal electrical layouts in reduced computation times. OWL considers all the most relevant design possibilities and factors, with the inclusion of HVDC connection and consideration of stochasticity in both wind inputs and component failures as well as losses. A real case study demonstration of the algorithm has been carried out based on Barrow Offshore Wind Farm in the East Irish Sea. OWL produces a substantially improved design, with total realizable savings of EUR 800k over the actual implementation of the farm. In addition, the optimal layout presents a remarkable lack of symmetry and redundancy in certain elements, supporting the need of a full optimization rather than the selection of a pre-established config-

uration. OWL exploits the structure of the problem to improve its MIP implementation with Benders' decomposition. In addition, efficiency has been increased by scenario aggregation and the dynamic addition of partially relaxed cuts. Moreover, an algorithm that has been named "Progressive Contingency Incorporation" accelerates convergence by solving a series of simplified instances of the same problem. The developed mechanisms reach time savings of two orders of magnitude.

Keywords offshore wind farm, stochastic optimization, Benders decomposition.

How RES Volatility Affects the Optimal Unit Commitment of Thermal Power Plants: an Analysis Performed by a Stochastic Power Market Simulator

Slot: Friday 20th 11:30-12:00, Room 144
Presenter: **Dario Siface** (RSE SpA, Italy)
Coauthors: **Maria Teresa Vespucci** (University of Bergamo, Italy) **Alberto Gelmini** (RSE SpA, Italy)

The increasing amount of Renewable Energy Sources (RES) ijected into power systems results in an increasing uncertainty in electricity generation, which has to be taken into account in energy market simulation models. The stochastic medium term (time horizon from one week to one whole year) market simulator s-MTSIM has been developed in a collaboration between RSE S.p.A. and University of Bergamo, as a stochastic extension of the existing deterministic market simulator MTSIM, originally developed by RSE. s-MTSIM solves the hourly large scale stochastic Unit Commitment (UC) problem for a Zonal Power System by means of Stochastic Linear Programming (LP) techniques and a heuristic procedure to cope with the Mixed Integer intrinsic nature of UC problem. RES generation uncertainty is taken into account by building different RES generation scenarios. Each scenario has a corresponding probability and it is derived from a statistical characterization of RES generation profiles performed on the historical data available on the Italian Transmission System Operator web site, with zonal and hourly detail. This work compares two different UC's for thermal generation units in a power system with high levels of RES penetration in a time horizon of one week characterized by low demand levels, in order to highlight the stress caused on the whole system by RES uncertainty. The first UC is calculated stochastically by means of s-MTSIM market simulator; the second one is, instead, calculated deterministically considering only one possible RES generation scenario. Then, the two UC's just calculated are tested on the same "actual RES generation" profile so that it is possible to compare their performances with respect to the costs of generation, CO2 emissions, fuel consumption, congestion of inter-zonal connections and zonal prices.

Keywords stochastic programming, renewable energy sources, unit commitment problem, medium term market simulation.

A Dynamic Stochastic Transmission Planning Model Solved by Efficient Benders' Decomposition

Slot: Friday 20th 12:00-12:30, Room 144
Presenter: **Andres Ramos** (Comillas Pontifical University, Spain)

Transmission expansion planning is becoming a hot topic at European level. A pan-European supergrid is considered an important necessity to allow the large-scale RES integration and the market integration to achieve the EU targets in a low carbon economy. Important initiatives are underway to develop decision support frameworks for addressing these goals. Ten-Year Network Development Plans (TYNDP) developed at regional level and e-HighWay 2050 are projects developed under the ENTSO-E support. Desertec and MedGrid are other proposals to develop high-voltage transmission lines around the Mediterranean Sea. Large-scale long-term transmission expansion planning tools are required as decision support tools. Uncertainty plays an important role in this time setting. Demand growth, RES penetration, generation localization, fuel and emission costs are the main future uncertain factors. This decision framework can be stated as two-stage dynamic stochastic planning problem. The problem is solved by an efficient Benders' decomposition algorithm. Results for a case study are analyzed.

Keywords transmission expansion planning, optimization.

Estimation and Relaxation Strategies for Global Optimisation I

Organisers: Alexander Mitsos, Benoit Chachuat
Chair: Benoit Chachuat

A Stochastic Capacity Expansion Model for the UK Energy System Using Decision Rules

Slot: Thursday 19th 13:30-14:00, Room 311
Presenter: **Angelos Georghiou** (Imperial College London, United Kingdom)
Coauthors: **Wolfram Wiesemann** (Imperial College London, United Kingdom) **Daniel Kuhn** (Imperial College London, United Kingdom)

Energy markets are currently undergoing one of their most radical changes in history. Both market liberalisation and the increasing penetration of renewable energy sources highlight the need to accommodate uncertainty in the design and management of future energy systems. This work aims to identify the most cost-efficient expansion of the UK energy grid, given a growing future demand for energy and the target to move towards a more sustainable energy system. To this end, we develop a multi-stage stochastic program where the investment decisions (generation units and transmission lines that should be built) are taken here-and-now, whereas the operating decisions are taken in hourly time stages over a horizon of 30 years. The resulting problem contains several thousand time stages and is therefore severely intractable. We develop a novel problem reformulation, based on the concept of time randomisation, that allows us to equivalently reformulate the problem as a two-stage stochastic program. By taking advantage of the simple structure of the decision rule approximation scheme, we can model and solve a problem that optimises over the entire UK energy grid with nearly 400 generators and 1000 transmission lines.

Keywords decision rule approximation, stochastic programming, energy.

Convergence Rate of Convex Relaxations

Slot: Thursday 19th 14:00-14:30, Room 311
Presenter: **Alexander Mitsos** (Massachusetts Institute of Technology, USA)
Coauthors: **Agustin Bompadre** (California Institute of Technology, USA)

Theory for the convergence order of the convex relaxations by McCormick [Mathematical Programming 10 (1), 147-175, 1976] for factorable functions is developed. Convergence rules are established for the addition, multiplication and composition operations. The convergence order is considered both in terms of pointwise convergence and of convergence in the Hausdorff metric. The convergence order of the composite function depends on the convergence order of the relaxations of the factors. No improvement in the order of convergence compared to that of the underlying bound calculation, e.g., via interval extensions, can be guaranteed unless the relaxations of the factors have pointwise convergence of high order. The McCormick relaxations are compared with the alphaBB relaxations by Floudas and coworkers [Journal of Chemical Physics 1993, Journal of Global Optimization 1995 1996], which guarantee quadratic convergence. Illustrative and numerical examples are given.

Keywords global optimization, relaxations, McCormick.

On Convergence of Taylor and McCormick-Taylor Model Estimators

Slot: Thursday 19th 14:30-15:00, Room 311
Presenter: **Benoit Chachuat** (Imperial College London, United Kingdom)
Coauthors: **Agustin Bompadre** (California Institute of Technology, USA) **Alexander Mitsos** (Massachusetts Institute of Technology, USA)

We analyze the convergence of Taylor and McCormick-Taylor model estimators, which have been highly

successful in enclosing the solutions of nonlinear differential equations and of nonlinear algebraic equations. Both estimators propagate a multivariate polynomial part symbolically that matches the Taylor expansion of the estimated function up to a specified order, together with an estimator of the Taylor remainder. The latter consists of an interval estimator in a Taylor model and of a pair of convex/concave McCormick relaxations in a McCormick-Taylor model. The concept of convergence order of an estimator finds its origins in interval extensions and compares the rates of convergence of the estimation error and of the range of the estimated function. Recently, Bompadre and Mitsos applied and extended this concept to McCormick relaxations. Building upon this work, we determine how the convergence orders of the remainder estimators propagate through addition, multiplication and composition operations. It is proved that the convergence orders of both qth-order Taylor models and qth-order McCormick-Taylor models are at least q+1, under relatively mild assumptions. Moreover, it is verified through simple numerical examples that these bounds are sharp. A consequence of this analysis is that, unlike McCormick relaxations over natural interval extensions, McCormick-Taylor models do not result in increased order of convergence over Taylor models in general. As demonstrated by the numerical case studies however, McCormick-Taylor models can provide sharper bounds or even result in a higher convergence rate.

Keywords non-convex optimization, global optimization, convex relaxations, McCormick relaxations, Taylor models, McCormick-Taylor models, interval extensions, convergence rate.

Estimation and Relaxation Strategies for Global Optimisation II

Organisers: Alexander Mitsos, Benoit Chachuat
Chair: Alexander Mitsos

Comparison of Bounding Techniques for Nonlinear ODEs

Slot: Friday 20th 14:00-14:30, Room 311
Presenter: **Boris Houska** (Imperial College London, United Kingdom)
Coauthors: **Mario Villanueva** (Imperial College London, United Kingdom) **Moritz Diehl** (University of Leuven, Belgium) **Benoit Chachuat** (Imperial College London, United Kingdom)

The ability to compute tight enclosures for the solutions of parametric ordinary differential equations (ODEs) is central to many deterministic global and robust optimization methods for dynamic systems. Many methods proposed in the literature to date fall into one of three main categories. The first class relies on the concept of differential inequalities and proceeds by constructing an auxiliary system of ODEs, the solutions of which enclose those of the original ODEs. The second class builds upon interval methods for ODEs to determine a rigorous enclosure of the solution set, whereby the integration domain is discretized into a finite number of steps and a predictor-corrector like approach is applied in each step. The third class considers parameterized matrix differential equations, the solution of which can be interpreted as an ellipsoidal enclosure of the ODE solution set. While all three methods can handle parametric ODEs, the first and third are more general as they can accommodate time-varying variations. In this paper, we compare these different bounding approaches in terms of tightness and computational efficiency. Special emphasis is on the order of convergence of the bounds, which plays a key role in terms of the number of branching/subdivision in global optimization. The comparisons are made for a number of numerical case studies of various complexity.

Keywords ordinary differential equations, uncertainty analysis, Taylor models, ellipsoidal calculus.

Branch-and-Sandwich: A Deterministic Global Optimisation Algorithm for Optimistic Bi-Level Programming Problems

Slot: Friday 20th 14:30-15:00, Room 311
Presenter: **Polyxeni-Margarita Kleniati** (Imperial College London, United Kingdom)
Coauthors: **Claire Adjiman** (Imperial College London, United Kingdom)

We present a global optimisation algorithm for nonconvex optimistic bilevel programming problems that are required to satisfy an appropriate regularity condition in the inner problem. These problems are hard to solve and only a few algorithms have been proposed for their solution (Mitsos et al., J. Global Optim. 42(4):475–513, 2008; Tsoukalas et al., J. Global Optim. 44(2):235–250, 2009). The proposed approach can be interpreted as the exploration of two solution spaces (corresponding to the inner and the outer problems) using a single branch-and-bound tree. A novel branching scheme is developed such that classical branch-and-bound is applied to both spaces without violating the hierarchy in the decisions and the requirement for (global) optimality in the inner problem. To achieve this, the well-known features of branch-and-bound algorithms are customised appropriately. For instance, two pairs of lower and upper bounds are computed: one for the outer optimal objective value and the other for the inner optimal value function. KKT-based relaxations are used to construct the inner upper bounding problem and the outer lower bounding problem. The inner upper bound serves as a constant bound cut in the outer lower bounding problem. These two problems result in convergent bounds on the inner and the outer optimal objective values; they are both nonconvex and must be solved globally. Well-known convexification techniques are employed to construct a convex inner lower bounding problem whose value is used in the selection operation and in fathoming. The upper bounding problem is motivated by Mitsos et al., but flexibility is added in that convex relaxations of the original inner problem over refined subsets of the inner space can be solved. These bounding problems do not grow in size during the algorithm and are obtained from the corresponding problems of the parent node. Thirty-five literature problems were tackled.

Keywords bi-level programming, non-convex inner problem, branch and bound.

The Use of Convex Nonlinear Relaxations in the Global Optimisation of Nonconvex Generalized Disjunctive Programs

Slot: Friday 20th 15:00-15:30, Room 311
Presenter: **Ignacio Grossmann** (Carnegie Mellon University, USA)
Coauthors: **Juan Pablo Ruiz** (Carnegie Mellon University, USA)

In this paper we address the global optimization of GDP problems that in addition to bilinear and concave terms, involve other terms such as linear fractional terms for which nonlinear convex relaxations have shown to provide rigorous convex envelopes that are much tighter than linear relaxations. The use of nonlinear convex relaxations leads to a nonlinear convex GDP which relaxation can be strengthened by using recently results from our work. We first define the general nonconvex GDP problem that we aim at solving and review the use of the hull relaxation, the traditional method to find relaxations. Second, we show how we can strengthen the relaxation of the traditional approach by presenting a systematic procedure to generate a hierarchy of relaxations based on the application of basic steps to nonlinear convex sets in disjunctive programming. We outline a set of rules that avoids the exponential transformation to the Disjunctive Normal Form leading to a more efficient implementation of the method. Finally we assess the performance of the method by solving to global optimality several instances of process network, reactor network and heat exchanger network problems. It is shown that strong nonlinear relaxations are obtained with which the number of nodes can be reduced in the NLP-based branch and bound method, often leading to reduced computational times.

Keywords disjunctive programming, convex sets, non-convex optimization, global optimization.

Financial Optimisation I

Chair: Valery Kalyagin

An Efficient Hybrid Approach to Constrained Portfolio Selection Problems

Slot: Wednesday 18th 16:15-16:45, Room 145
Presenter: **Fang He** (University of Nottingham, United Kingdom)

To tackle the large scale combinatorial optimization problem efficiently, decomposing the problem into sub-problems which are easy to solve is a reasonable approach. For example, to construct a portfolio, we can first decide which assets are to be included, and then decide how much each asset should be held. In this paper, we investigate a decomposition method for large scale constrained portfolio selection problems. Based on the decomposition, a hybrid method named Local Search Branching Branch-and-Bound (LS branching BB) is proposed. This method effectively integrates local search into the Branch-and-Bound (BB) algorithm to implement an incomplete search which aims to seek near optimal solution heuristically in a limit computational time.

In this method, a set of core variables of the problem are first selected according to the property of the problem. A new local search branching strategy is proposed and performed on these core variables to decompose the problem into a sequence of sub-problems. The default BB search then solves these restricted sub-problems optimally due to their reduced size comparing to the original one. Due to the inherent similar structures of the sub-problems, the reusability of solution information evokes the repairing heuristics in the default BB. This thus accelerates the BB solving procedure of the sub-problems. The tight upper bound identified at early stage of the search can prune more nodes (sub-problems) in the tree. This will speed up LS branching BB to the optimal solution to the original problem.

Our study is performed on a set of portfolio selection problems in the OR Library with a number of additional trading constraints. The algorithm has been implemented based on CPLEX 10.0. It can obtain near optimal solutions and requires far less computational time compared to the standard BB algorithm.

Keywords hybrid algorithm, branch-and-bound, local search, portfolio selection problems.

Network Approach for the Russian Stock Market

Slot: Wednesday 18th 16:45-17:15, Room 145
Presenter: **Arsenii Vizgunov** (National Research University Higher School of Economics, Russia)
Coauthors: **Panos Pardalos** (University of Florida, USA) **Boris Goldengorin** (National Research University Higher School of Economics, Russia) **Valery Kalyagin** (National Research University Higher School of Economics, Russia) **Alexander Koldanov** (National Research University Higher School of Economics, Russia) **Peter Koldanov** (National Research University Higher School of Economics, Russia)

We consider a network representation of the Russian stock market. We constructed the stock market graph as follows: each vertex represents a stock, and the vertices are adjacent if the correlation coefficient between them over a certain period of time is greater than or equal to specified threshold. We construct market graphs for different time periods to understand the dynamics of its characteristics. We compute maximum cliques and maximum independent sets for the considered market graphs and analyze the stability of the cliques and independent sets over time. The building of the considered model allows one to obtain new knowledge about the Russian stock market and compare the Russian stock market characteristics with different stock markets around the world. This is joint work with Panos M. Pardalos, Boris Goldengorin, Valery Kalyagin, Alexander Koldanov, Peter Koldanov.

Keywords Russian stock market, market graph, maximum clique, maximum independent set.

An ALM Framework for the Employees Provident Fund of Malaysia

Slot: Wednesday 18th 17:15-17:45, Room 145
Presenter: **Gautam Mitra** (Brunel University, United Kingdom)

Coauthors: **Siti Sheik Hussin** (Brunel University, United Kingdom) **Diana Roman** (Brunel University, United Kingdom)

We present an ALM framework for the main pension scheme of Malaysia, the Employees Provident Fund (EPF). There are several challenges faced by the EPF, perhaps the biggest one being the "aging population" phenomenon, which occurs even faster in Asia than in the Western countries. EPFs are defined contribution pension schemes; thus, the increase in life expectancy brings the risk that participants could outlive their savings. The liabilities include a minimum annual dividend guaranteed to participants, pension payments and early withdrawals for mortgages, education and health. We are using two multi-period stochastic programs that maximise the final expected wealth, in which the required decisions are on investment. One program uses money injections to account for cash inflows that are increasing with time and pay liabilities. The other program has integrated chance constraints on the cash inflows being larger than the liabilities. We evaluate these models in and out-of-sample. We also investigate the effect of changes on the minimum amount of guaranteed dividend and on pension age.

Keywords Asset Liability Management.

Sign-Correlation Model for the Market Graph

Slot: Wednesday 18th 17:45-18:15, Room 145
Presenter: **Valery Kalyagin** (National Research University Higher School of Economics, Russia)
Coauthors: **Alexander Koldanov** (National Research University Higher School of Economics, Russia) **Peter Koldanov** (National Research University Higher School of Economics, Russia) **Panos Pardalos** (University of Florida, USA) **Boris Goldengorin** (National Research University Higher School of Economics, Russia)

The market graph as a tool for the stock market investigation was proposed in [Boginsky, Butenko and Pardalos, 2003]. The market graph construction involves the Pearson correlation between returns, volumes and liquidity of the market stocks. In this context the Pearson correlation is used as a measure of similarity between two stocks. This approach is justified from the statistical point of view under the assumption that the common distribution of the observed random variables is normal. The assumption of normality is very strong in real settings as it is observed to be violated in many situations on the stock markets. This observation leads to the choice of other characteristics and measures of similarity of the behavior of stocks which are more stable under the perturbation of the market. Our contribution is a new measure (sign-correlation) for the similarity between two stocks on the market related to the well known Fechner test. We show that this sign-correlation is more appropriate for the construction of the market graph especially in the computation and interpretation of the maximum cliques of the graph. Finally, we compare the size of maximum cliques and independent sets obtained by using Pearson and sign-correlations for the construction of the market graph.

Keywords market graph, sign-correlation, Fechner test, maximum clique.

Financial Optimisation II

Chair: Christoforos Charalambous

Hedging a Commodity-Linked Portfolio

Slot: Thursday 19th 08:30-09:00, Room 145
Presenter: **Mickaël Sahnoun** (ECE Paris, France)
Coauthors: **Yves Rakotondratsimba** (ECE Paris, France) **Charles Ouanounou** (ECE Paris, France)

With the recent developments in commodity markets, it appears to be crucial for people, coming both from the academic/financial industry, to grant some care to the hedging mechanisms of a given commodity-linked portfolio. In this project we assume that a commodity-linked portfolio with its related instruments is given. Our purpose is to perform a general analysis for hedging against unfavorable price changes.The approach relies on a one-factor structure model for the future as the one introduced by Clewlow. This model can fit the initial forward curve in contrast to the model introduced by Schwartz (1997). It reflects the mean reverting nature of commodity prices. However, it has the disadvantage of the constant volatility structure of forward prices.

Therefore we first derive the sensitivities of various products (futures, swaps, spot/future options, caps/floors) with respect to the shock responsible for the price changes. The latter is the one that underlies the single factor model under consideration. The point of this work, unlike some classical results, is about the sensitivities' nature and the high orders considered. As a matter of fact it is common to make use of sensitivities with respect to the spot/future price or even the uncertainty factor with limitations to the first order.

We will show that introducing higher order sensitivities leads to find more accurate hedging operations. Particularly, under a conservative viewpoint of the uncertainty factor, our approach enables to derive deterministic and pointwise hedging error estimates. This is economically meaningful in contrast to the standard hedging error. The method considers sensitivities with respect to the shocks that are related to the risk/opportunity factor. We show that once a high order for sensitivities is chosen, the shock levels do not matter since potential losses/gains are under control and deterministically derived by our approach.

Keywords commodity derivatives, sensitivities, hedging, one factor model.

Reliability Based Portfolio Optimisation for Extreme Value Asset Returns under Asymmetric Loss Functions

Slot: Thursday 19th 09:00-09:30, Room 145
Presenter: **Raghu Sengupta** (Indian Institute of Technology Kanpur, India)
Coauthors: **Siddarth Sahoo** (Deutsche Bank AG, India)

In this paper we derive the expressions of risks (i.e., expected loss) of a portfolio, under asymmetric (namely LINear EXponential (LINEX) and relative LINEX) loss functions, considering asset return as Gumbel distributed (an example of Extreme Value Distribution (EVD)). We propose and then solve four Reliability Based Portfolio Optimization (RBPO) models, where the risk and expected return, of the portfolio is modeled using RBPO formulations. In the first three models we minimize unknown threshold values, such that the risks of the portfolio returns under three different loss functions, namely LINEX, relative LINEX and Squared Error Loss (SEL) (an example of symmetric loss), are less than or equal to their respective unknown threshold values, by certain known fixed levels of reliabilities. The fourth model is a maximization problem, when our aim is to find the unknown value of threshold, such that the expected return for the Hyperbolic Absolute Risk Aversion (HARA) utility function of the portfolio return is greater than or equal to this value, with some predefined fixed probability. It is observed that the expected return for HARA utility function is a linear function of the mean of the Gumbel distribution. We finally test our models using data from the German stock market.

Keywords finance, investment analysis, reliability, risk analysis, risk management.

Robust Portfolio Optimisation with Copulas

Slot: Thursday 19th 09:30-10:00, Room 145
Presenter: **Iakovos Kakouris** (Imperial College London, United Kingdom)
Coauthors: **Berc Rustem** (Imperial College London, United Kingdom)

Conditional value-at-risk (CVaR) is widely used in portfolio optimization as a measure of risk. CVaR is clearly dependent on the underlying probability distribution of the portfolio. We show how copulas can be introduced to any problem that involves distributions and how they can provide solutions for the modelling of the portfolio. We use this to provide the copula formulation of the CVAR of a portfolio. Given the critical dependence of CVaR on the underlying distribution, we use a robust framework to extend our approach to Worst Case CVaR (WCVaR) through the use of rival copulas.

Keywords robust, optimization, copulas, CVaR, WCVaR.

Selecting the Product Portfolio for Production in Manufacturing Systems Using Multi-objective Evolutionary Algorithms Based on Decomposition

Slot: Thursday 19th 10:00-10:30, Room 145
Presenter: **Christoforos Charalambous** (Frederick University, Cyprus)
Coauthors: **Andreas Konstantinidis** (Frederick University, Cyprus) **Savvas Pericleous** (Frederick University, Cyprus)

For manufacturing systems in the process industry, where the number of SKUs is frequently large, selecting the portfolio of products to manufacture, or subcontract (partially or fully), or terminate, has significant impact on the system's operations and performance. Traditional, MILP-based approaches to address the problem are limited by the fact that they assume a deterministic nature of parameters, concentrate on a single objective (profit) and ignore interrelationships between variables.

In this work, we aim at developing a strategic planning system that concurrently tackles several important, often conflicting, objectives such as expected profit, investment risk and production flexibility. To achieve this, a constrained multi-objective optimisation problem (MOP) is formulated and detailed evaluation functions for each objective are defined, which take as input an association of each product with a production (or non-production) mode. Subsequently, the proposed MOP is tackled using a well-known multi-objective evolutionary algorithm (MOEA), namely, MOEA based on Decomposition (MOEA/D), hybridized with local search. MOEA/D, the state-of-the-art of decompositional MOEAs, initially decomposes the MOP into a set of scalar optimization problems, which are then tackled simultaneously using scalar techniques and neighborhood information. The evolutionary process generates a diverse and (near) optimal Pareto front that is provided to the decision maker. These non-dominated solutions facilitate the decision making process by indicating for each solution the expected performance on the objectives concerned as well as the required operational setting the solution is associated with (e.g. plant capacity). To assess the effectiveness of the proposed solution, a paints-manufacturing system in Cyprus (decorative and industrial) has been used as a case study.

Keywords multi-objective optimisation, evolutionary algorithms, production planning, product portfolio selection.

Financial Optimisation III

Organisers: Alex Weissensteiner, Michael Hanke
Chair: Alex Weissensteiner

Can Danish Households Benefit from Stochastic Programming Models? - An Empirical Study of Mortgage Refinancing in Denmark

Slot: Thursday 19th 16:30-17:00, Room 145
Presenter: **Kourosh Marjani Rasmussen** (Technical University of Denmark, Denmark)

A number of Stochastic Programming (SP) models on mortgage choice and refinancing for Danish households have been introduced during recent years. A major Danish mortgage bank has adapted the SP framework, but they yet hesitate to use model-based advice for ordinary households. Whereas most mortgage banks in Denmark today advise private home owners to finance their property with one loan only, these models suggest that most households are better off with two loans. With regards to refinancing, the models suggest a higher level of refinancing activity than what is observed today. The empirical study, which is the subject of this paper, is designed to perform a historical ex-ante test of the advice generated by this model framework for the period 1995-2010. We compare SP-based advice with current practice which is based on rules of thumb and short-sighted forecasts. Even though the study is tailored for the Danish market, the framework may be generalized to other countries.

Keywords mortgage lending, model-based refinancing, stochastic programming.

Modelling Economic Scenarios and Their Challenges Within a Solvency II Environment

Slot: Thursday 19th 17:00-17:30, Room 145
Presenter: **Sonja Huber** (Towers Watson, United Kingdom)

The simulation of economic scenarios such as interest rates, inflation etc has become an essential part for risk management purposes and ALM studies. For a consistent approach, an Economic Scenario Generator should drive both, asset risk and liability models. However, it faces various challenges from computational natures to accurate modelling of the indices - especially the latter will impact the results of the ALM significantly. This talk will introduce Towers Watson's approach and the reasons why not only the optimiser matters in ALM but also the underlying scenarios.

Keywords economic scenario generators, solvency II, real-world modelling.

Arbitrage-Free Scenario Trees for Financial Optimisation

Slot: Thursday 19th 18:00-18:30, Room 145
Presenter: **Alex Weissensteiner** (Free University of Bozen-Bolzano, Italy)
Coauthors: **Michael Hanke** (University of Liechtenstein, Liechtenstein) **Alois Geyer** (Vienna University of Economics (WU), Austria)

This paper presents a method which is designed to generate arbitrage-free scenario trees representing multivariate return distributions. Our approach is embedded in the setting of Arbitrage Pricing Theory (APT), and asset returns are assumed to be driven by orthogonal factors. In a complete market setting we derive no-arbitrage bounds for expected excess returns using the least possible number of scenarios (i.e. the smallest dimension of the discrete state space) necessary to match the first two moments and to exclude arbitrage at the outset. This not only safeguards against the curse of dimensionality: Numerical results from solving two-stage asset allocation problems show that highly accurate results can be obtained with the smallest possible scenario tree.

Keywords no-arbitrage bounds, scenario generation, financial optimization.

A Simplex Rotation Algorithm for the Factor Approach to Generate Financial Scenarios

Slot: Thursday 19th 17:30-18:00, Room 145
Presenter: **Michael Hanke** (University of Liechtenstein, Liechtenstein)
Coauthors: **Alois Geyer** (Vienna University of Economics (WU), Austria) **Alex Weissensteiner** (Free University of Bozen-Bolzano, Italy)

Scenario trees to be used for financial optimization must be free of arbitrage opportunities. Geyer et al. (2012) propose a factor approach which is designed to generate arbitrage-free scenario trees. They distinguish three regions for expected excess returns, for one of which arbitrage is not guaranteed ex ante, and requires re-sampling. Here we present a new algorithm to implement the factor approach which is based on purposeful rotations of simplexes. This algorithm offers several computational advantages: First, it does not require Cholesky decomposition, but uses a deterministically constructed simplex as its starting point. Second, for cases where the absence of arbitrage is not theoretically guaranteed ex ante, (potentially frequent) re-sampling, as required in the original algorithm, is avoided by purposefully rotating this simplex. Hence, the new algorithm completely avoids any need for checking scenarios for arbitrage in these cases. As a by-product, the derivation of our algorithm provides interesting geometrical insights.

Keywords scenario trees, multi-stage stochastic programming, no-arbitrage, financial optimization.

Financial Optimisation IV

Chair: Hatem Ben Ameur

A Mixed Integer Linear Programming Model for Optimal Sovereign Debt Issuance

Slot: Friday 20th 08:30-09:00, Room 145
Presenter: **Paresh Date** (Brunel University, United Kingdom)
Coauthors: **Alessandra Canepa** (Brunel University, United Kingdom) **Malek Abdel-Jawad** (Brunel University, United Kingdom)

Governments borrow funds to finance the excess of cash payments or interest payments over receipts, usually by issuing fixed income debt and index-linked debt. The goal of this work is to propose a stochastic optimization-based approach to determine the composition of the portfolio issued over a series of government auctions for the fixed income debt, to minimize the cost of servicing debt while controlling risk and maintaining market liquidity. We show that this debt issuance problem can be modeled as a mixed integer linear programming problem with a receding horizon. The stochastic model for the interest rates is calibrated using a Kalman filter and the future interest rates are represented using a recombining trinomial lattice for the purpose of scenario-based optimization. The use of a latent factor interest rate model and a recombining lattice provides us with a realistic, yet very tractable scenario generator and allows us to do a multi-stage stochastic optimization involving integer variables on an ordinary desktop in a matter of seconds. This, in turn, facilitates frequent re-calibration of the interest rate model and re-optimization of the issuance throughout the budgetary year allows us to respond to the changes in the interest rate environment. We successfully demonstrate the utility of our approach by out-of-sample back-testing on the UK debt issuance data.

Keywords multi-stage stochastic programming, public debt management.

Asset-Liability Management for Individual Investors in a Multi-Scenario and Multi-Period Setting

Slot: Friday 20th 09:00-09:30, Room 145
Presenter: **Jonela Lula** (University of Geneva, Switzerland)
Coauthors: **Manfred Gilli** (University of Geneva, Switzerland)

Introducing liabilities in the asset management problem of an investor, involves long planning horizons, and multi-period reallocations in order to adapt to the evolution of the market. Dynamics of the assets in the successive periods are represented in a scenario tree. Wealth evolves according to the realized returns and the predefined reallocation strategy at each time step. We evaluate the transition probabilities from one tree node to the other by a multivariate lognormal regime switching model. The utility function we suggest guarantees the satisfaction of liabilities at predetermined time moments and comforts the investor's risk aversion profile. The reallocations are computed by a multistage programming approach.

Keywords portfolio optimization, multi-stage programming, asset liability management.

A Dynamic Program for Valuing Corporate Debts

Slot: Friday 20th 09:30-10:00, Room 145
Presenter: **Hatem Ben Ameur** (HEC Montréal, Canada)
Coauthors: **Mohamed Ayadi** (Brock University, Canada) **Tarek Fakhfakh** (FSEG Sfax, Tunisia)

We design and implement a dynamic program for valuing corporate debt portfolios, seen as derivatives on a firm's assets, and computing its term structure of yield spreads and of default probabilities. Our setting extends the models of Black and Cox (1976), Geske (1977), Leland (1994), Leland and Toft

(1996), and Nivorozhkin (2005a and 2005b) for it accommodates 1- arbitrary corporate debts, 2- multiple seniority classes, 3- sinking funds, 4- American-style embedded options, 5- dividends, 6- tax benefits, 7- bankruptcy costs, and 8- alternative Markov dynamics for the state process. The default barriers inferred at payment dates are completely endogenous, and follow from an optimal decision process. This flexibility comes at the expense of a minor loss of efficiency; the analytical approach proposed in the literature, which solves for the structural model, is exchanged here for a numerical approach based on dynamic programming coupled with finite elements. We provide several theoretical properties of the debt- and equity-value functions. Finally, to assess our construction, we carry out a numerical study along with a sensitivity analysis, and perform an empirical investigation for a North American public company.

Keywords option theory, no-arbitrage pricing, structural models, corporate-bond portfolios, corporate bankruptcy prediction, dynamic programming, finite elements, numerical integration.

Global Optimisation in Process Design

Organiser: Claire Adjiman
Chair: Claire Adjiman

Application of Deterministic Global Optimisation Techniques to Kinetic Models of Metabolic Networks

Slot: Friday 20th 08:30-09:00, Room 311
Presenter: **Gonzalo Guillén-Gosálbez** (Rovira i Virgili University, Spain)

The identification of the enzymatic profile that achieves a maximal production rate of a given metabolite is an important problem in the biotechnological industry, especially if there is a limit on the number of enzymatic modulations allowed.

The intrinsic nonlinear behavior of metabolic processes enforces the use of kinetic models, such as the generalized mass action (GMA) models, giving rise to nonconvex MINLP formulations with multiple local solutions. In this work, we introduce a customized spatial branch-and-bound strategy devised to globally optimize nonlinear kinetic models of metabolic networks. A tight MILP-based relaxation of the original nonconvex MINLP is constructed using logarithmic transformations, piecewise linear underestimators and first order linearizations. The overall solution procedure is expedited through the use of bound tightening techniques and a special type of cutting plane. The capabilities of the strategy proposed are tested through its application to the maximization of the citric acid production in Aspergillus niger. Numerical results demonstrate that our algorithm outperforms the commercial package BARON and an outer approximation-based method proposed by the authors in a previous work.

Keywords metabolic engineering, spatial branch and bound.

Global Optimisation of Reverse Osmosis Seawater Desalination Systems

Slot: Friday 20th 09:00-09:30, Room 311
Presenter: **Alexander Mitsos** (Massachusetts Institute of Technology, USA)
Coauthors: **Amin Ghobeity** (Hatch Ltd, Canada) **Christopher M. Williams** (Massachusetts Institute of Technology, USA)

Global optimization of the size and time-variant operation is presented for seawater reverse osmosis (SWRO).

SWRO has high electricity consumption (3-4 kWh per m3 of product water). Two recent key developments are low energy consuming membranes and the incorporation of energy recovery systems. Time-variable operation and the systematic optimization of design and operation, on the other hand, have received little attention. The objective herein is reducing the total specific cost of the product water rather than minimizing the specific energy consumption.

A well-established and fairly detailed model, developed initially by DOW, is extended to model a SWRO system equipped with highly efficient pressure exchangers and variable frequency drives. For the optimization of short-term operation assuming a fixed design plant, a variable operating conditions and a time-of-use electricity tariff rate is considered. The problem is formulated as a mixed-integer nonlinear program (MINLP), allowing for periods without operation during high electricity price periods. The time domain (24 h) is discretized into 0.5 h increments, and a pseudo steady-state assumption is used. The cost savings via variable operation are significant, especially when the electricity prices fluctuate considerably throughout the day. Also, the results show the under some electricity price markets, oversizing the plant will yield even more savings. For the optimization case studies considering a long-term operation, the models are modified to have a variable plant size controlled by the number of modules. The number of modules and the half-hourly varying operating frequency are optimized to minimize the total annualized cost of the water produced. The results show that variable operation and oversizing can produce savings of 7% for a highly fluctuating electricity price.

Keywords desalination, RO, SWRO, global optimization.

Global Optimisation of Water Network Design and Synthesis: A Computational Study

Slot: Friday 20th 09:30-10:00, Room 311
Presenter: **Cheng Seong Khor** (Imperial College London, United Kingdom)
Coauthors: **Benoit Chachuat** (Imperial College London, United Kingdom) **Nilay Shah** (Imperial College London, United Kingdom)

Process network problems are frequently encountered in large-scale systems that entail numerous important applications particularly in the process industry. A particular occurrence of such problems is in water network design and synthesis, which gives rise to nonconvex mixed-integer nonlinear programs (MINLP) or the more specific class of mixed-integer quadratically-constrained quadratic programs (MIQCQP). In this work, we formulate a model to address a large-scale water network case study of industrial significance. We highlight two contributions that potentially offer more insights on computational strategies in solving such models. First, we incorporate redundant constraints into the model in the form of logic-based linear inequalities that are formulated using discrete binary variables by exploiting the underlying physics of the problem. These logical constraints enforce certain design and structural specifications that generally apply to any instantiation posed by the problem. From a computational aspect, these constraints function as cutting planes in the form of logic cuts. They increase solution convergence by cutting off fractional solutions through restricting possible values of the 0–1 variables in a branch-and-bound scheme. Consequently, the number of nodes enumerated in a search tree is reduced along with the computational load. The second contribution is on computational comparisons of the performance of several commercial global optimization solvers for nonconvex MINLP. The solvers considered in our study include BARON (version 9.3.1), LindoGLOBAL (version 6.1.1.488), Couenne (version 0.3), and SBB (version level 009), as well as the recently available MIQCQP global solver GloMIQO. The solver performances are assessed in terms of CPU time and the relative gap between the best possible solution (i.e., as given by the lower bound of a minimization program) and the best known solution (i.e., the upper bound). We analyze the performances, where possible, by inferring on the strengths of the algorithmic components in the solvers.

Keywords mixed-integer nonlinear programming (MINLP), quadratically-constrained quadratic programs (QCQP), water network synthesis, branch-and-bound, global optimization.

Inventory Problems

Chair: Maria Grazia Speranza

A Distributionally Robust Multi-Item Newsvendor Problem with Bimodal Demand Distributions

Slot: Thursday 19th 08:30-09:00, Room 342
Presenter: **Grani Adiwena Hanasusanto** (Imperial College London, United Kingdom)
Coauthors: **Daniel Kuhn** (Imperial College London, United Kingdom) **Stein Wallace** (Lancaster University, United Kingdom) **Steve Zymler** (Imperial College London, United Kingdom)

We consider a distributionally robust multi-product newsvendor problem with a mean-risk objective that accounts for the expectation as well as the Conditional Value-at-Risk (CVaR) of the loss. The demand for the products depends on a binary state variable. The state determines which products become fashionable and are therefore in higher demand. The state follows a Bernoulli distribution, while the conditional distribution of the demand given the state is uncertain in the sense that only its first- and second-order moments are known. We formulate an optimization model that takes into consideration all probability distributions that are compatible with this information and minimizes a weighted combination of worst-case CVaR and worst-case expected loss. We analyze the structure of the optimal product portfolios and the expected value of perfect state information in the context of a fashion production example.

Keywords distributionally robust, multi-Item newsvendor, bimodal demand distributions.

Obtaining Vendor's Inventory Diagram Change in a Vendor-buyer Problem

Slot: Thursday 19th 09:00-09:30, Room 342
Presenter: **Sepideh Alavi** (Amirkabir University of Technology, Iran)
Coauthors: **Hamid Davoudpour** (Amirkabir University of Technology, Iran)

In today's competitive and dynamic market conditions, the effective collaboration of partners and coordination of all activities within the supply chain is prerequisite. This paper studies average inventory diagram for a manufacturer in a vendor-buyer problem in case of two buyers being served by the buyer and that how orders released by buyers affect vendor's inventory change. Unlike other papers in this field, which mostly consider one buyer to be served by each vendor and do not apply a specific inventory ordering policy, this paper considers a vendor serving two buyers and the buyers follow the continuous inventory review policy as their ordering policy.

Keywords inventory, vendor, review policy.

Inventory Routing Problem for Distribution of Perishable Goods

Slot: Thursday 19th 09:30-10:00, Room 342
Presenter: **Samira Mirzaei** (Amirkabir University of Technology, Iran)
Coauthors: **Abbas Seifi** (Amirkabir University of Technology, Iran)

This paper presents a mathematical formulation for inventory routing problem (IRP) that is especially designed for allocating stock of perishable goods. It is assumed herein that the age of perishable inventory has negative impact on the demand of end customers and the percentage of the inventory that is not sold is considered as lost sale. The model balances the transportation cost with the holding cost and lost sale. In addition to regular inventory routing constraints, the model considers a linear function defining lost sale in terms of inventory age. We assume that the demands of retailers are deterministic and the number of planning periods is finite.

We have developed a non-linear mixed integer programming model for the problem first and then linearized it to be able to solve its relaxation efficiently. The model is solved to optimality for small instances and used to obtain lower bounds for larger instances. We have also devised a heuristic solution

method to find good solutions for this class of problems. The proposed heuristic method starts with a predefined delivery pattern, and uses a neighborhood search to improve the pattern, then solves the inventory lost-sale subproblem and routing subproblem and improves the solution within a metaheuristic framework.

Computational results indicate that for small-sized problems up to 15 customers, the heuristic method can find solutions that are on average not farther than 25% away from the optimal solution in a few seconds. The optimality gap found by Cplex grows exponentially with the problem size while the ones obtained by the proposed heuristic increase linearly in a reasonable time. Therefore, the proposed solution method has shown some promise for solving large instances.

Keywords inventory routing, vehicle routing problem, perishable goods, lost sale.

A Matheuristic for an Inventory-routing Problem

Slot: Thursday 19th 10:00-10:30, Room 342
Presenter: **Maria Grazia Speranza** (University of Brescia, Italy)
Coauthors: **Claudia Archetti** (University of Brescia, Italy) **Luca Bertazzi** (University of Brescia, Italy) **Alain Hertz** (Ecole Polytechnique de Montréal, Canada)

We consider an inventory routing problem in discrete time where a supplier has to serve a set of customers over a multi-period horizon. A capacity constraint for the inventory is given for each customer and the service cannot cause any stock-out situation. Two different replenishment policies are considered, the order-up-to level and the maximum level policies. A single vehicle with a given capacity is available. The transportation cost is proportional to the distance traveled, whereas the inventory holding cost is proportional to the level of the inventory at the customers and at the supplier. The objective is the minimization of the sum of the inventory and transportation costs. We present a heuristic that combines a tabu search scheme with ad hoc designed mixed integer linear programming models (MILPs). Such MILPs explore in depth the neighborhood of the incumbent solution. Although the MILPs are shown to be NP-hard, their exact solution did not create any computational problem on instances with up to 200 customers with a horizon of 6 time units. The availability of the optimal solutions allowed us to calculate the exact errors generated on small size instances. The average error is less than 0.1improves the solutions obtained by a known heuristic.

Keywords inventory routing problems, mixed integer linear programming, heuristics.

Large Scale Optimisation

Chair: Amir Beck

Gradient Based Approach for Large Scale MRF Minimisation Problem

Slot: Wednesday 18th 11:15-11:45, Room 311
Presenter: **Duy Luong** (Imperial College London, United Kingdom)
Coauthors: **Berc Rustem** (Imperial College London, United Kingdom) **Panos Parpas** (Imperial College London, United Kingdom) **Daniel Rueckert** (Imperial College London, United Kingdom)

Markov Random Fields (MRFs) minimization is a well-known method in many computer vision applications. The original integer programming model of MRFs is NP-hard. In this paper, we employ dual decomposition technique and present a gradient-based approach to solve the dual of the MRF minimization problem. The dual problem comprises a large non-smooth objective function and many simple linear constraints. We reformulate the problem and exploit the constraints such that it benefits from faster convergence of entropy projection and euclidean projection method. Experimental results on synthetic and vision problems demonstrate the effectiveness of our approach.

Keywords mirror descent, projection, large scale, MRF optimization, computer vision.

New Mathematical Programming Formulations for Resource-Constrained Project Scheduling Problems

Slot: Wednesday 18th 11:45-12:15, Room 311
Presenter: **Georgios Kopanos** (Imperial College London, United Kingdom)
Coauthors: **Thomas Kyriakidis** (University of Western Macedonia, Greece) **Michael Georgiadis** (Aristotle University of Thessaloniki, Greece)

In this work, two binary integer programming discrete-time models and two precedence-based mixed-integer continuous-time formulations are developed for the solution of Resource-Constrained Project Scheduling Problems (RCPSPs). The classical RCPSP involves determining the starting (and/or finishing) times for the activities of a project, such that the precedence and resource constraints are fully satisfied, and the overall completion time of the project is minimized. All activities have to be executed for the project to complete successfully and the type of resources involved is renewable.

During the preprocessing phase, the Critical-Path Method (Kelley, Jr and Walker, 1959) is employed to estimated the Earliest Starting Time (ESTi) and Earliest Finishing Time (EFTi) for each activity i. Additionally, we use the parallel scheduling scheme (Kolisch, 1996) under two different rules: the minimum latest finishing time rule, and the minimum latest starting time rule, so as to set an upper bound to the time horizon, and then calculate Latest Starting Time (LSTi) and Latest Finishing Time (LFTi). More specifically, the upper bound on the time horizon is equal to the minimum time horizon found by the two rules applied. Note that the computational time of such a simple preprocessing phase is negligible, and activities time-window lengths can be significantly reduced.

These four new mathematical formulations are compared with four representative literature models using a total number of 2760 well-known and open-accessed benchmark problem instances (j30 and j60 from the PSPLIB, and 1800 problem instances generated by RanGen2). A detailed computational comparison study illustrates the very good performance of the proposed mathematical formulations. More specifically, the continuous-time mathematical formulations feature the best overall performance in comparison with all the other models. Finally, interesting observations are made through the computational study and potential future research lines are revealed.

Keywords project scheduling, scheduling, mixed integer programming, mathematical programming.

On the Solution of the GPS Localisation and Circle Fitting Problems

Slot: Wednesday 18th 12:15-12:45, Room 311
Presenter: **Amir Beck** (Technion - Israel Institute of Technology, Israel)

Coauthors: **Dror Pan** (Technion - Israel Institute of Technology, Israel)

We consider the problem of locating a user's position from a set of noisy pseudoranges to a group of satellites. Two different formulations are studied: the nonlinear least squares formulation in which the objective function is nonconvex and nonsmooth, and the nonlinear squared least squares variant in which the objective function is smooth, but still nonconvex. We show that the squared least squares problem can be solved efficiently, despite is nonconvexity. Conditions for attainment of the optimal solutions of both problems are derived. The problem is shown to have tight connections to the well known circle fitting and orthogonal regression problems. Finally, a fixed point method for the nonlinear least squares problems is derived and analyzed.

Keywords localization problems, non-convex programming, fixed point methods.

Modelling and Optimisation for the Process Industry I

Organisers: Vivek Dua, Lazaros Papageorgiou
Chair: Lazaros Papageorgiou

Effect of Fouling Factors on the Optimisation of MSF Desalination Process for Fixed Water Demand Using gPROMS

Slot: Wednesday 18th 11:15-11:45, Room 342
Presenter: **Iqbal Mujtaba** (University of Bradford, United Kingdom)
Coauthors: **Said Said** (University of Bradford, United Kingdom) **Mansour Emtir** (Academy of Graduate Studies, Libya)

Industrial desalination of sea water is becoming an essential part in providing sustainable source of fresh water for a large number of countries around the world. The multistage stage flash (MSF) process represents more than 56

In this work, a steady state fouling resistance model has been developed and implemented in the full MSF mathematical model developed earlier by using gPROMS. This model take into consideration the effect of surface temperature on the calcium carbonate fouling resistance in the flashing champers in the heat recovery section, heat rejection section, and brine heaters of MSF desalination plants at fluid velocity 1 m/s. The effect of seasonal variation of seawater temperature and top brine temperature on the calcium carbonate fouling resistance has been studied throughout the flashing stage. We observe that the fouling resistance increased as seawater temperature and top brine temperature.

In addition, optimisation of design and operating parameters of MSF desalination process is considered. For fixed water demand throughout the year and with variation of seawater temperature and fouling resistance, total annual operating cost is minmised, while optimising the operating parameters such as seawater rejected flow rate, brine recycle flow rate and steam temperature.

Keywords MSF desalination, fouling, modelling, optimisation, freshwater.

MILP-based Approaches for Integrated Management of Sustainable Water Resources

Slot: Wednesday 18th 11:45-12:15, Room 342
Presenter: **Songsong Liu** (University College London, United Kingdom)
Coauthors: **Petros Gikas** (Technical University of Crete, Greece) **Lazaros Papageorgiou** (University College London, United Kingdom)

Water resources are often limited for the small and medium size islands. Groundwater and rainwater have been used traditionally for water supply, while water importation from the mainland, during the hot months, has been practiced as well. However, these water resources are either limited or expensive. Nowadays, a number of affordable alternative sustainable water production processes from seawater and wastewater are available. Desalinated seawater is readily potable, while reclaimed water can be primarily used for non-potable applications. However, the optimal water resources management is an important issue for the implementation of seawater and water reclamation form wastewater, in order to avoid high water conveyance cost and overdesign of water production plants. In this work, we extend our previous work and propose a mixed-integer linear programming (MILP) model was proposed for integrated optimisation of water resources management, which takes into account the localised water needs (including water quality), the sustainably available groundwater and the local wastewater production geographical information (e.g., population distribution, topographical data) and cost of water management and conveyance facilities, to determine the locations and capacities of seawater desalination plants, water reclamation plants and wastewater treatment plants, and the appropriate water and wastewater conveyance infrastructure (pipelines, pipe sizes, pumping stations and capacities, storage tanks), so to minimise the total annualised cost, including both capital and operational costs. In addition, in order to overcome the computational complexity aroused by the large instances, we develop a hierarchical approach, in which an approximation model is solved at the first step to determine the plant locations

and the proposed MILP model is the second step. The developed approaches have been applied to two real case studies, the island of Santorini and the municipality of Kasteli in the island of Crete.

Keywords water resources management, optimisation, MILP, desalination, reclamation.

System Integration of SOFC Micro-CHP for Residential Energy Demand Reduction

Slot: Wednesday 18th 12:15-12:45, Room 342
Presenter: **Alexandros Adam** (University College London, United Kingdom)
Coauthors: **Eric S. Fraga** (University College London, United Kingdom) **Dan Brett** (University College London, Ukraine) **Cliff Elwell** (University College London, United Kingdom)

One of the most promising technologies for reducing energy consumption is combined heat and power (CHP). CHPs benefit from the simultaneous generation of electricity and heat increasing their efficiency. Solid oxide fuel cell (SOFC) based micro-CHPs can efficiently meet heating and electricity needs of residential dwellings.In this research project an investigation of the design of a SOFC micro-CHP under varying conditions is carried out and ways of integration with the building energy system are presented. Fuel cell based micro-CHP system components need to be sized appropriately to satisfy the domestic energy demand profile and to serve heat loads effectively. Overestimating the size of a CHP unit decreases its potential while underestimating its size reduces its benefits. Residential electricity, heating and hot water demands fluctuate daily and seasonally. The operation of the fuel cell is subject to constraints. It is therefore important to define the operation strategy (scheduling of demands, electricity/heat generation etc.) and the control method that is utilised to meet the building energy demands because they define the overall performance and efficiency of the building energy system as a whole. A mathematical model that describes the operation of a fuel cell micro-CHP based system in dwellings is presented. The model is dynamic and includes the fuel cell, the backup gas boiler, and hot water thermal storage. The evaluation is based on a typical UK residential dwelling in accordance with the current building regulations and includes electricity, heating and domestic hot water loads. The aims are to investigate methods of integration of the fuel cell micro-CHP with the fluctuating energy patterns and examine the benefits of electricity and heating generation using fuel cell CHPs in houses. A multi-objective optimisation procedure is used to identify the trade-off curve for total CO2 emissions versus annualised costs for different system configurations.

Keywords fuel cell, micro-CHP, building modelling, optimisation.

Modelling and Optimisation for the Process Industry II

Organisers: Vivek Dua, Lazaros Papageorgiou
Chair: Vivek Dua

Multi-Parametric Programming Generated Approximations for Linear Model Predictive Control of Nonlinear Systems

Slot: Wednesday 18th 14:15-14:45, Room 342
Presenter: **Romain Lambert** (Imperial College London, United Kingdom)
Coauthors: **Efstratios Pistikopoulos** (Imperial College London, United Kingdom) **Pedro Rivotti** (Imperial College London, United Kingdom)

Computational modelling has known an exponential development in both academia and industrial research. The undeniable powerful capability of such models has yet to overcome the difficulty of applying them in an industrial context. Increased model complexity means increased model run time memory usage and optimality problems which prohibit industrial applications like control and online optimisation. Consequently, most current industrial and practical implementations often utilize linear models obtained from linear black-box system identification or linearization of first principle models. These approaches are often ineffective for highly nonlinear systems as the validity of such approximations lies only in a limited area of the operating conditions. Extension of such approximations into piecewise affine or weighted sums representation addresses the issue but generates more complexity due to the nonlinearity of weights or the introduction of integer variables. A convenient way to address the issue would be the development of "adaptive" "equation-free" techniques to generate high accuracy predictions with low computational cost for the control problem. In this paper we introduce an approach for online generation of approximate linear dynamic representations of the system. The method uses the fact that predictions of the system are only required for a limited number of steps ahead for control purposes. The approximation task is formulated as a multi-parametric quadratic programming problem. The resulting dynamics form an N-steps-ahead prediction. Control vector parameterization of the decision variables is used to postulate the form of the approximation a priori. The approximation is equivalent to a set of affine expressions of the control variables alone. The coefficients defining the approximations are obtained by function evaluation via the resolution of an mp-QP problem and the dynamics are integrated in matricial form into a new linear online controller, thus equating to a multi-Model Predictive-Control scheme.

Keywords multi-parametric programming, model predictive control, model approximation, model reduction.

Scheduling and Planning in Food Process Industries

Slot: Wednesday 18th 14:45-15:15, Room 342
Presenter: **Georgios Kopanos** (Imperial College London, United Kingdom)
Coauthors: **Michael Georgiadis** (Aristotle University of Thessaloniki, Greece)

A plethora of contributions addressing production scheduling and planning problems can be found in the OR and PSE communities literature. However, the use of optimizationbased techniques for scheduling real-life food process industries is still in its infancy. This can be mainly attributed to the complex production recipes, the large number of products to be produced under tight operating and quality constraints and the existence of mixed batch and continuous production modes. Recently, we have dealt with several scheduling and planning problems arising from two real-life industrial food production facilities: a yoghurt, and an ice-cream production plant.

In this work, a novel continuous-time MIP model is proposed to address production scheduling problems in a multistage ice-cream production facility. The overall mathematical framework relies on an efficient modelling approach of the sequencing decisions, the integrated modelling of all production stages, and the inclusion of a set of strong tightening constraints. Notice that the simultaneous optimization of all processing stages aims at facilitating the interaction among the different departments of the production facility. Moreover, an alternative MIP-based solution strategy is proposed for dealing

with largescale food processing scheduling problems. Although this method may not guarantee global optimality, it favours low computational requirements and solutions of very good quality.

Both solution approaches feature a salient computational performance (especially the MIP-based solution strategy) for 50 industrial-scale problem instances solved. It should be mentioned that for even more complex scheduling problems, the MIP performance will likely be rendered due to big model sizes and high memory requirements, while the performance of the MIP-based solution method is expected to be more stable, since the user can define the degree of decomposition and thus controlling the computational performance of the method. Finally, the comparison with other approaches, such as the timed automata framework, will be of particular interest.

Keywords scheduling, planning, mixed integer programming, food industry.

Planning for the Integrated Refinery Subsystems

Slot: Wednesday 18th 15:15-15:45, Room 342
Presenter: **Edith Ejikeme-Ugwu** (Cranfield University, United Kingdom)
Coauthors: **Meihong Wang** (Cranfield University, United Kingdom)

Refinery Planning is a high level decision making process which helps to determine the right crude oil to purchase, the products to produce, and at which volumes by making the best use of the existing resources. In modern refineries, the planning department is relied upon for such decisions due to the increasing demand for petroleum products, the increasing cost of crude oils and the set environmental regulations. These activities need to be observed and monitored strictly, hence the tools required for production planning and management decision making become inevitable for the refinery economic evaluation. This work aims to provide insight on tactical planning for the integrated refinery subsystems with Mixed Integer Linear Programming (MILP) under deterministic condition. The three main subsystems of a refinery shall be integrated. This include a modified scheduling model on unloading subsystem by Lee et al. (1996), an aggregate model based on linear regression method for production and product blending area developed by the authors, and product distribution subsystems developed by Alabi and Castro (2009). The profit is maximized considering the revenue from the products, raw material costs, inventory costs, transportation costs, and operation costs. Case study is used to demonstrate the applicability of the proposed model and solution approach.

Keywords refinery planning, linear programming, linear regression, process modelling.

Modelling and Optimisation for the Process Industry III

Organisers: Vivek Dua, Lazaros Papageorgiou
Chair: Lazaros Papageorgiou

A Multi-Parametric Dynamic Programming Approach for Model Predictive Control of Hybrid Linear Systems

Slot: Thursday 19th 13:30-14:00, Room 342
Presenter: **Pedro Rivotti** (Imperial College London, United Kingdom)
Coauthors: **Martina Wittmann-Hohlbein** (Imperial College London, United Kingdom) **Efstratios Pistikopoulos** (Imperial College London, United Kingdom)

The potential of using multi-parametric programming in the context of Model Predictive Control (MPC) has been widely recognised in the open literature. In this approach, the optimal control actions are computed offline, as a function of the states, and the computational burden of implementing online MPC is thus reduced. One limitation of this approach is the rapid increase in complexity of the multi-parametric MPC problem when the prediction horizon increases. This increase in complexity is especially relevant, and may become prohibiting, for systems described by hybrid dynamics. These include, apart from continuous variables, integer variables that relate to logic rules such as discrete event systems, piecewise affine systems or systems with discrete inputs. Dynamic Programming has been reported as a suitable tool to reduce the complexity of the optimisation problem involed in MPC. This technique consists of dissembling the original problem into a set of smaller sub-problems which are sequentially solved. Faísca et. al. proposed an algorithm for multi-parametric MPC based on dynamic programming. In this work, that approach is extended to hybrid linear systems. A numerical example is presented to illustrate the proposed developments.

Keywords multi-parametric programming, model predictive control, dynamic programming, hybrid systems.

Model-Based Design and Optimisation for Sustainable Water Desalination Using a Low-Temperature Solvent Extraction Process

Slot: Thursday 19th 14:00-14:30, Room 342
Presenter: **Eleftheria Polykarpou** (University College London, United Kingdom)
Coauthors: **Vivek Dua** (University College London, United Kingdom)

Poor quality and availability of the drinking water is one of the major causes of illness and death in the developing world. In the developed world, increasing energy prices are challenging the economic feasibility of the traditional desalination technologies like flash and membrane based technologies.

On the other hand, process and other industries routinely emit a large amount of heat into the atmosphere as a waste, further exacerbating the climate change problem. This waste heat is a low-grade heat i.e. the temperature of the emissions is low, making it difficult to be recovered and utilised for the processes within the industry. In this project we aim to model and optimise the utilisation of the low-grade heat for desalination, thus simultaneously addressing the challenges of sustainable potable water production and global warming.

A solvent extraction based process is considered for water desalination. The process consists of a heat-transfer contactor (HTC), a wash contactor (WC) and heat exchangers. The solvent recovers the salt from the saline feed stream in the HTC and gives up the salt in the WC. This process relies on the following two properties of the solvent: (i) it is immiscible with water at particular temperatures and miscible at others, and (ii) it has low solubility in water, hence when the polymer separates from the water, the aqueous phase contains no solvent. An objective of this work is to use optimisation-based techniques in order to minimise the energy consumption of the existing process, by investigating the effect of varying specific operating conditions.

Acknowledgement: Financial support from EPSRC grant EP/G059195/1 is gratefully acknowledged.

Keywords optimisation, water desalination, solvent extraction.

Flexible Design and Operation of MSF Desalination Process: Coping with Uniform and Irregular Freshwater Demand

Slot: Thursday 19th 14:30-15:00, Room 342
Presenter: **Iqbal Mujtaba** (University of Bradford, United Kingdom)
Coauthors: **Mansour Emtir** (Academy of Graduate Studies, Libya) **Said Said** (University of Bradford, United Kingdom)

Industrial desalination of sea water is becoming an essential part in providing sustainable source of fresh water around the world. Multi-Stage Flash (MSF) distillation process has been used for many years and is now the largest sector in the desalination industry. The variation in seawater temperature and the fresh water demand throughout the day will affect the operating conditions and the rate of production of freshwater using MSF desalination process. For a given design and operating conditions, the freshwater production varies significantly with the variation of the seawater temperature, producing more freshwater at low temperature (night) than at high temperature (day time). The dynamic variation in fresh water demand can be uniform during a working day and irregular during a holiday. Two cases reflecting uniform and irregular demand are included in this study. In this work, an intermediate storage tank between the plant and the client is considered to provide additional flexibility in the operation and maintenance of the MSF process throughout the day. Also, a simple polynomial based dynamic seawater temperature and uniform and irregular freshwater demand correlations is developed based on actual data. These correlations with a dynamic model for the storage tank are implemented in the full steady state MSF mathematical model developed earlier. For different number of flash stages, operating parameters such as seawater rejected flow rate and brine recycle flow rate are optimised, while the total annual operating cost of the MSF process is selected to minimise.

Keywords MSF desalination, seawater temperature, variable demand, dynamic modelling, optimisation.

Networks and Graphs

Organiser: Leonidas Pitsoulis
Chair: Leonidas Pitsoulis

Decomposition of Strongly Unimodular Matrices into Network-Representable Classes

Slot: Thursday 19th 08:30-09:00, Room 343
Presenter: **Konstantinos Papalamprou** (London School of Economics, United Kingdom)

An important subclass of totally unimodular matrices is that of strongly unimodular (SU) matrices. We present a new decomposition result for SU matrices based on the fact that they represent regular matroids over the real field. Specifically, strongly unimodular matrices are shown to be closed under the special operation of k-sums (for k = 1, 2) implying a decomposition into highly connected blocks which are proved to have a special network-representable structure. Finally, based on its graphical representation we shall explore possible implications in optimization problems.

Keywords strongly unimodular matrices, network-representable classes.

Network Optimisation Approaches for Studying the Dynamics of Financial Markets

Slot: Thursday 19th 09:00-09:30, Room 343
Presenter: **Panos Pardalos** (University of Florida (USA) & Higher School of Economics (Russia), USA)

In recent years, network theory has been used to analyze many large data-sets that can be represented as a graph. In particular financial networks can be used to understand the dynamics of the market and the effects of globalization. One model, where the vertices represent stocks and the connections are defined using prize correlations has been shown to follow the power-law model. Computing clique partitions, cliques, and independent sets have a clear practical interpretation and their analysis can be a complementary tool in financial decision making. In this talk we are going to discuss results of network optimization approaches to analyze the USA stock market, the Chinese stock market, and the Russian stock market.

Keywords network optimization, financial marker, globalization.

Patrolling Games

Slot: Thursday 19th 09:30-10:00, Room 343
Presenter: **Katerina Papadaki** (London School of Economics, United Kingdom)

A key operational problem for those charged with the security of vulnerable facilities (such as airports or art galleries) is the scheduling and deployment of patrols. Motivated by the problem of optimizing randomized, and thus unpredictable, patrols, we present a class of patrolling games. The facility to be patrolled can be thought of as a network or graph Q of interconnected nodes (e.g., rooms, terminals), and the Attacker can choose to attack any node of Q within a given time T. He requires m consecutive periods there, uninterrupted by the Patroller, to commit his nefarious act (and win). The Patroller can follow any path on the graph. Thus, the patrolling game is a win-lose game, where the Value is the probability that the Patroller successfully intercepts an attack, given best play on both sides. We determine analytically either the Value of the game, or bounds on the Value, for various classes of graphs, and we discuss possible extensions and generalizations.

Keywords search games, network security.

Community Detection by Modularity Optimisation

Slot: Thursday 19th 10:00-10:30, Room 343
Presenter: **Leonidas Pitsoulis** (University of Thessaloniki, Greece)
Coauthors: **Maria Nascimento** (Universidade Federal de São Paulo, Brazil)

Community structure in a graph is an important large scale characteristic, and can be described as a natural division of the vertices into densely connected groups, or clusters. Detection of community structure remains up to this date a computationally challenging problem despite the efforts of many researchers from various scientific fields in the past few years. The modularity value of a set of vertex clusters in a graph is a widely used quality measure for community structure, and the relating problem of finding a partition of the vertices into clusters such that the corresponding modularity is maximized is an NP-Hard problem.

In this talk we present a Greedy Randomized Adaptive Search Procedure (GRASP) with path relinking, for solving the modularity maximization problem in weighted graphs. A new class of $\{0, 1\}$ matrices is introduced that characterizes the family of clusterings in a graph, and a distance function is given enables us to define an l-neighborhood local search, which generalizes most of the related local search methods that have appeared in the literature. Computational experiments comparing the proposed algorithm with other heuristics from the literature in a set of artificially generated graphs and some well known benchmark instances, indicate that our implementation of GRASP with path relinking consistently produces better quality solutions.

Keywords communities, modularity, networks.

New Trends in Operations Research I

Chair: Vladimir Roitch

Balancing Efficiency and Equity in Emergency Medical Dispatching

Slot: Wednesday 18th 14:15-14:45, Room 311
Presenter: **Laura McLay** (Virginia Commonwealth University, USA)
Coauthors: **Maria Mayorga** (Clemson University, USA)

The decision of which servers to dispatch to which customers is an important aspect of service systems. This decision is complicated when servers must be equitably—as well as efficiently—dispatched to customers. In this paper, we formulate a model for determining how to optimally dispatch distinguishable servers to prioritized customers given a set of equity constraints. These issues are examined through the lens of emergency medical service (EMS) dispatch, for which a Markov decision process model is developed that captures how to dispatch ambulances (servers) to prioritized patients (customers). It is assumed that customers arrive sequentially, with the priority and location of each customer becoming known upon arrival. Four types of equity constraints are considered—two of which reflect customer equity and two of which reflect server equity—all of which draw upon the decision analytic and social science literature to compare the effects of different notions of equity on the resulting dispatching policies. The Markov decision processes are formulated as equity-constrained linear programming models. A computational example is applied to an EMS system to compare the different equity models.

Keywords emergency medical services, server-to-customer systems, fairness, Markov decision processes, linear programming.

Topology Optimisation of Gas Transmission Networks

Slot: Wednesday 18th 14:45-15:15, Room 311
Presenter: **Jesco Humpola** (Zuse-Institute-Berlin, Germany)
Coauthors: **Benjamin Hiller** (Zuse-Institute-Berlin, Germany) **Robert Schwarz** (Zuse-Institute-Berlin, Germany) **Jonas Schweiger** (Zuse-Institute-Berlin, Germany)

The aim of our work is topology optimization of large-scale, real-world gas transmission networks. The problem and data for this study are provided by Open Grid Europe GmbH, one of the largest gas transmission operators in Germany.

Gas networks are complex structures which consist of passive elements like pipelines between sources and sinks, and active elements such as valves and compressors. Given a set of nominations, i.e., balanced allocations of source and sink flows, a suitable setting of all network components such that the nominated amount of gas can be transmitted through the network without violating physical or operational constraints defines a feasible nomination. If a nomination is not feasible, the goal is to decide which combination of possible network extensions, such as pipelines, compressors or valves should be added to the gas network, so that every nomination becomes feasible.

The gas transmission network is modeled by a directed graph. An extension is given by a series of pipelines and active elements, where the physical state of each active element needs to be optimized in order to minimize the construction cost. The gas flow on a pipeline is induced by a non-linear and non-convex relationship of the pressure differences at its end nodes. Thus, the model for the topology optimization problem is a mixed integer non-linear program. Discrete decisions correspond to active network elements, and the non-linearity origins from described gas flow properties.

A framework which yields a global optimal solution for this large-scale topology extension planning problem is implemented as a special tailored combination of the solvers SCIP and IPOPT. Preliminary computational results based on real-world instances with several hundred nodes and about 3000 arcs are presented.

Keywords network design, nonlinear network flows, MINLP.

Robust Pricing of Monopolistic Cloud Computing Services with Service Level Agreements

Slot: Wednesday 18th 15:15-15:45, Room 311
Presenter: **Vladimir Roitch** (Imperial College London, United Kingdom)
Coauthors: **Daniel Kuhn** (Imperial College London, United Kingdom) **Yike Guo** (Imperial College London, United Kingdom)

Cloud Computing is a new computing paradigm that gives end-users on-demand access to computing resources of major IT companies such as Google or Amazon. In this talk we address the optimal pricing of cloud computing services from the perspective of a monopolistic service provider that needs to manage demand responsiveness and uncertainty. We formulate the pricing problem for on-demand based services as a multi-stage stochastic program and model service level agreements via chance constraints. Under weak assumptions about the demand uncertainty we show that the resulting model can be reduced to an equivalent two-stage stochastic program. As cloud computing is only just emerging, it is impossible to reliably estimate demand distributions from historical data. Indeed, such data may also be very difficult to collect in the first place. We address this type of model uncertainty by adopting a distributionally robust approach, assuming that only information about the location, size and support (but not the shape) of the demand distribution is available. We show that the arising robust model can be reformulated as a second-order cone program, and we analytically derive the worst-case distributions. Several extensions of the basic model are discussed. First, we study generalized models in which higher-order moments of the demand distribution are known. Next, we include multiple products and account for different commodities that correspond to the same product but different qualities. Finally we investigate the possibility of selling unused capacity (if any) on a spot market.

Keywords cloud computing, robust optimisation, chance constraints, pricing on-demand services, service level agreement.

New Trends in Operations Research II

Chair: Iakovos Kakouris

An Evolution Strategy Approach to the Inverse Prioritisation Problem in AHP

Slot: Friday 20th 08:30-09:00, Room 343
Presenter: **Bosko Blagojevic** (University of Novi Sad, Serbia)
Coauthors: **Bojan Srdjevic** (University of Novi Sad, Serbia) **Zorica Srdjevic** (University of Novi Sad, Serbia)

In the Analytic Hierarchy Process (AHP) priority vectors at all levels of the hierarchy are computed for given decision-making problem. Vectors contain weights of the decision elements compared in pairwise manner by the decision maker while creating judgment matrices. Priority vector are commonly computed by so called prioritization methods such as eigenvector, logarithmic mean squares, etc. Deriving priority vector from given matrix is underdetermined problem, especially if there are more than three decision elements to be compared at a time. The decision makers usually demonstrate inconsistencies which may come from different reasons, e.g. inappropriateness and/or inherent limitations of a scale used for comparisons. A set of feasible priority vectors is enlarging dramatically with raising the number of decision elements. Goodness of derived priority vector for given judgment matrix is usually measured by error functions created on the sets of initial judgments and ratios of computed weights at each position in the matrix. Well known functions are Euclidean distance (ED), consistency ratio (CR) if eigenvector prioritization method is used, geometric consistency index (GCI) if logarithmic least squares method is used, minimum violation (MV) error, etc. The inversion problem in AHP prioritization is solved aimed to recognize the decision maker's behavior during the judgment process. Given the priority vector, information on prioritization method, and a set of consistency measures, a large set of 'feasible' judgment matrices is generated and assessed as alternatives with the TOPSIS multicriteria method to identify the one with a minimum consistency error. A fit-for-purpose evolution strategy algorithm (ESA) generated alternative matrices; fitness function is defined as closeness of priority vector derived from a matrix with (generated) judgments belonging to a mating pool (population), mutation operator is implemented, elitist reproduction is preserved and roulette-wheel selection of parents is applied.

Keywords analytic hierarchy process (AHP), evolution strategy algorithm, TOPSIS.

New Heuristic for the Integrated Problem of Cutting and Sizing Bins (3D)

Slot: Friday 20th 09:00-09:30, Room 343
Presenter: **Mariem Baazaoui** (FSEG Sfax, Tunisia)
Coauthors: **Racem Mellouli** (Universite de SFAX, ESC, Tunisia) **Habib Chabchoub** (Universite de SFAX, IHEC, Tunisia)

Cutting and packing problems are numerous and have a wide range of practical applications. In our research, we are interested to the cutting of mousse blocks in SOTIM industrial company. Indeed, we present a general optimization problematic of integrated cutting and sizing of the 3D-mousse bins by defining a new type of cutting and packing problem. The latter is a combination of the assembly problem and the cutting problem in 3D. This is an NP-hard problem for which it is difficult to find the optimal solution. So, it is be better to use heuristic methods to find a good solution in a reasonable lap time. We propose a new heuristic made in three steps for the case of SOTIM. In the first step, in conscious leisure account of the rotation of pieces, we classify the items into similar sets called clusters in such a way that the lengths of all pieces in the same cluster are close. In the second step, we sort the clusters according to the largest cardinality and the pieces in each cluster according to the decreasing height. While in the third step, we reconstruct the mousse blocks with fictitious manner by placing the pieces in the predefined order. For this, we use an overlap of 2D-heuristic packing procedure generating a succession of layers whose boundaries are eligible to delimit the blocks (the sizing part). To implement and evaluate our heuristic, we test random, SOTIM and some literature instances. We conduct a sensitivity analysis while taking into account the variation in the number of pieces and changing the nature of the pieces.

Keywords heuristic method, integrated problem of cutting and sizing.

Dealer Selection for an Automotive Company Using ELECTRE I and TOPSIS Methodologies

Slot: Friday 20th 09:30-10:00, Room 343
Presenter: **Elif Mac** (Kocaeli University, Turkey)
Coauthors: **Zerrin Aladag** (Kocaeli University, Turkey)

Sales Aftersales network has vital importance as of customer satisfaction for automotive companies. However new technologies, competitive price and charming vehicle design increase new customer potential and of course customer satisfaction; these key points are not enough stand alone to sustain long term customer satisfaction and loyalty. Customer satisfaction is mainly based on the nearest experience of the service or product. As far as the nearest experience exceeds previous expectations, it seems to have higher customer satisfaction. Dealers are the gates opening long term customer satisfaction and afterwards loyalty. Therefore, automotive companies have to select accurate contacts for dealer role. Most of the automotive companies including the ones having the largest production capacity and/or sales numbers do not pay satisfactory importance to dealer selection business. Dealer selection is widely related to the financial power of the candidates. There are of course some other criteria like location, service area capability, etc. but the evaluation processes are not usually involved any scientific selection methodologies. The application of multicriteria analysis is a meaningful way of integrating various aspects into a uniform evaluation process. For this reason; this paper proposes to use ELECTRE I and TOPSIS multicriteria analysis methodologies to choose one dealer among 6 dealership applicants for an automotive company in Turkey. The research relies on data produced according to the both quantitative opinions gained within the framework of the Sales Aftersales Region Managers and qualitative information about applicants.

Keywords dealer selection, ELECTRE I, TOPSIS, multi-objective decision making.

Option Pricing and Calibration

Organiser: Paolo Foschi
Chair: Paolo Foschi

An Empirical Study of Stock and American Option Prices

Slot: Wednesday 18th 11:15-11:45, Room 145
Presenter: **Diego Ronchetti** (Columbia University, USA)

This paper describes an empirical study of the generating processes of daily share prices and American option mid-quotes. Stock return and its volatility are considered to be the risk factors, and without parameterizing their historical joint dynamics, two results are obtained. First, in order to quantify both equity and variance risk premia, it is necessary to simultaneously analyze share prices and option mid-quotes. Second, an arbitrage-free pricing model is useful to obtain more precise estimates of the historical joint dynamic properties of return and volatility. For example, the study analyzes different estimates over time of the correlation between return and volatility, the Sharpe ratio of an investment on the stock, skewness and kurtosis of returns.

Keywords American option, equity risk premium, variance risk premium, leverage effect, Sharpe ratio, skewness and kurtosis, non-parametric estimation, model calibration, generalized method of moments, extended method of moments.

Multi-Stage Product Development with Exploration, Value-Enhancing, Preemptive and Innovation Options

Slot: Wednesday 18th 11:45-12:15, Room 145
Presenter: **Nicos Koussis** (Frederick University, Cyprus)
Coauthors: **Spiros Martzoukos** (University of Cyprus, Cyprus) **Lenos Trigeorgis** (University of Cyprus, Cyprus)

We provide a real options framework for the analysis of product development that incorporates research and exploration actions, product attribute value-enhancing actions with uncertain outcome, preemption and innovation options. We derive two-stage analytic formulas and propose a general multi-period solution using a numerical lattice approach. Our analysis reveals that exploration actions are more important when the project is out or at-the-money (near zero NPV) and less important for high project values. In a multi-stage setting exploration actions are important even for in-the-money projects when follow-on actions exist that can enhance the expected value of the project. With path-dependency early actions are more valuable since they enhance the impact or reduce the cost of subsequent actions. Preemptive controls affecting rare event (jump) frequency and innovations that introduce positive jumps are more valuable for firms with higher frequency of competitive threats involving low volatility.

Keywords real options, RD, technical risk, path-dependency, sequential (compound) options, jump-diffusion.

Pricing American Options by Means of Barrier Options

Slot: Wednesday 18th 12:15-12:45, Room 145
Presenter: **Paolo Foschi** (University of Bologna, Italy)

Once the optimal exercise region is known an American option can be priced as a Barrier option. Furthermore, if a non-optimal exercise region is used the Barrier option price still provides a bound to that of the American contingent claim. Here we exploit the fact that for some specific boundaries the price of the barrier option can be directly computed. Then, the American option pricing problem is formulated as an optimization problem on the parameters describing the barrier.

Keywords American options, barrier options, option pricing, hedging.

Portfolio Selection and Econometrics I

Organiser: Alessandra Amendola
Chair: Alessandra Amendola

Factor Copulas Through a Vine Structure

Slot: Wednesday 18th 16:15-16:45, Room 343
Presenter: **Giorgia Rivieccio** (Parthenope University of Naples, Italy)

Copula functions have been widely used in actuarial science, finance and econometrics. Though multivariate copulas allow for a flexible specification of the dependence structure of economic variables, in high dimensional contexts they are not particularly attractive. A factor model which involves the copula functions has proved to be a powerful tool in credit risk applications, e.g. for the pricing of CDO, due to its capability in describing, in a both flexible and tractable way, the joint default for a large number of names within a semi-analytical framework. Many of the factor copula models proposed in theoretical and empirical application are embedded into a stochastic correlations framework or in analysing simulation and pricing, not considering the estimation of copula parameters. We exploit a new approach to obtain a factor copula model based on a vine structure for the asset returns, which enables to modeling the dependence and conditional dependence of variables through a representation of a cascade of arbitrary bivariate copulas. According to the Inference for Margins (IFM) method, we have computed, separately, the margins and the copula parameters via maximum likelihood estimation. In the first, GARCH models for margins are applied and then, given the conditional independence of the transformed standardized residuals with respect to common factors, vine copulas are estimated, providing the parameters of an "implied copula" for the asset returns. Finally, a tail dependence measure is given for the implied copula estimated.

Keywords vine copulas, factor copula models, GARCH models, tail dependence.

Nonparametric Sensitivity Analysis for Risk Evaluation

Slot: Wednesday 18th 16:45-17:15, Room 343
Presenter: **Maria Lucia Parrella** (University of Salerno, Italy)
Coauthors: **Francesco Giordano** (University of Salerno, Italy)

Parametric regression may be not suitable for adequately fitting curves to many datasets that arise in practise. In such cases, nonparametric methods can be used. Anyway, estimating nonparametrically a high-dimensional regression function is notoriously difficult, due to the curse of dimensionality. The local polynomial estimator is particularly affected by this problem, since it becomes unfeasible when the number of covariates is high. For some applications a sparse condition can be formulated, which assumes that the true function only depends on a small number of the total covariates. In such cases, an estimation procedure which is capable of doing a sensitivity analysis and isolating the relevant variables can reach rates of convergence which are satisfactory. In this work, we present an iterative estimation procedure based on the local polynomials and on a modified version of the sparseness condition. In particular, we focus on the number of nonlinear covariates. We show that the procedure has a good rate of convergence even when the number of relevant covariates is high, provided that the number of nonlinear regressors is low. An application to financial data is presented to show how the method can be used for risk evaluation.

Keywords nonparametric regression, variable selection, local polynomial estimator.

Sieve Boot. for Longevity

Slot: Wednesday 18th 17:15-17:45, Room 343
Presenter: **Valeria D'Amato** (University of Salerno, Italy)
Coauthors: **Steven Haberman** (Cass Business School, United Kingdom) **Gabriella Piscopo** (University of Florence, Italy) **Maria Russolillo** (University of Salerno, Italy)

From the life insurance company, it is essential to assess the uncertainty around the mortality dynamics carefully. The risk that a population lives longer than anticipated can lead to pernicious effects in terms of profitability for these institutions. The Lee Carter is one of the standard benchmark models to forecast mortality, used in many countries. Lee and Carter proposed a simple method for projecting future mortality, consisting of a base model of age-specific death rate with a dominant time component and a fixed relative age component and a time series model of the time component. The mortality experience of countries in the industrialized world over the course of the twentieth century would suggest a substantial age-time interaction: the two dominant trends affected different age groups at different times. This indicates a dependence structure. Also the dependence between ages is an important component in the modeling of mortality. It is observed that the mortality improvements are similar for individuals of contiguous ages. Moreover, considering the dataset by single ages, the correlations between the residuals for adjacent age groups tend to be high. This suggests the value in exploring the dependence structure, also across time, in other words the inter-period correlation. In this research we focus on deriving reliable survival probabilities in the Lee Carter setting by taking into account the presence of spatial dependence across age and time, since it leads to systematic over-estimation or under-estimation of uncertainty in the estimates. Our paper analyzes a sieve bootstrap methodology, the LC Sieve Bootstrap, for capturing the spatial dependence in deriving prediction intervals. In particular, we propose a method which combines model-based predictions with a consistent bootstrap procedure, and so both the historical parametric structure and the intergroup error correlation structure are preserved. The approach is illustrated with an empirical example.

Keywords longevity, dependence, Lee Carter, bootstrap.

Comparison of Variables Selection Methods in Competing Risks Model

Slot: Wednesday 18th 17:45-18:15, Room 343
Presenter: **Alessandra Amendola** (University of Salerno, Italy)
Coauthors: **Marialuisa Restaino** (University of Salerno, Italy) **Luca Sensini** (University of Salerno, Italy)

A challenging task in statistical analysis is that of variable selection. Often, there are a large number of potential predictors and a selection among them is recommended. For dealing with this problem, the automated procedures are the most commonly used methods, without taking into account their disadvantages. For overcome them, the shrinkage methods are good alternative. Our aim is to investigate the performance of different variable selection methods, focusing on a statistical procedure suitable for the competing risks model. In this theoretical setting, the same variables might have different degrees of influence on the risks due to multiple causes and this effect has to be taken into account in the choice of the "best" subset. The performance of the proposed procedure has been evaluated in a context of default risk predictions by means of an empirical analysis on a data-set of financial indicators.

Keywords shrinkage methods, variable selection, default risk, competing risk.

Portfolio Selection and Econometrics II

Organiser: Peter Winker
Chair: Bjoern Fastrich

New Insights Into Optimal Control of Nonlinear Dynamic Econometric Models: Application of a Heuristic Approach

Slot: Thursday 19th 13:30-14:00, Room 145
Presenter: **Ivan Savin** (Friedrich Schiller University and Max Planck Institute of Economics, Germany)
Coauthors: **Dmitri Blueschke** (University of Klagenfurt, Austria) **Viktoria Blueschke-Nikolaeva** (University of Klagenfurt, Austria)

Optimal control of dynamic econometric models has a wide variety of applications including economic policy relevant issues. There are several algorithms extending the basic case of a linear-quadratic optimization and taking nonlinearity and stochastics into account, but being still limited in a variety of ways, e.g., symmetry of the objective function. To overcome these problems, an alternative approach based on heuristics is suggested. To this end, we apply a 'classical' algorithm (OPTCON) and a heuristic approach (Differential Evolution) to three different econometric models and compare their performance. Among scenarios considered are symmetric and asymmetric quadratic objective functions and different data frequencies between control variables. Results provide a strong support for the heuristic approach encouraging its further application to optimum control problems.

Keywords differential evolution, dynamic programming, nonlinear optimization, optimal control.

Overconfident Consumers in the Credit Card Market

Slot: Thursday 19th 14:00-14:30, Room 145
Presenter: **Susan Kriete-Dodds** (University of Basel, Switzerland)
Coauthors: **Dietmar Maringer** (University Basel, Switzerland)

Consumers who borrow on their credit cards without originally intending to do so are preferred customers by credit card issuers since they are more likely to repay their debt compared to those who deliberately borrow on their credit cards. In economic literature, the first type of customers have been described as overconfident. Overconfidence is a phenomenon originating from psychology that has been used increasingly in economics and has been employed in security markets to explain high trading volumes or the behaviour of fund managers. While agent-based modelling can offer great insight into overconfidence, many models that consider overconfidence are instead experimental, empirical or market-based. In a previous paper, evidence of overconfidence could be shown in a simplified credit card market model. This first model included consumption, two means of payment - cash and one type of credit card - and a distortion to agents' income expectations by overconfidence. Customers had an inherent preference to repay their credit card debt, either the full amount or less than the full amount. It could be shown that overconfident agents failed to meet their obligations more often and accidentally borrowed on their credit card. The model presented here is an extension of the first model, allowing agents to select from a range of credit card issuers, each offering different conditions. These credit card issuers compete for customers by changing their conditions, namely interest rates, annual fees, bonus payments and enticements. Customers attempt to reduce the cost of borrowing from a credit card by finding a cheaper credit card given limited information and switching costs.

Keywords agent-based modelling, overconfidence, credit card market.

Regularisation Methods for Optimal Portfolio Selection

Slot: Thursday 19th 14:30-15:00, Room 145
Presenter: **Bjoern Fastrich** (Justus-Liebig-University Giessen, Germany)
Coauthors: **Sandra Paterlini** (University of Modena and Reggio Emilia, Italy) **Peter Winker**

(Justus Liebig University Giessen, Germany)

The portfolio theory of Markowitz (1952, 1959) indisputably constitutes a milestone in modern finance, even though the resulting mean-variance portfolios typically exhibit an unsatisfying out-of-sample performance, especially when the number of securities is high and when they are highly correlated. This is because estimation errors in the covariance matrix and in the expected return vector can deposit unhindered in the portfolio weights. Recent studies show that imposing a convex L1-penalty on the objective function regularizes the problem, thereby improving the out-of-sample performance of the optimized portfolios. Simultaneously, L1-regularization allows for the choice of the best subset of assets to invest in from a pool of candidates that is often high-dimensional. However, L1-regularization might lead to the construction of biased solutions. In this work, we propose to tackle this issue by considering several alternative (non-convex) penalties and show that they can exhibit a superior out-of-sample performance in comparison to the established L1-penalty and several standard benchmarks, especially in high dimensional problems. Empirical results are based on simulated and real-worl U.S.-stock market data.

Keywords minimum variance portfolio, LASSO, non-convex regularization.

Portfolio Selection and Econometrics III

Organiser: Victor DeMiguel
Chair: Victor DeMiguel

Robust Performance Hypothesis Testing with the Sharpe Ratio and the Variance

Slot: Friday 20th 14:00-14:30, Room 145
Presenter: **Michael Wolf** (University of Zurich, Switzerland)
Coauthors: **Olivier Ledoit** (University of Zurich, Switzerland)

Applied researchers often test for the difference of the Sharpe ratios of two investment strategies. A very popular tool to this end is the test of Jobson and Korkie (1981), which has been corrected by Memmel (2003). Unfortunately, this test is not valid when returns have tails heavier than the normal distribution or are of time series nature. Instead, we propose the use of robust inference methods. In particular, we suggest to construct a studentized time series bootstrap confidence interval for the difference of the Sharpe ratios and to declare the two ratios different if zero is not contained in the obtained interval. This approach has the advantage that one can simply resample from the observed data as opposed to some null-restricted data. A simulation study demonstrates the improved finite sample performance compared to existing methods. In addition, two applications to real data are provided.

We also discuss the related problem of testing for the difference of the variances of two investment strategies.

Keywords bootstrap, HAC inference, performance hypothesis testing, Sharpe ratio.

Size Matters: Calibrating Shrinkage Estimators for Portfolio Optimisation

Slot: Friday 20th 14:30-15:00, Room 145
Presenter: **Alberto Martin-Utrera** (Universidad Carlos III de Madrid, Spain)
Coauthors: **Victor DeMiguel** (London Business School, United Kingdom) **Francisco J. Nogales** (Universidad Carlos III de Madrid, Spain)

We provide a comprehensive study of shrinkage estimators for portfolio selection. We study both portfolios computed from shrinkage estimators of the moments of asset returns (including new shrinkage estimators of the mean and the inverse covariance matrix), as well as shrinkage portfolios obtained by shrinking the portfolio weights directly. We propose two calibration approaches to determine the shrinkage intensity: a parametric approach based on the assumption that returns are independent and identically distributed as a normal (that leads to closed-form expressions for the shrinkage intensity), and a nonparametric approach that makes no assumptions on the return distribution. We carry out extensive empirical tests on six datasets and identify a number of findings. First, we find that our proposed shrinkage estimator for the vector of means substantially reduces estimation error and improves the out-of-sample performance of mean variance portfolios. Second, we find that the condition number of the estimated covariance matrix matters on the calibration of its shrinkage estimator. Finally, we find that for shrinkage portfolios that consider the vector of means, minimizing the portfolio variance is the best calibration criteria, whereas for shrinkage portfolios that do not consider the vector of means, the best calibration criterion is the minimization of the expected quadratic loss.

Keywords portfolio choice, estimation error, shrinkage estimators, bootstrap.

Stock Return Serial Dependence and Out-of-Sample Portfolio Performance

Slot: Friday 20th 15:00-15:30, Room 145
Presenter: **Victor DeMiguel** (London Business School, United Kingdom)
Coauthors: **Raman Uppal** (EDHEC Business School, United Kingdom) **Francisco J. Nogales** (Universidad Carlos III de Madrid, Spain)

We study whether investors can exploit stock return serial dependence to improve the out-of-sample performance of their portfolios. To do this, we first show that a vector autoregressive (VAR) model captures daily stock return serial dependence in a statistically significant manner. Second, we characterize (analytically and empirically) the expected return of an arbitrage (zero-cost) portfolio based on the VAR model, and show that it compares favorably to that of other arbitrage portfolios in the literature. Third, we evaluate the performance of three investment (positive-cost) portfolios: a conditional mean-variance myopic portfolio obtained using the linear VAR model; a conditional mean-variance portfolio using a nonparametric autoregressive (NAR) model; and, a portfolio that is dynamic rather than myopic in its use of the VAR model. We show that, subject to a suitable norm constraint, all three investment portfolios substantially outperform the traditional (unconditional) portfolios, even in the presence of transaction costs of up to 10 basis points. Moreover, we show that our findings are robust to the use of open-to-close as well as weekly returns, which demonstrates that our observations cannot be attributed solely to the presence of asynchronous return observations.

Keywords serial dependence, vector auto-regression, portfolio choice, dynamic portfolio choice, out-of-sample performance.

Resource Allocation

Chair: Stefan Pickl

A Matching Model of the Global Tanker Shipping Industry

Slot: Thursday 19th 13:30-14:00, Room 343
Presenter: **Sophia Parker** (University College London, United Kingdom)

The oil tanker shipping industry is an integral part of a complex energy infrastructure where getting the right sort of oil to the right place with the right ship at the right time is crucial. Like all decentralized markets, buyers and sellers in shipping try to transact with agents to maximise their profits. On the seller side, oil traders choose ships that enable them to profit from geographical arbitrage, while on the seller side, shipowners make logistical decisions about where to position vessels based on the trade-off between costs, revenue and expected future profits. The price of their transaction reflects these considerations. While the operations research literature has focused on algorithms to solve resource allocation problems for fleet management in other transportation industries, there has been little research on the resource allocation problem in shipping that incorporates both agent groups' perspectives at the micro-level. A matching model is one theoretical framework for modeling the equilibrium formation of these relationships and can be used to explain prices and output. This method combines linear programming to solve the resource allocation problem and dynamic programming to value agent's future period payoffs. A simulation of this market with different oil price scenarios will be shown as an example of its computational applicability.

Keywords matching model, linear programming, dynamic programming.

Business Process Synthesis with Various Resource Needs

Slot: Thursday 19th 14:00-14:30, Room 343
Presenter: **Zsolt Ercsey** (University of Pécs, Hungary)
Coauthors: **Zoltán Süle** (University of Pannonia, Hungary) **Tamás Kovács** (University of Szeged, Hungary) **Botond Bertók** (University of Pannonia, Hungary) **Zoltán Kovács** (University of Szeged, Hungary)

There is a large number of different methods and tools to support the description, representation and analysis of business processes. After the design of the processes, the business model can be examined based on various viewpoints, and simulations of different circumstances can also be done. In this paper a synthesis based method is introduced, where already during the design phase of the business process all design viewpoints are enforced to be considered. These design viewpoints include work flow, costs, resource need, event constrains etc. Several robust and reliable process optimization algorithms have been developed and implemented on the basis of the P-graph framework by Friedler and his collaborators in the last decade (Friedler et al. 1992, 1993, 1998). The transformation steps from the Business Process Diagram (BPD) to P-graph representation were introduced by Kalauz et al (2010) presenting opportunity for examining the structural properties of business processes algorithmically. That work reveals a methodology that provides an adequate basis to model business processes mathematically and formally as well as to algorithmically synthesize optimal and alternative business processes. Generally, activities in the business processes are represented by operating units, while the set of data and events are material type nodes in P-graph. In this paper a P-graph based mathematical model is introduced, which handles the different types of resource needs of the business processes. It can be answered with the help of this model what resource need is necessary to the given business process considering the input loads; and vica versa what business process has to be considered in case the resources are limited. As an illustration, an exact business process synthesis example is given, where the human resource need with various competence was optimized with the help of this novel method.

Keywords business process, synthesis, P-graph, optimal resource allocation.

Design and Optimisation of International Resource Planning Processes - The Role of System Dynamics, Agent Based Models and Data Mining within a Computational Management Approach for Complex Energy Systems

Slot: Thursday 19th 14:30-15:00, Room 343
Presenter: **Stefan Pickl** (University of the German Federal Armed Forces, Germany)

Interactive resource planning becomes more and more important within future energy and emission trading markets. The conferences of Rio de Janeiro 1992 and Kyoto 1997 demand for such new economic instruments which focussed originally on environmental protection in both macro and micro economy. An important economic tool in that area is Joint-Implementation (JI) which is defined in Art. 6 of the Kyoto Protocol. A sustainable development can only be guaranteed if the instrument is embedded in an optimal global energy management: In this contribution we describe an international procedure within uncertain markets which helps to establish such an optimal energy management and interactive resource planning processes. The role and potential of System Dynamics, Agent Based Approaches and Data Mining within such a process is described. We introduce the TEM (Technology Emissions Means) model and revise it via specific methods from computational management: First numerical results (which are based on new algorithm engineering methods) will be presented. By taking discrete algorithms and combining them with a hardware device connected to real world data, you are able to verify and validate immediately the algorithm results. In a second step the underlying dynamic behavior should be characterized. Such an empirical analysis supports an optimal decision making within complex energy systems.

Keywords resource allocation, system dynamics, agent based model, data mining, algorithm engineering, decision making.

Risk Analysis I

Chair: Michalis Kapsos

The Convexity of the Efficient Frontier and its Impact on Risk Elasticity

Slot: Wednesday 18th 14:15-14:45, Room 343
Presenter: **João Telhada** (University of Lisbon, Portugal)
Coauthors: **João Duque dos Santos** (University of Lisbon, Portugal)

Markowitz's mean-variance model has set the grounds for modern portfolio management theory. One major concern is the estimation of the underlying assets' volatility, which usually disregards specific time-dependent behaviour. This has motivated our work on a new exponential smoothing based estimation technique for volatility. On the other hand, investors may have some expectations on the portfolio return given some measure of the opportunity cost of risk. As observed in a particular investment firm scenario, investors set some return measure and evaluate the associated risk. Risk elasticity regarding the returns may allow, however, for very different decisions. The convexity of the efficient frontier may lead to such measure and allow for better trading decisions, especially in the long-term. An automated and self-learning procedure may encapsulate these ideas and provide a robust decision-making method which maximizes portfolio value. Thorough computational studies have been undertaken to carefully evaluate the quality of the proposed measures. Some artificial portfolios based on risky assets were considered, and different portfolio management strategies were tested.

Keywords portfolio optimization, risk management, volatility estimation.

Risk Adjusted Growth Optimal Portfolios

Slot: Wednesday 18th 14:45-15:15, Room 343
Presenter: **Sergey Sosnovskiy** (Frankfurt School of Finance & Management, Germany)

We apply idea of evolutionary optimization for online portfolio selection adjusted for risk. Existing non-parametric methods such as Universal Portfolios (Cover'91), Exponential Gradient (Kivinen, Warmuth'97) and others aim at approximation of rebalancing strategy which maximizes growth rate of investment. However, it is known that the Growth Optimal Portfolio (GOP) can be quite risky, especially in short term horizons. One possible approach of controlling the risk of the GOP is the so-called fractional Kelly strategy, but it does not provide a clear tradeoff between risk and growth rate. We embed selection of strategies which maximize growth rate within specified risk limits into Universal Portfolios framework. As an example, we provide numerical simulations and comparisons of strategies with limited volatility and drawdown. Another possible application of the method is downside protection of the GOP (portfolio insurance). We provide comparison of online algorithm to the existing methods, such as CPPI and OBPI.

Keywords growth optimal portfolios, universal portfolios, drawdown, portfolio insurance, online learning.

Robust Equally-Weighted Risk Contribution Portfolios

Slot: Wednesday 18th 15:15-15:45, Room 343
Presenter: **Michalis Kapsos** (Imperial College London, United Kingdom)
Coauthors: **Berc Rustem** (Imperial College London, United Kingdom)

The recent market instability has increased the popularity of the risk budgeting concept, known as Risk Parity or Equal Risk Contribution. The Risk Parity is agnostic about the expected returns. Its aim is to achieve equally weighted risk contribution from each asset/investment. Risk Parity portfolios have demonstrated higher risk adjusted returns than the typical institutional portfolios. As a result, a number of large US pension plans have recently adopted Risk Parity concepts.

In this talk, we address the benefits and disadvantages of Risk Parity portfolios and we introduce the Robust Risk Parity. This is a robust variant of the nominal equal risk contribution problem. Unlike the

standard approach, the robust variant does not assume that return distributions are known exactly, and hedges against uncertainty in the input parameters. We show that the problem remains tractable under different types of uncertainty.

Keywords equal risk, risk allocation, risk parity, robust portfolio allocation.

Risk Analysis II

Chair: Ana-Maria Fuertes

Robust Dynamic Risk Measures

Slot: Wednesday 18th 16:15-16:45, Room 342
Presenter: **Dimitra Bampou** (Imperial College London, United Kingdom)
Coauthors: **Daniel Kuhn** (Imperial College London, United Kingdom)

Recent progress in the theory of dynamic risk measures has found a strong echo in stochastic programming, where the time consistency of dynamic decision making under uncertainty is currently under scrutiny. In this talk we first review the concepts of coherence and time consistency of dynamic risk measures and then discuss their ramifications for stochastic programming. Next, we extend these concepts to stochastic programming models subject to distributional ambiguity, which motivates us to introduce robust dynamic risk measures. We discuss conditions under which these robust risk measures inherit coherence and time consistency from their nominal counterparts. We also propose an approximation scheme based on polynomial decision rules for solving linear multistage stochastic programs involving robust dynamic risk measures. The theoretical concepts are illustrated through numerical examples in the context of inventory management.

Keywords multi-stage stochastic programming, distributional ambiguity, robust dynamic risk measures, time consistency.

Local Risk-Minimisation in a Jump-Diffusion Framework with Numerical Implementation and Examples

Slot: Wednesday 18th 16:45-17:15, Room 342
Presenter: **Florian Löcker** (Vienna University of Economics and Business, Austria)

We consider the well-known problem of quadratic hedging in the context of Lévy models with possibly stochastic volatility, when the reference measure for hedging is the statistical one. We relate the properties of our model to results from the general theory and give an explicit construction of the related Föllmer-Schweizer decomposition, which yields the locally-risk-minimizing strategy as a by-product. We formulate a partial integro-differential equation and show how prices and hedge ratios can be obtained simultaneously from its solution, resulting in a numerically efficient framework. Our findings are then applied to a number of derivative contracts and we compare locally-risk-minimizing strategies to their mean-variance-optimal counterparts and use the practically important Delta hedge as a benchmark. Using Monte Carlo simulation, we quantify dispersion and other statistical properties of the resulting profit and loss distribution and arrive at a number of implications that are important from a risk management point of view and give indications as to the importance of including jumps in the hedging procedure.

Keywords hedging, local risk-minimization, levy processes, incomplete markets.

Systemic and Default Propagation Risk Modelling

Slot: Wednesday 18th 17:15-17:45, Room 342
Presenter: **David Song** (ECE Paris, France)

Systemic risks involve huge losses where whole countries or banking groups go bankrupt. Before that happens, it is interesting to study the symptoms of contagion because it might help prevent the loss. In our study, we try to highlight effects where individual smaller blocks of banks collapse and propagate their defaults to bigger ones, spreading the defaults up to the central bank.

This paper will first expose the topology of the networks of lenders (such as banks) and borrowers (such as corporate). Banks can transfer their default risk by selling CDO to other banks leading to bankruptcy when corporates fail. Along the Blinder-Bernanke rationality of decision between bonds and loans, secondary banks will absorb more or less securities, depending also on rate differentials. The study

examines what happens when some key parameters, such as this (? – i) difference, as well as the size and proportions of the 2 populations of primary and secondary banks. To some extent, a "tertiary" bank, as the "rest-of-the-world" can absorb the losses of the secondary banks as they default.

The model is implemented using JAVA and Excel VBA. This simulation involves creation and death of corporates following a Gaussian distribution, and to be more realistic, we will generate different scenarios of crises and various macroeconomic sub-models, which will affect several parameters such as inflation, interest rate.

We will thus be able to identify which parameters would have the most impact on bankruptcies. The originality of our project comes from macroeconomic multi-actors simulation and where we have tried to merge qualitative and quantitative approach.

Keywords risk, modeling, default, CDO, simulation, contagion.

Optimally Harnessing Inter-Day and Intra-Day Information for Daily Value-at-Risk Prediction

Slot: Wednesday 18th 17:45-18:15, Room 342
Presenter: **Ana-Maria Fuertes** (Cass Business School, United Kingdom)
Coauthors: **Jose Olmo** (Centro Universitario de la Defensa and City University London, Spain)

Despite the acclaimed success of forecast combination in many contexts, this topic has been barely explored for tail risk prediction where the benefits of expanding the information set through combination might be particularly worthwhile. This paper proposes a robust encompassing test for Value-at-Risk (VaR) forecasts that builds on quantile regression theory. Our test naturally accounts for model risk and estimation uncertainty and is valid for any quantile forecasts from (non)nested models. We deploy it for two daily VaR models from the location-scale family to assess the merit of pooling inter-day and intra-day information. The techniques are illustrated for equity, FOREX, fixed income and commodity trading desks. In various cases, the out-of-sample 5% VaR predictions from an ARFIMA realized volatility model that exploits five-minute prices outperform the GARCH-based VaRs that exploit daily-recorded closing, high and low prices. By contrast, there is little evidence of encompassing for the 1% tail risk predictions which warrants optimal quantile combination. Thus our paper formally demonstrates through CQFE inference that the use of intra-day information, either on its own or combined with inter-day information, is worthwhile for setting one-day-ahead loss limits for individual trading desks.

Keywords encompassing, high-frequency data, leverage effects, quantile combination, realized measures, value-at-risk.

Robust Optimisation I

Chair: Dick den Hertog

Performance Bounds for Infinite Discounted Horizon Controllers

Slot: Wednesday 18th 16:15-16:45, Room 144
Presenter: **Bart P. G. Van Parys** (ETH Zurich, Switzerland)
Coauthors: **Paul Goulart** (ETH Zurich, Switzerland) **Manfred Morari** (ETH Zurich, Switzerland)

In this talk, we propose a method to bound the performance of causal controllers on uncertain linear systems with mixed state and input constraints. The performance is measured by the expected value of an infinite linear quadratic discounted horizon cost function.

Our method computes a causal affine controller, which satisfies the constraints robustly over an infinite horizon, while simultaneously providing a lower bound on the achievable performance of this or any other causal control policy constructed by any other method. The controller and performance guarantee can be found by solving two convex conic optimisation problems which are intimately related.

In a last part of the talk, we illustrate our method on 2 numerical examples to illustrate that the obtained bounds are usually tight.

Keywords constrained control, affine policies, robust control, discounted horizon cost, performance bounds.

On the Robustness of Two-Stage Estimators

Slot: Wednesday 18th 16:45-17:15, Room 144
Presenter: **Mikhail Zhelonkin** (University of Geneva, Switzerland)
Coauthors: **Elvezio Ronchetti** (University of Geneva, Switzerland) **Marc G. Genton** (Texas A&M University, USA)

Many estimators in the statistics and econometrics literature are obtained following a two-stage (2S) procedure. These procedures are mostly based on 2S Maximum Likelihood (ML) or Least Squares (LS) estimation. It is well known that classical ML and LS estimators are very sensitive to deviations from the underlying stochastic assumptions of the model or to outliers in the data. We present a general framework of treating 2S models based on M-estimation. The class of M-estimators has the advantage to include most of the 2S estimators available in literature, to suggest a general way to robustify 2S estimators, and to clarify the structure of their asymptotic variance. Moreover, we provide an extension of these results to multi-stage procedures. Finally we provide two specific examples of applications, namely the 2S least squares estimator and time series modeling when the deterministic and stochastic parts are modeled separately.

Keywords M-estimator, asymptotic variance, time series, two-stage least squares.

Robust Counterparts of Inequalities Containing Sums of Maxima of Linear Functions

Slot: Wednesday 18th 17:15-17:45, Room 144
Presenter: **Bram Gorissen** (Tilburg University, The Netherlands)
Coauthors: **Dick den Hertog** (Tilburg University, The Netherlands)

This talk adresses the robust counterparts of optimization problems containing sums of maxima of linear functions and proposes several reformulations. These problems include many practical problems, e.g. problems with sums of absolute values, and arise when taking the robust counterpart of a linear inequality that is affine in the decision variables, affine in a parameter with box uncertainty, and affine in a parameter with general uncertainty.

In the literature, often the reformulation that is exact when there is no uncertainty is used. However, in robust optimization this reformulation gives an inferior solution and provides a pessimistic view. We

observe that in many papers this conservatism is not mentioned. Some papers have recognized this problem, but existing solutions are either too conservative or their performance for different uncertainty regions is not known, a comparison between them is not available, and they are restricted to specific problems. We provide techniques for general problems and compare them with numerical examples in inventory management, regression and brachytherapy. Based on these examples, we give tractable recommendations for reducing the conservatism.

Keywords robust optimization; sum of maxima of linear functions; biaffine uncertainty; robust conic quadratic constraints.

Deriving Robust Counterparts of Nonlinear Uncertain Inequalities

Slot: Wednesday 18th 17:45-18:15, Room 144
Presenter: **Dick den Hertog** (Tilburg University, The Netherlands)
Coauthors: **Aharon Ben-Tal** (Technion - Israel Institute of Technology, Israel) **Jean-Philippe Vial** (Ordecsys, Switzerland)

We provide a guide to construct the Robust Counterpart for a nonlinear uncertain inequality that is concave in the uncertain parameters. We use convex analysis (support functions, conjugate functions, Fenchel duality) in order to convert the robust counterpart into an explicit and computationally tractable optimization program.

It turns out that one has to calculate the support function for the uncertainty set and the concave conjugate of the nonlinear constraint function. Surprisingly, these two computations are completely independent. This approach has different advantages.

First, it provides an easy, structured, way to construct the Robust Counterpart both for linear and nonlinear inequalities. Second, it shows that for new classes of nonlinear optimization problems tractable counterparts can be derived. Third, it paves the way to a new, more flexible, Globalized Robust Counterpart approach.

Keywords Fenchel duality, robust counterpart, nonlinear inequality, robust optimization, support functions.

Robust Optimisation II

Organiser: Nalan Gulpinar
Chair: Nalan Gulpinar

Multivariate Marginal Bounds for Probabilistic Optimisation Problems

Slot: Thursday 19th 16:30-17:00, Room 144
Presenter: **Xuan Vinh Doan** (University of Warwick, United Kingdom)
Coauthors: **Karthik Natarajan** (Singapore University of Technology and Design, Singapore)

Given a combinatorial optimization problem with an arbitrary cover of random objective coefficients, we evaluate the tightest possible bound on the expected optimal value over all joint distributions consistent with the given multivariate marginals of the elements in the cover. We discuss the computational tractability of the evaluation of the tight bound and the construction of the extremal distributions that achieve the bound, especially when the marginals are non-overlapping. We apply the proposed model for PERT networks to evaluate the bounds for project tardiness and show that the minimax two-stage project crashing problem under the discrete multivariate marginal assumption is tractable. This is joint work with Karthik Natarajan.

Keywords multivariate marginal, distribution ambiguity, extremal distribution, PERT, project crashing.

Predictive Analysis Using Quantified News and Market Data

Slot: Thursday 19th 17:00-17:30, Room 144
Presenter: **Xiang Yu** (Brunel University, United Kingdom)
Coauthors: **Gautam Mitra** (OptiRisk Systems, United Kingdom) **Xiaohui Liu** (Brunel University, United Kingdom) **Keming Yu** (Brunel University, United Kingdom)

We report an empirical study of a predictive analysis model for equities; the model uses high frequency (minute-bar) market data and quantified news sentiment data. The purpose of the study is to identify a predictive model which can be used in designing automated trading strategies. Given that trading strategies take into consideration three important characteristics of an asset, namely, return, volatility and liquidity, our model is designed to predict these three parameters for a collection of assets (finance industry stocks) in a multivariate setting. The minute-bar market data as well as intraday news sentiment data (Thomson Reuters News Analytics) have been provided by Thomson Reuters.

Keywords predictive analysis.

Safe Approximations of Chance Constraints Using Historical Data

Slot: Thursday 19th 17:30-18:00, Room 144
Presenter: **Ihsan Yanikoglu** (Tilburg University, The Netherlands)
Coauthors: **Dick den Hertog** (Tilburg University, The Netherlands)

This paper proposes a new way to construct uncertainty sets for robust optimization. Our approach uses the available historical data for the uncertain parameters and is based on goodness-of-fit statistics. It guarantees that the probability that the uncertain constraint holds is at least the prescribed value. Compared to existing safe approximation methods for chance constraints, our approach directly uses the historical-data information and leads to tighter uncertainty sets and therefore to better objective values. This improvement is significant especially when the number of uncertain parameters is low. Other advantages of our approach are that it can handle joint chance constraints easily, it can deal with uncertain parameters that are dependent, and it can be extended to nonlinear inequalities. Several numerical examples illustrate the validity of our approach.

Keywords robust optimization, chance constraint, phi-divergence, goodness-of-fit statistics.

Robust Facility Location Problem Under Demand Uncertainty

Slot: Thursday 19th 18:00-18:30, Room 144
Presenter: **Nalan Gulpinar** (University of Warwick, United Kingdom)
Coauthors: **Dessislava Pachamanova** (Babson College, USA) **Ethem Canakoglu** (University of Warwick, United Kingdom)

In this paper, we consider a stochastic facility location problem in which multiple capacitated facilities serve customers with a single product, and a stockout probabilistic requirement is stated as a chance constraint. Customer demand is assumed to be uncertain and to follow either a normal or an ambiguous distribution. We study robust approximations to the problem in order to incorporate information about the random demand distribution in the computationally tractable way. We present computational experiments in order to illustrate the performance of different facility location strategies.

Keywords robust facility location decisions, robust inventory management, ambiguous demand distributions.

Scheduling

Chair: Mauricio de Souza

An Application on Flow Shop Scheduling

Slot: Friday 20th 14:00-14:30, Room 343
Presenter: **Sündüs Dag** (Istanbul University, Turkey)

Flow shop scheduling problem has been well known as a research field for fifty years. In recent years, researchers have suggested many heuristic procedures to solve this type of problems. Most of these proposed algorithms in flow shop literature were applied to the benchmark problems. Few studies in flow shop literature include a real production application. The aim of this paper is to apply scheduling activity in a real flow shop production line. A cable production line is choosen for the application. All of the jobs are processed with same order which is named as permutational environment. The production line which is composed of eight different machines produces twelve kinds of cable. In other words, the problem size is 12 jobs x 8 machines. The objective of this problem focuses on minimizing total completion time and makespan. An ant colony algorithm is proposed to solve the problem. By changing initial solution of the algorithm, effect on objective function was monitored.

Keywords scheduling, flow shop, ant colony, real production environment.

Robust Integer Programming and Flexible Scheduling of Electricity Loads

Slot: Friday 20th 14:30-15:00, Room 343
Presenter: **Robin Vujanic** (Institut fuer Automatik, Switzerland)
Coauthors: **Paul Goulart** (ETH Zurich, Switzerland) **Sébastien Mariéthoz** (ETH Zurich, Switzerland) **Manfred Morari** (ETH Zurich, Switzerland)

After the liberalization of the electricity sector, new markets have emerged including markets for network ancillary services. Large electricity consumers' interest in participating in these markets is growing as they see an opportunity to make profits by selling flexibility of consumption. Indeed, time margins for shifting part of their scheduled consumption often exist, and they can be used to provide said flexibility. On the other hand, such large consumers operate on schedules which are typically settled one week in advance. Therefore, if flexibility is to be offered, the schedules themselves have to be flexible, i.e. they have to be able to support consumption shifts without incurring into infeasibility problems (e.g. related to safety constraints).

We tackle the problem of generating such flexible schedules and propose an approach based on robust integer optimization. We formulate the above problem as a scheduling problem subject to uncertainty, and show that the solution of the corresponding robust counterpart is the flexible schedule. For this, we construct an uncertainty with a particular structure and develop a new explicit robust counterpart. We verify that the proposed method works with an example involving the scheduling of two cement milling machines.

Keywords robust optimization, integer programming, scheduling, smart grids, large electricity consumers.

Models for Scheduling in Continuous Ingot Casting with Parallel Machines

Slot: Friday 20th 15:00-15:30, Room 343
Presenter: **Mauricio de Souza** (Universidade Federal de Minas Gerais, Brazil)
Coauthors: **Martín Ravetti** (Universidade Federal de Minas Gerais, Brazil) **Aloísio Gomes Júnior** (Universidade Federal de Minas Gerais, Brazil) **Allan Bretas** (Usiminas, Brazil)

In this work we propose models for detailed scheduling in continuous ingot casting. The study is based on a real case of a steel plant where this is the bottleneck. The shop floor area is composed of parallel machines where the melt steel is solidified into slabs. Jobs to be processed at the continuous casting

correspond to ladles containing melt steel with certain chemical properties (grades) and required slab widths as well. The decision maker faces two possible actions when processing a sequence of two different jobs: to make an intermix slab, or to perform a setup operation. An intermix slab is formed when two jobs with different grades and/or widths are processed without stopping the machine. This may generate a poor material, which has low commercial value or is used as scrap, whose quantity and quality varies according to the jobs being processed consecutively. Hence, such a process characteristic yields a sequence dependent cost. On the other hand, the machine may be stopped between two consecutive jobs to allow a setup, which consists of the replacement of the tundish (or distributor). This operation takes about 2 hours, but no intermix slab is formed with two consecutive jobs with a setup in between. There is a minimal and a maximal time allowed between two consecutive setups. Thus, the scheduling problem consists of (i) allocating jobs to machines, (ii) defining the sequence on each machine, and (iii) deciding for every two consecutive jobs whether an intermix slab or a setup operation must take place in between, in order to minimize the total cost incurred with the generated intermix slabs. We propose models based on the approaches of Manne and of Wagner, and compare them upon real data.

Keywords scheduling, continuous casting, mixed-integer programming, steelmaking.

Stochastic Finance

Organiser: Paolo Foschi
Chair: Paolo Foschi

Adjoint Expansions in Local Lévy Models

Slot: Wednesday 18th 14:15-14:45, Room 145
Presenter: **Candia Riga** (Scuola Normale Superiore di Pisa, Italy)

We propose a novel method for the analytical approximation in local volatility models with Lévy jumps. The main result is an expansion of the characteristic function in a local Lévy model, which is worked out in the Fourier space by considering the adjoint formulation of the pricing problem. Combined with standard Fourier methods, our result provides efficient and accurate pricing formulae. In the case of Gaussian jumps, we also derive an explicit approximation of the transition density of the underlying process by a heat kernel expansion: the approximation is obtained in two ways, using PIDE techniques and working in the Fourier space. Numerical tests confirm the effectiveness of the method.

Keywords Lévy process, local volatility, analytical approximation, partial integro-differential equation, Fourier methods.

Empirical Pricing Kernel Estimation Using a Functional Gradient Descent Algorithm Based on Splines

Slot: Wednesday 18th 14:45-15:15, Room 145
Presenter: **Pirmin Meier** (University of St. Gallen, Switzerland)
Coauthors: **Francesco Audrino** (University of St. Gallen, Switzerland)

We propose a new methodology to estimate the empirical pricing kernel implied from option data. Contrary to most of the studies in the literature that use an indirect approach, i.e. estimating first the physical and risk-neutral densities and obtaining the pricing kernel in a second step, we follow a direct approach. Departing from an adequate parametric and economically motivated pricing kernel, we apply a functional gradient descent (FGD) algorithm based on B-splines. This approach allows us to locally modify the initial pricing kernel and hence to improve the final estimate. We illustrate empirically the estimation properties of the method and test its predictive power on S&P 500 option data, also in comparison with other recent approaches introduced in the empirical pricing kernel literature.

Keywords empirical pricing kernel, FGD, B-splines.

Semiparametric Estimation and Forecasting of Self-exciting Processes

Slot: Wednesday 18th 15:15-15:45, Room 145
Presenter: **Nuria Ruiz-Fuentes** (Universidad de Jaén, Spain)
Coauthors: **Paula R. Bouzas** (University of Granada, Spain) **Francisco M. Ocaña-Peinado** (University of Granada, Spain)

A self-exciting process is a counting process which evolves with after-effects, it is that its intensity process depends on the past of the counting process. This work deals with conditional orderly self-exciting processes observed as panel count data, so the process is only periodically observed and it is not assumed any given structure of dependence. As the intensity process and hence the mean process depend on the past, this paper proposes to estimate them by a time series. Firstly, the mean process is estimated in discrete time points using the isotonic regression estimator so these estimations form a sample path of the mean process observed in given points. We introduce the isotonic regression estimator for the intensity and so, an estimated sample path of this process is also achieved in given points. Taking into account these estimated sample paths, time series estimation and forecasting methodology can be applied to both the mean and the intensity processes of the observed counting process.

Keywords counting processes, self-exciting processes, forecasting.

Stochastic Optimisation I

Organisers: Rudabeh Meskarian, Huifu Xu
Chair: Huifu Xu

Exact Penalisation Method for Stochastic Programming Problems with Multivariate Second Order Stochastic Dominance Constraints with Application in Portfolio Optimisation

Slot: Wednesday 18th 16:15-16:45, Room 311
Presenter: **Rudabeh Meskarian** (University of Southampton, United Kingdom)
Coauthors: **Joerg Fliege** (University of Southampton, United Kingdom) **Huifu Xu** (University of Southampton, United Kingdom)

We study optimization problems with multivariate stochastic dominance constraints where functions are not necessarily linear. We propose a penalization scheme for the multivariate stochastic dominance constraints. We solve the penalized problem by the level function methods, and a modified cutting plane method and compare them to the cutting surface method linearized method proposed in the literature. All methods are applied to portfolio optimization problem and some numerical test results are presented.

Keywords stochastic programming, multivariate stochastic dominance, penalty method, portfolio optimization.

Medium-Term Trading Strategy of a Dominant Electricity Producer

Slot: Wednesday 18th 16:45-17:15, Room 311
Presenter: **Arash Gourtani** (University of Southampton, United Kingdom)

This paper presents a multi-objective two-stage bilevel stochastic programming framework for a dominant electricity producer to determine an optimal trading strategy in a deregulated electricity spot market in a medium-term time horizon: at the first stage and upper level, the dominant producer aims to maximize its expected market share and profit taking into account the trade-off between the two objectives, and at the second stage and lower level, the independent system operator (ISO) determines the dispatches and power flow on hourly basis after realization of uncertainty in market demand by solving an optimization problem which aims to maximizes the total social welfare. Through Karush-Kuhn-Tucker conditions, the lower level problem is formulated as a complementarity problem and subsequently the dominant producer's optimal decision making problem as a two stage Stochastic Mathematical Problem with Equilibrium Constraints (SMPEC).To solve the SMPEC, it is proposed to reformulate the SMPEC as a Mixed Integer Linear Program (MILP) by presenting the complementarity constraints as a system of mixed integer linear inequalities with binary variables. Numerical tests results are reported through an illustrative example and a medium size case study.

Keywords stochastic mathematical problem with equilibrium constraints, electricity market, bi-level stochastic programming, bidding strategy.

On Stochastic Bilevel Programming

Slot: Wednesday 18th 17:15-17:45, Room 311
Presenter: **Georg Pflug** (University of Vienna, Austria)
Coauthors: **Raimund Kovacevic** (University of Vienna, Austria)

In deciding about offering a contract, the reaction of the counterparty has to be anticipated in some way. If the reaction of the counterparty is a decision problem of its own, the problem is called bilevel. Typically, the upper level offers a certain price and the lower level decides about the demand in view of the price.

A particular subclass of these problems are electricity swing options, where the upper level (the option seller) decides about the offered price right at contracting time, while the lower level (the option

seller) may decide about the daily or hourly demands during the whole contract period, just with one day ahead notice. The lower level decision maker may decide to get his demand from the contract or from the spotmarket, which has daily changing prices. Based on a stochastic model for the spotprices, the overall problem is a stochastic multiperiod bilevel problem. We review some solution methods for these problems (stochastic quasigradient methods, stochastic MPEC methods, ...) and present an algorithm which is based on the penalizing the duality gap of the lower level problem, reducing in this way the overall problem to a single-level large scale optimization problem.

Some numerical experiences with these algorithms are also presented.

Keywords MPEC, Stackelberg game, primal-dual algorithms, flexible options pricing.

Exact Penalisation, Level Function Method for Stochastic Programs with Second Order Dominance Constraints

Slot: Wednesday 18th 17:45-18:15, Room 311
Presenter: **Huifu Xu** (Southampton University, United Kingdom)
Coauthors: **Hailin Sun** (Harbin Institute of Technology, China) **Rudabeh Meskarian** (University of Southampton, United Kingdom)

Level function methods and cutting plane methods have been recently proposed to solve stochastic programs with stochastic second order dominance (SSD) constraints. A level function method requires an exact penalization setup because it can only be applied to the objective function, not the constraints. Slater constraint qualification (SCQ) is often needed for deriving exact penalization. In this paper, we show that although the original problem usually does satisfy the SCQ but, through some reformulation of the constraints, the constraint qualification can be satisfied under some moderate conditions. Exact penalization schemes based on L_1-norm and L_∞-norm are subsequently derived through Robinson's error bound on convex system and Clarke's exact penalty function theorem. Moreover, we propose a modified cutting plane method which constructs a cutting plane through the maximum of the reformulated constraint functions. In comparison with the existing cutting methods, it is numerically more efficient because only a single cutting plane is constructed and added at each iteration. We have carried out a number of numerical experiments and the results show that our methods display better performances particularly in the case when the underlying functions are nonlinear w.r.t. decision variables.

Keywords second order dominance, Slater constraint qualification, level function method, exact penalization.

Stochastic Optimisation II

Chair: Wolfram Wiesemann

Cash-Flow Based Valuation of Pension Liabilities

Slot: Thursday 19th 08:30-09:00, Room 311
Presenter: **Teemu Pennanen** (King's College London, United Kingdom)
Coauthors: **Petri Hilli** (Quantitative Solvency Analysts Ltd, Finland) **Matti Koivu** (Finnish Financial Supervision Authority, Finland)

This paper presents a computational framework for cash-flow based valuation of insurance liabilities in incomplete markets. It accounts for the risks associated with both insurance claims and investment returns over the lifetime of the liabilities. The valuation framework is market consistent in the sense that it takes into account the investment opportunities available to the insurer at the time of valuation. The framework is easily adapted to different lines of insurance and it can effectively employ advanced tools for strategic portfolio management. As an application, we value the insurance portfolio of the Finnish private sector occupational pension system where the liabilities extend over 82 years.

Keywords finance, insurance, ALM, convex optimization.

Integrating Stochastic Optimisation with Simulation: Service Pricing on a Social Network

Slot: Thursday 19th 09:00-09:30, Room 311
Presenter: **Alexei Gaivoronski** (Norwegian University of Science and Technology, Norway)
Coauthors: **Denis Becker** (Trondheim Business School, Norway)

We develop a combined simulation and optimization model that allows to optimize different service pricing strategies defined on the social networks under uncertainty. For a specific reference problem we consider a telecom service provider whose customers are connected in such network. Besides the service price, the acceptance of this service by a given customer depends on the popularity of this service among the customer's neighbors in the network. One strategy that the service provider can pursue in this situation is to stimulate the demand by offering the price incentives to the most connected customers whose opinion can influence many other participants in the social network. We develop a simulation model of such social network and show how this model can be integrated with stochastic optimization in order to obtain the optimal pricing strategy. A method that belongs to the family of stochastic gradient methods is used for optimization of this model. Our results show that the differentiated pricing strategies can increase substantially the revenue of a service provider operating on a social network.

Keywords stochastic optimization, stochastic gradient methods, service pricing.

Towards Quasi-Monte Carlo Scenario Generation in Stochastic Programming

Slot: Thursday 19th 09:30-10:00, Room 311
Presenter: **Werner Römisch** (Humboldt University of Berlin, Germany)

Quasi-Monte Carlo methods are considered for generating scenarios in two-stage stochastic linear programming. The relevant integrands are piecewise linear, but neither smooth nor of bounded variation in the sense of Hardy and Krause. Hence, a theoretical justification for applying Quasi-Monte Carlo methods to such models is still an open question, although randomly shifted lattice rules performed very well in computational tests. As a step towards rigorous convergence results we consider the ANOVA decomposition of two-stage integrands and show that all ANOVA terms except the one of highest order are smooth if the underlying probability density is smooth and a weak geometric condition is satisfied. The role of the latter condition is illustrated and discussed. For smooth integrands randomly shifted lattice rules achieve the optimal rate of convergence.

Keywords quasi-Monte Carlo, two-stage stochastic programs, ANOVA decomposition.

Two-Stage Stochastic Programming Facets

Slot: Thursday 19th 10:00-10:30, Room 311
Presenter: **Ruediger Schultz** (University of Duisburg-Essen, Germany)

The talk is a journey through two-stage stochastic programming. Starting from the pleasantly convex risk neutral linear models we pass through models with risk aversion, both in the objective and the constraints, continue with mixed-integer linear models and the discontinuities they involve until we finally arrive at infinite dimension, more precisely, shape optimization with linearized elasticity and stochastic loading, still in the two-stage stochastic programming setting. On the way, we report about structures, algorithms, and applications.

Keywords stochastic programming, decomposition algorithms, shape optimization under uncertainty.

Stochastic Optimisation III

Chair: Maria Teresa Vespucci

Multi-Stage Stochastic Optimisation and Approximations with Applications

Slot: Thursday 19th 16:30-17:00, Room 343
Presenter: **Anna Timonina** (University of Vienna, Austria)

Multi-stage stochastic optimization problems play a very important role in the management of financial portfolios, energy production, trading, insurance portfolios etc. The natural decision spaces for the multi-stage stochastic optimization problems are spaces of functions, that is why the exact analytical solution can be found only in very exceptional cases and the necessity of an approximation of the initial problem arises immediately. Since every finitely valued stochastic process is representable as a tree, we deal with tree approximations of stochastic processes.

The aim of this research is to study the approximation of the stochastic process (given by its distribution only) by the probability valued finite tree. As the amount of stage-wise available information is crucial in multi-stage stochastic optimization, we use the concept of nested distribution to describe the information structure keeping the setup purely distributional and without specification of the probability space (the nested distribution contains information about filtration, i.e. increasing sequence of sigma-algebras, and about probabilities). The concept of nested distance allows to measure the distance between nested distributions and to quantify the quality of approximation.

We introduce the algorithm for calculating the nested distance between tree and stochastic process given by its distribution. Minimization of this distance can lead to the new method for generating values from some specific distribution along with Monte Carlo generating and Optimal Quantization. The algorithm approximates the distribution at each stage by finite number of weighted points and finds the expected value of the difference between these points and the tree given the past, i.e. we calculate the distance. The main advantage of this algorithm is that it takes into account conditional distributions at each stage, that allows to approximate a large class of processes.

Keywords multi-stage, optimization, approximation, stochastic process, tree.

Parallel Algorithm for Solving Multistage Stochastic Mixed 0-1 Problems using BFC-MS with CPLEX within COIN-OR and MPI

Slot: Thursday 19th 17:00-17:30, Room 343
Presenter: **Gloria Pérez** (University of the Basque Country, Spain)
Coauthors: **Unai Aldasoro** (University of the Basque Country, Spain) **Laureano Escudero** (University Rey Juan Carlos, Spain) **María Merino** (University of the Basque Country, Spain)

The aim of this paper is to present some detailed explanations in order to help to understand and use the Message Passing Interface (MPI) parallel programming for solving mixed integer optimization (MIO) problems. We have developed a C++ experimental code that uses the IBM ILOG CPLEX optimizer within the COIN-OR (COmputational INfrastructure for Operations Research) for solving the optimization models and MPI (Message Passing Interface) parallel computing to send out the subsets of MIO models to each thread. This scheme can be applied for solving multistage stochastic mixed 0-1 problems by using our exact decomposition algorithm BFC-MS (Branch and Fix Coordination Multistage), since It requires the resolution of a very large number of MIO submodels. The computational experience consists of a broad set of problems (in particular, 44) which are asymmetric with respect to the number of integer and continuous variables and the number of constraints. We report a comparative study on the speedup and efficiency of several strategies that are implemented for some available number of threads. Additionally, we present the computational experience by using a testbed of multistage stochastic mixed 0-1 instances as a pilot case taking into account the possible break stages to generate the scenario cluster MIO submodels at the computational cluster ARINA provided by the SGI/IZO-SGIker at the UPV/EHU.

Keywords Multi-stage, stochastic optimization, parallel computing, COIN-OR, CPLEX.

Ambiguity of Tree Models with Application to Real World Problems

Slot: Thursday 19th 17:30-18:00, Room 343
Presenter: **Bita Analui** (University of Vienna, Austria)
Coauthors: **Georg Pflug** (University of Vienna, Austria)

A multistage stochastic optimization problem with uncertainty about the underlying model is considered. In this paper and for the first time we introduce and develop an approach that explicitly takes into account the ambiguity in probability model for the real world class of multistage stochastic optimization problems where the robustness of the decisions are highly expected. This is done by studying and developing the concept of ambiguity of dynamic trees and related results for multistage stochastic optimization problems incorporating the results from multistage distance. In the absence of complete knowledge about the model one approach is to study a set of possible models in which the true model sits. In this line, we define this set as an epsilon-radius (for the given epsilon) ball around a reference measure P with respect to a multistage distance dl and therefore robustify the original problem by a worst case approach with respect to this ambiguity neighborhood. This way we analyze the sensitivity with respect to model changes.

For implementation, we consider an optimization horizon of 8 weeks with weekly discretization, the uncertainty is the random behavior of electricity spot prices. Decisions are to be made on the thermal energy production before knowing the prices at which the produced energy can be sold.

Keywords multi-stage stochastic optimization, multi-stage distance.

A Multistage Stochastic Model for Determining the Electric Power Generation Capacity Expansion of a Price-Taker Power Producer in a Multi-Year Horizon

Slot: Thursday 19th 18:00-18:30, Room 343
Presenter: **Maria Teresa Vespucci** (University of Bergamo, Italy)
Coauthors: **Marida Bertocchi** (University of Bergamo, Italy) **Laureano Escudero** (University Rey Juan Carlos, Spain) **Stefano Zigrino** (University of Bergamo, Italy)

We consider the optimal electric power generation capacity expansion problem, over a multi-year time horizon of a price-taker power producer, who has to choose among thermal power plants and power plants using renewable energy sources (RES), while taking into account regulatory constraints on CO2 emissions, incentives to generation from RES and risk due to fuel price volatility which affects the generation variable costs. A multi-stage stochastic mixed integer model is developed that determines the number of new power plants for each chosen technology as well as the years in which the construction of the new power plants is to begin. The solution allows determining the evolution of the power producer's generation system along the time period, such that the expected total profit is maximzed aong the time period, with revenues from sale of electricity and of Green Certificates and costs for the annual debt repayment of new power plants, purchase costs of CO2 emission permits and of Green Certificates, fixed and variable production costs of new power plants and of power plants owned by the producer at the beginning of the planning period, subject to a set of constraints to be satisfied for each scenario, including the nonanticipativity constraints for each scenario group at each stage. Additionally, the maximization of the expected profit will be subject, alternatively, to first-order stochastic dominance constraints (sdc) for a set of profiles given by the pairs of threshold profit values and the probability of not reaching them, and to second-order sdc, whose set of profiles is given by the pairs of threshold profit values and bounds on the expected shortfalls on reaching the thresholds. Provisional results of a computational comparison between the following strategies will be reported: parameters' expected value, risk neutral and first- and second-order sdc.

Keywords restructured electricity market, generation capacity expansion, multi-stage stochastic mixed-integer model, stochastic dominance constraints.

Stochastic Optimisation IV

Organisers: Rudabeh Meskarian, Huifu Xu
Chair: Rudabeh Meskarian

Optimisation Modelling using R

Slot: Friday 20th 10:30-11:00, Room 311
Presenter: **Ronald Hochreiter** (Vienna University of Economics and Business, Austria)

Simplifying the task of modeling optimization problems is an important task. Many commercial products have been created to support the modeling process, but none of these products has been adopted by a significantly large number of users. As soon as real-world decision problems under uncertainty have to be modeled, flexible and quick changes to the underlying model are necessary. Simplifications are crucial to implement such optimization models into some business process successfully. Furthermore, the learning overhead for users should be minimized. In this talk, we outline an approach on how to simplify optimization modeling using R and external optimization modeling languages as well as by building model generators for specific application problems. Examples from the areas of Finance and Energy will substantiate the applicability of the chosen approach.

Keywords optimization modeling, modeling, R, optimization under uncertainty.

A New Algorithm for Moment-Matching Scenario Generation with Application to Financial Portfolio Optimisation

Slot: Friday 20th 11:00-11:30, Room 311
Presenter: **Diana Roman** (Brunel University, United Kingdom)
Coauthors: **Paresh Date** (Brunel University, United Kingdom) **Ksenia Ponomoreva** (Brunel University, United Kingdom)

We present an algorithm for moment-matching scenario generation. This method produces scenarios and corresponding probabilities that match exactly the given first moment, the covariance matrix, the average marginal skewness and the average marginal kurtosis of a random vector. In contrast with previous approaches, this method does not employ optimisation in the scenario generation process and thus it is computationally much simpler. The algorithm is used for generating scenarios in a mean-CVaR portfolio optimisation model. It is shown that desirable properties for a scenario generator are satisfied, including computational simplicity and good in-sample as well as out-of-sample stability of solutions. It is also shown that optimal solutions vary only marginally with increasing number of scenarios; thus, good solutions can be obtained with a relatively small number of scenarios.

Keywords scenario generation, moment matching, CVaR.

Diversification Consistent Data Envelopment Analysis with Generalized Deviation Measures

Slot: Friday 20th 11:30-12:00, Room 311
Presenter: **Martin Branda** (Charles University, Czech Republic)

Our goal is to identify investment opportunities that perform well without specifying our attitude to risk. We propose nonparametric test based on traditional DEA models which takes into account diversification. This leads to nonlinear convex programming problems. We show that the DEA efficency test are equivalent to mean-deviation portfolio problems.

Keywords data envelopment analysis, diversification, generalized deviation measures.

Contamination Techniques and Robustness in Decision Making

Slot: Friday 20th 12:00-12:30, Room 311
Presenter: **Milos Kopa** (Charles University, Czech Republic)
Coauthors: **Jitka Dupacova** (Charles University, Czech Republic)

This paper deals with robustness analysis for stochastic programs whose set of feasible solutions depends on the probability distribution P. For various reasons, probability distribution P may not be precisely speci

fied and we study robustness of results with respect to perturbations of P. The main tool is the contamination technique. For the optimal value, local contamination bounds are derived and applied to robustness analysis of the optimal value of a portfolio performance under risk-shaping CVaR constraints. A new robust portfolio efficiency test with respect to the second order stochastic dominance criterion is suggested and the contamination methodology is exploited to analyze its resistance with respect to additional scenarios. Similar analysis is presented for chance constrained programs and applied to the first order stochastic dominance portfolio efficiency. Various stumbling blocks are discussed.

Keywords portfolio selection, contamination, robustness, stochastic dominance.

Supply Chain Management

Chair: Henry Thille

Optimisation of Integrated First/Second Generation Biofuel Supply Chains

Slot: Thursday 19th 16:30-17:00, Room 342
Presenter: **Ozlem Akgul** (University College London, United Kingdom)

There has been a growing interest in the development and use of renewable energy technologies in the recent years to tackle major problems such as global climate change, depleting fossil fuel resources and increasing oil prices. Among the renewable energy technologies, liquid biofuels are considered as a potential solution to reduce emissions resulting from road transport. Liquid biofuels are commonly addressed as first, second and third generation biofuels. First generation technologies utilise mainly food crops whereas second and third generation technologies use non-food crops such as dedicated energy crops and biomass waste. The integration of the emerging second generation technologies with the well-established first generation technologies is considered to reduce the negative impacts on food production, provide better utilisation of biomass resources and take advantage of the reduced carbon emissions.

A biofuel supply chain is a multi-echelon network consisting of biomass cultivation sites, bioethanol production facilities and demand centres. Application of supply chain optimisation to such systems means consideration of all these nodes in the chain as well as transport of biomass and bioethanol between these nodes. This work presents an MILP optimisation framework for a hybrid first/second generation bioethanol supply chain network based on a "neighbourhood flow" approach considering different sustainability issues such as land availability. The model applicability is highlighted with a case study of hybrid first/second generation bioethanol production in the UK. The bioethanol demand is determined based on the UK domestic and EU biofuel targets. Wheat, wheat straw (co-product of wheat) and dedicated energy crops including miscanthus and SRC are the potential biomass feedstocks. Biomass imports are considered as a possible option to meet domestic ethanol demand. The effect of technological learning on economic and environmental performance of the bioethanol supply chain is also investigated.

Keywords biofuel, supply chain, MILP, optimisation.

Optimisation of an Outbound Logistics Smart Meter Supply Chain with Learning Effects and Uncertainty

Slot: Thursday 19th 17:00-17:30, Room 342
Presenter: **Mark G. Jennings** (Imperial College London, United Kingdom)
Coauthors: **Nilay Shah** (Imperial College London, United Kingdom)

Mathematical programming and optimization has frequently been applied to supply chain management of the upstream network nodes. Outbound logistics are also important to consider where customer interfacing employees must be trained and performance measured. In particular, the downstream supply chain of energy suppliers has not been optimized. This work presents a multi-period MILP model incorporating distribution centres, energy suppliers, energy meter readers and installers. Inventory levels and the training rates of new installers are optimized for a case study of the installation of 1.25 million smart meters in London between 2014 and 2019. Alternative objective functions are offered: those minimizing/maximising the time for finishing the installations, and those minimizing/maximizing the associated costs. Learning rates of smart meter installers are modelled endogenously and are log-linearly dependent on the number of previous installations, based on information from UK energy suppliers. A separable nonlinear function of the product of the number of trained installers and average times of installations is estimated by SOS2 variables using the piecewise lambda method. Probabilistic scenarios of retirements and uncertain building conditions are compared. This formulation allocates lognormal distributions to meter types k with each class of meter presenting a separate learning curve. Retirement stochastics influence the training requirements and subsequent month of completion of the rollout. For a given solution time, tradeoffs must be made between the number of piecewise breakpoints and the accuracy of piecewise estimation. The log of the residual sum of squares to the estimated nonlinear function increases

with decreasing numbers of piecewise breakpoints. The optimality gap also suffers for more breakpoints. Optimization including endogenous learning of labourers and uncertainty to decisions of labour training and inventory levels of energy suppliers is thought novel. Such computations are applicable to a wide range of supply chain management decisions in the gas and electricity markets.

Keywords supply chains, labour management, smart meters, endogenous learning, stochastic programming.

An Analysis of Equilibrium Coordination Incentives in Reverse Supply Chain

Slot: Thursday 19th 17:30-18:00, Room 342
Presenter: **Fereshteh Mafakheri** (University of Greenwich, United Kingdom)
Coauthors: **Fuzhan Nasiri** (University College London, United Kingdom)

This paper investigates the issue of coordination in reverse supply chains, modeling the decision problems of coordinating parties (i.e. manufacturer and retailer). To capture the existing feedbacks in the above model and the resulting delays, a system dynamics approach is employed. A typical reverse supply chain initiates when the manufacturer offers a revenue sharing scheme and the retailer responds to it by setting an incentive for returns. This resembles a leader-follower (Stackelberg) strategic decision making game, with an equilibrium solution that causes a lower performance for environmental criteria. In this sense, we further investigate if a coordination scheme can be orchestrated, under a carbon tax or cap-and-trade scenario, such that to yield a higher environmental performance.

Keywords reverse logistics, green supply chain, coordination, system dynamics, game theory, green house gas emissions.

New Product Adoption with Dynamic Consumer Preferences and Endogenous Pricing

Slot: Thursday 19th 18:00-18:30, Room 342
Presenter: **Henry Thille** (University of Guelph, Canada)
Coauthors: **Monica Cojocaru** (University of Guelph, Canada) **Ed Thommes** (University of Guelph, Canada) **Dominic Nelson** (, Canada)

We examine a pricing game between firms that produce differentiated products in which consumer preferences evolve in response to the market shares of the available products. One of the products is new and a subset of consumers (early adopters) have a relatively strong preference for it, while the remaining consumers are influenced by the relative market shares of the two products, being drawn to the product with the higher market share. Consumer heterogeneity is represented by differences in the characteristics of their "ideal" product and consumers face a cost associated with the distance a consumed product is from their ideal. We allow the location of consumers ideal products to vary over time by having the density of consumers locations follow a system of partial differential equations.

We assume that consumers can be categorized as belonging to broad personality types. These personality types manifest themselves in the evolution of the densities for the alternative types. This evolution of densities is modeled using a set of convection-diffusion partial differential equations, which differ based on the personality type. For example, for consumers drawn towards popular products, the mass of their density will be drawn towards the product with the largest market share. The diffusion term serves to maintain consumer heterogeneity by not allowing the density to collapse to a single point. The solution to this PDE yields the density of consumers' preferences at any point in time.

The two firms choose prices at discrete points in time, given the state of consumer preferences at that time, allowing firms to react to the changing distribution of consumer preference. We find that allowing for the evolution of consumer preference in this way results in interesting dynamics for prices. In particular, price paths can be non-monotonic over time.

Keywords consumer choice, differentiated products, dynamic preferences, pricing game.

Surrogate and Derivative-Free Optimization: Algorithms and Applications

Organiser: Nick Sahinidis
Chair: Nick Sahinidis

Derivative-Free Robust Optimisation for Circuit Design Problems

Slot: Thursday 19th 16:30-17:00, Room 311
Presenter: **Francesco Rinaldi** (Sapienza University of Rome, Italy)
Coauthors: **Vittorio Latorre** (Sapienza University of Rome, Italy) **Stefano Lucidi** (Sapienza University of Rome, Italy) **Giampaolo Liuzzi** (IASI – CNR, Italy)

In many engineering and practical design problems, analytical solutions often become suboptimal when measurment errors are present. Such errors are tipically due to the uncertainty, which is typically present in real-world applications. The classic theory of robust optimization cannot be applied when cost function is not explicitely given, which is the case, for instance, in many simulation-based optimization problems. In this work, we present a derivative-free method that is well-suited for nonlinear, nonconvex robust optimization problems. We use the proposed method to solve a set of test problems. Further we employ the method for solving different formulations of a hard real-world circuit design problem.

Keywords derivative-free method, robust optimization, circuit design.

Local Approximate Models for Crystal Structure Prediction

Slot: Thursday 19th 17:00-17:30, Room 311
Presenter: **Erik Santiso** (Imperial College London, United Kingdom)
Coauthors: **Andrei Kazantsev** (Imperial College London, United Kingdom) **Claire Adjiman** (Imperial College London, United Kingdom) **Costas Pantelides** (Imperial College London, United Kingdom)

Crystallization is an extremely important process in the food, chemical and pharmaceutical industries, among others. Many compounds of commercial or medical interest exhibit polymorphism, or the ability to solidify into different crystalline forms. The experimental determination of all possible polymorphs of a given material is, however, an extremely challenging problem due to the large experimental parameter space that needs to be explored. This makes computer simulations attractive for the determination of the possible crystal structures of a material.

Computer-based prediction of crystal structures is, however, still a very difficult problem. Most empirical potential energy functions have been designed to predict properties of materials on the liquid and gaseous state, and fail to accurately predict solid properties. Therefore, more general ab initio methods, which are much more computationally expensive, are necessary. Additionally, small changes in the predicted energies usually lead to wrong estimated crystal structures, which limits the approximations that can be made.

In this work, we present a global search algorithm, CrystalPredictor, that we have developed to predict the crystal structures of many small to intermediate-size molecules. The program uses Density Functional Theory calculations, augmented with an empirical dispersion correction, as the method to estimate the energies of different molecular conformations. In earlier versions of CrystalPredictor, Hermite interpolants were used to reduce the computational cost associated with these calculations. In the most recent developments, we have introduced local approximate models which are shown to lead to a more accurate representation of the energy function, and which allow a larger set of degrees of freedom to be considered. This is especially important for flexible molecules.

We will give a detailed description of the method and illustrate with several examples what are the strengths of our approach, as well as the remaining challenges.

Keywords crystallization, crystal structure prediction, density functional theory, local approximate models.

Derivative-Free Optimisation Enhanced-Surrogate Models for Energy Systems Optimisation

Slot: Thursday 19th 17:30-18:00, Room 311
Presenter: **Nick Sahinidis** (Carnegie Mellon University, USA)
Coauthors: **Alison Cozad** (Carnegie Mellon University, USA) **David Miller** (National Energy Technology Laboratory, USA)

We propose a model generation method that uses derivative-based and derivative-free optimization alongside machine learning and statistical techniques to learn algebraic models of detailed simulations. Once a candidate set of models is defined, they are tested, exploited, and improved through the use of derivative-free solvers to adaptively sample new points. We provide extensive computational experience with ALAMO, a code that we have developed and implements this strategy for Automatic Learning of Algebraic Models for Optimization. We combine the set of surrogate models generated by ALAMO with design specs to formulate an algebraic mixed-integer nonlinear problem for energy systems optimization. Finally, we use BARON for the global optimization of the derived algebraic model.

Keywords derivative-free optimization, CO2 capture, surrogate modeling, machine learning.

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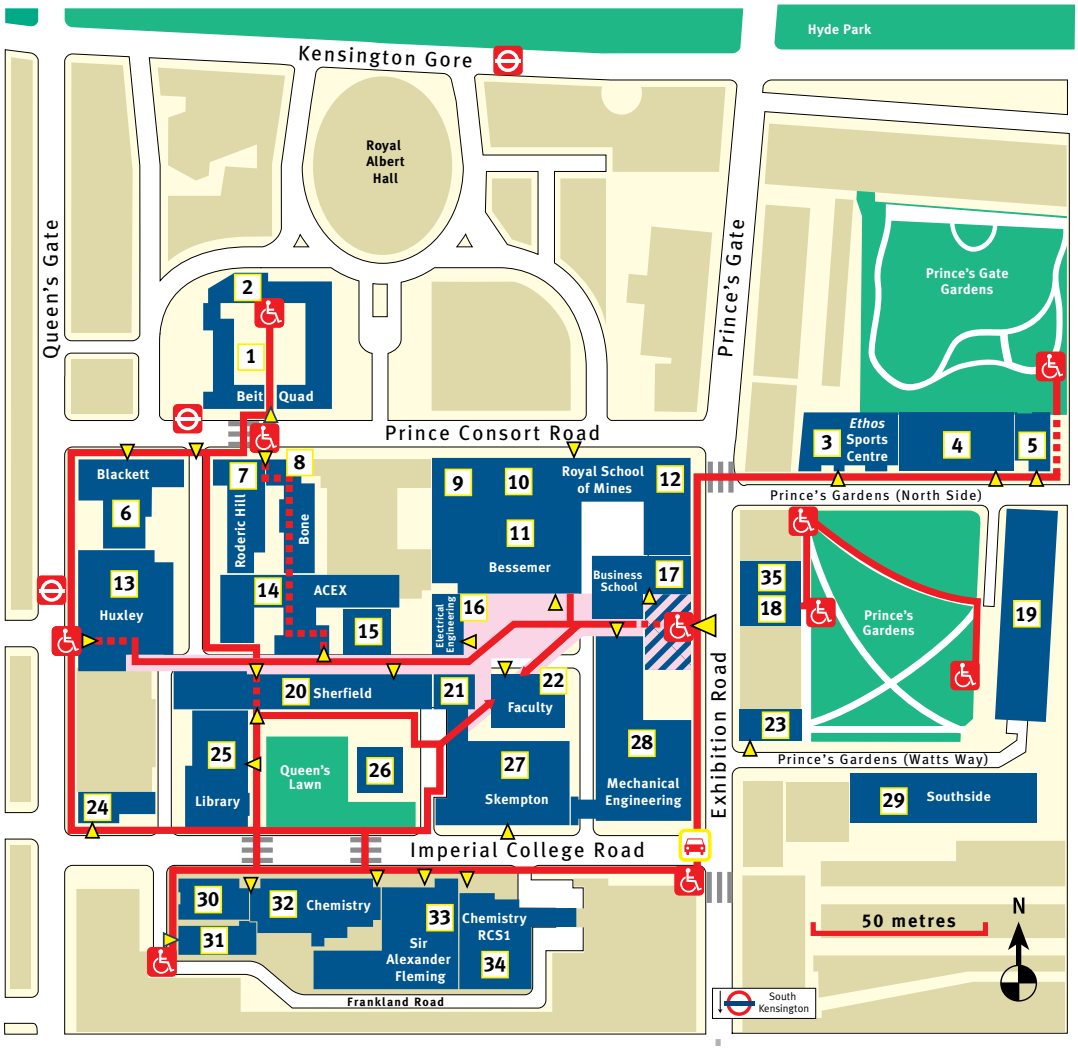
Imperial College London

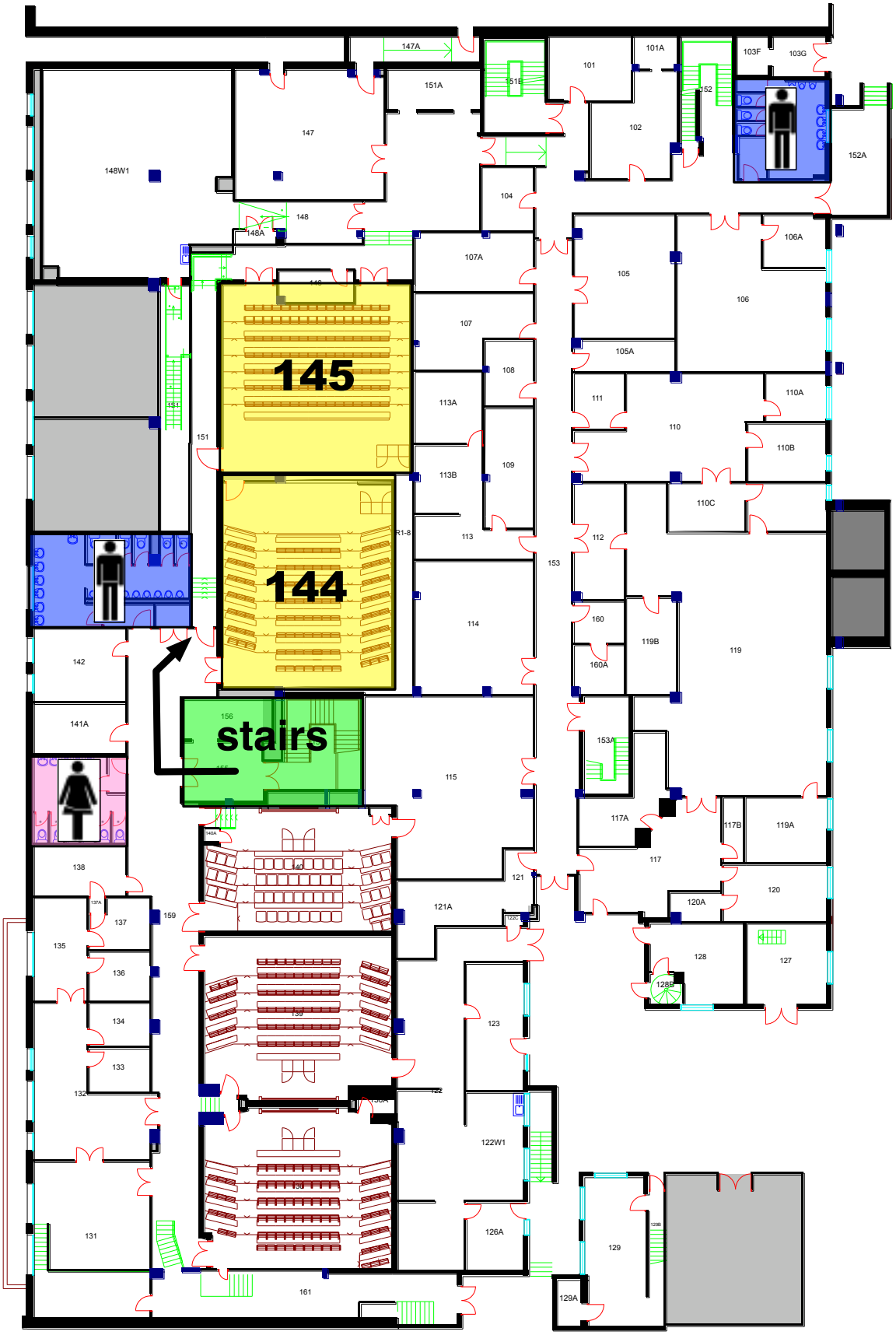
South Kensington Campus



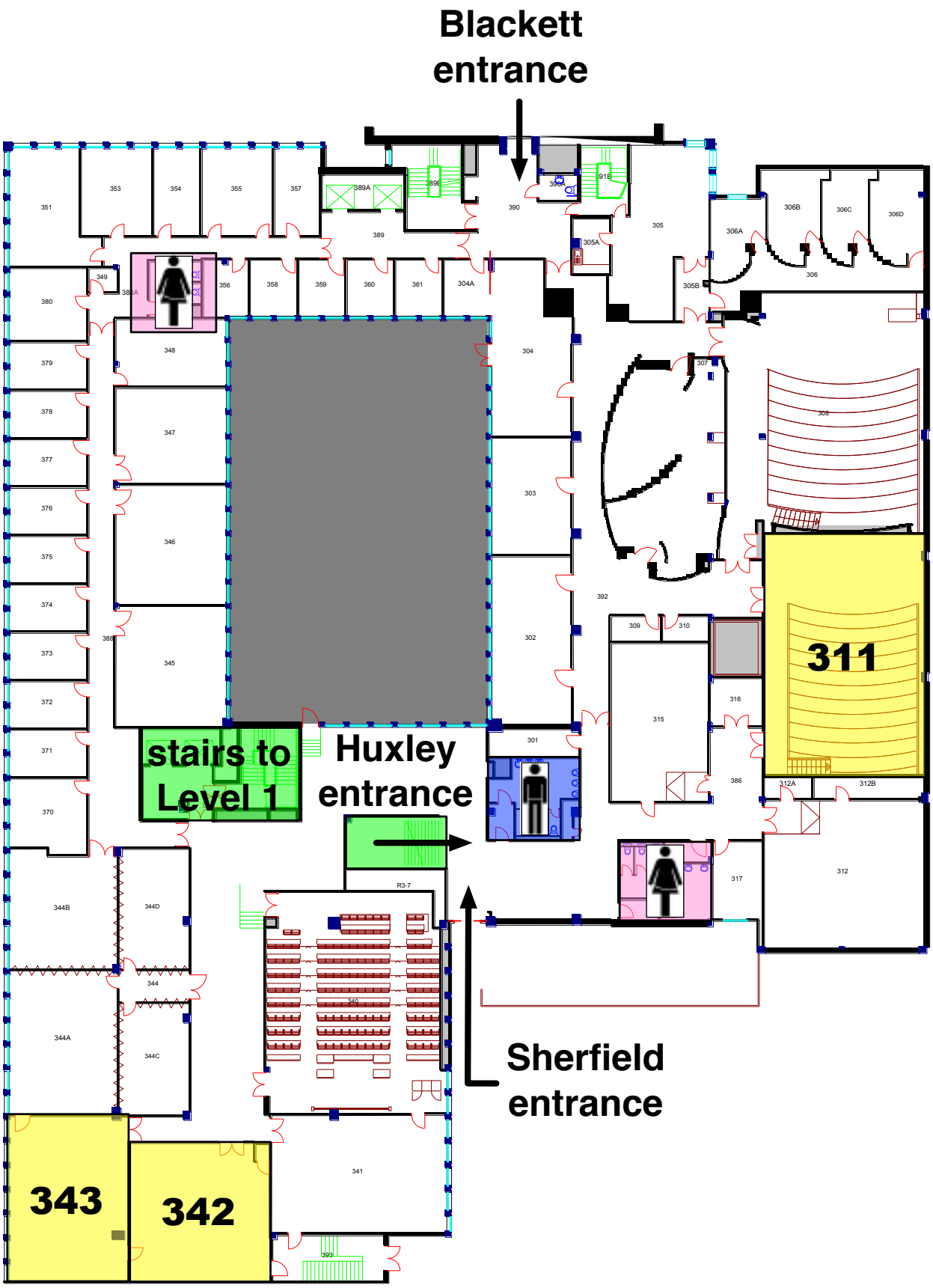
Buildings where wheelchair access is not possible at this time

1	Beit Quadrangle
2	Imperial College Union
3	*Ethos* Sports Centre
4	Prince's Gdns, North Side Garden Hall
5	Weeks Hall
6	Blackett Laboratory
7	Roderic Hill Building
8	Bone Building
9	Royal School of Mines
10	Aston Webb
11	Bessemer Building
12	Goldsmiths Building
13	Huxley Building
14	ACE Extension
15	William Penney Laboratory
16	Electrical Engineering
17	Business School
18	53 Prince's Gate
19	Eastside
20	Sherfield Building Student Hub Conference Office
21	Grantham Institute for Climate Change
22	Faculty Building
23	58 Prince's Gate
24	170 Queen's Gate
25	Imperial College and Science Museum Libraries
26	Queen's Tower
27	Skempton Building
28	Mechanical Engineering Building
29	Southside
30	Sir Ernst Chain Building
31	Flowers Building
32	Chemistry Building
33	Sir Alexander Fleming Building
34	Chemistry RCS1
35	52 Prince's Gate

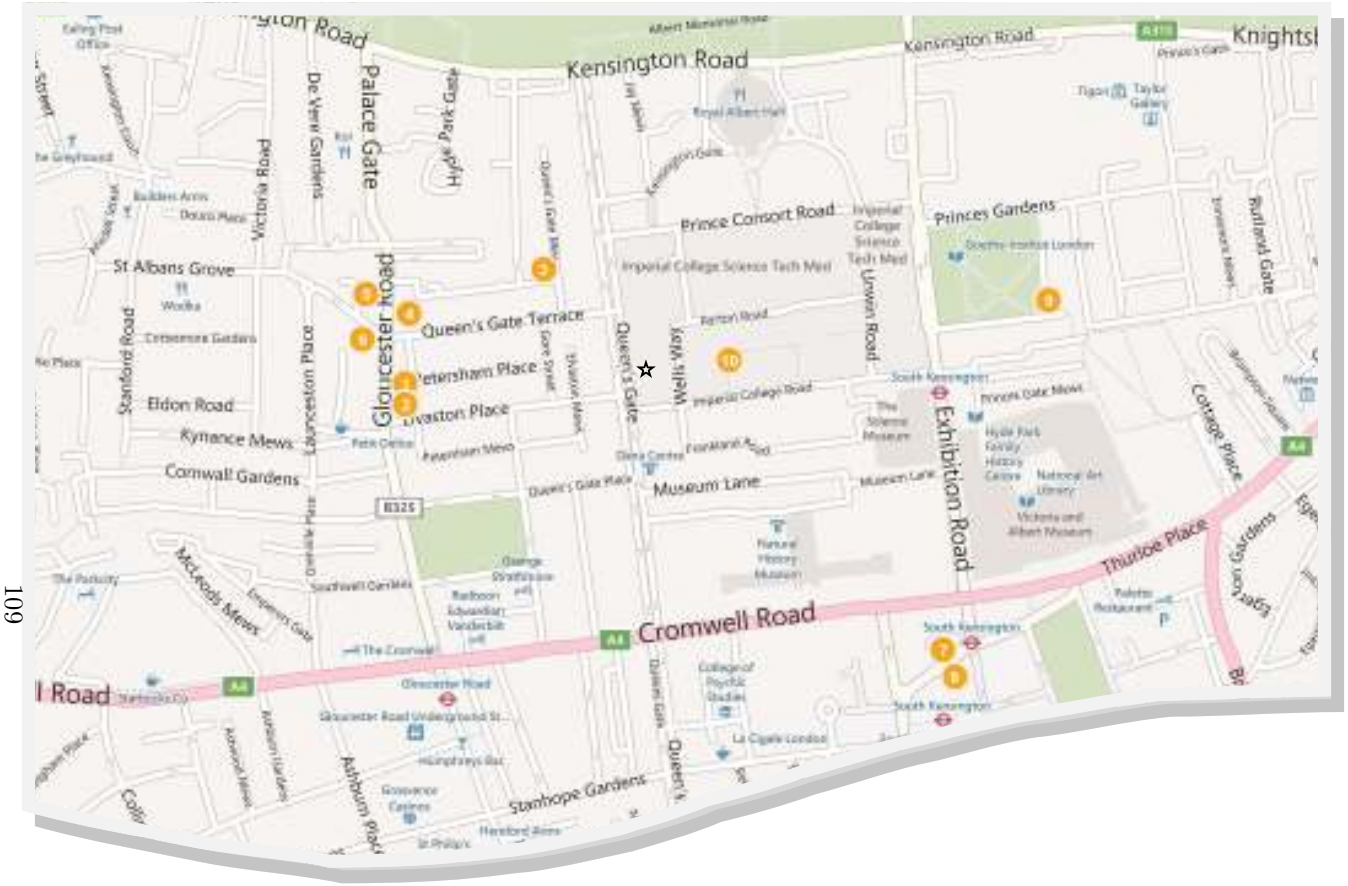
Huxley Building, Level 1



Huxley Building, Level 3



Map of South Kensington



Restaurant Index

- ☆ Conference is here!
- 1 Med Kitchen (Restaurant)
- 2 Coco Momo (Restaurant)
- 3 Queen's Arms (Pub)
- 4 Da Mario (Restaurant)
- 5 Jakob's (Restaurant/Cafe)
- 6 L' Etranger (Restaurant $)
- 7 Pierino Pizza & Pasta (Restaurant)
- 8 Le Pain Quotidien (Café/Restaurant)
- 9 East Side (Imperial College Bar/ Restaurant)
- 10 Senior Common Room (Imperial College Restaurant/Cafe)

Note:

- There are numerous sandwich places on Gloucester Road.
- More restaurants can be found around South Kensington underground station.