RESEARCH CENTRE

Inria Centre at the University of Lille

IN PARTNERSHIP WITH:

Ecole Centrale de Lille, Université Libre de Bruxelles

2023
ACTIVITY REPORT

Project-Team

INOCS

INtegrated Optimization with Complex Structure

DOMAIN

Applied Mathematics, Computation and Simulation

THEME

Optimization, machine learning and statistical methods

Contents

Project-Team INOCS

Creation of the Project-Team: 2019 May 01

Keywords

Computer sciences and digital sciences

A6. – Modeling, simulation and control

A6.1. – Methods in mathematical modeling

A6.2. – Scientific computing, Numerical Analysis & Optimization

A6.2.6. – Optimization

A9. – Artificial intelligence

A9.6. – Decision support

Other research topics and application domains

B2. – Health

B4. – Energy

B6. – IT and telecom

B6.7. – Computer Industry (harware, equipments...)

B7. – Transport and logistics

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B7.1.2. – Road traffic

B7.2. – Smart travel

B8.1. – Smart building/home

B8.1.1. – Energy for smart buildings

B8.2. – Connected city

B8.4. – Security and personal assistance

1 Team members, visitors, external collaborators

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- Hélène Le Cadre [INRIA, Researcher]

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- Martine Labbé [Université Libre de Bruxelles, Professor]
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External Collaborator

- Pierre Gruet [EDF, from September 2023]

2 Overall objectives

2.1 Introduction

INOCS is a cross-border "France-Belgium" project team in the Applied Mathematics Computation and Simulation Inria domain. The main goal of this team is the study of optimization problems involving complex structures. The scientific objectives of INOCS are related to modeling and methodological concerns. The INOCS team focuses on:

(i) integrated models for problems with Complex Structure (CS) taking into account the whole structure of the problem;

(ii) the development of solution methods taking explicitly into account *the nature and the structure of the decisions as well as the properties of the problem.*

Even if CS problems are in general NP-hard due to their complex nature, exact solution methods or matheuristics (heuristics based on exact optimization methods) are developed by INOCS. The scientific contribution of INOCS will result in a toolbox of models and methods to solve challenging real-life problems.

2.2 Schedule of tasks

The research program development of INOCS is to move alternatively:

- *from problems towards new approaches in optimization*: models and solution algorithms will be developed to fit the structure and properties of the problem. From them, new generic approaches will be used to optimize problems with similar properties.
- *from innovative approaches towards problems*: The relevance of the proposed approaches will be assessed by designing new models and/or solution methods for various classes of problems. These models and methods will be based on the extension and integration of specific, well-studied models and methods.

Even if these two axes are developed sequentially in a first phase, their interactions will lead us to explore them jointly in the mid-term.

3 Research program

3.1 Introduction

An optimization problem consists in finding a best solution from a set of feasible solutions. Such a problem can be typically modeled as a mathematical program in which decision variables must (i) satisfy a set of constraints that translate the feasibility of the solution and (ii) optimize some (or several) objective function(s). Optimization problems are usually classified into *strategic*, *tactical* and *operational* problems, according to the types of decisions to be taken.

We consider that an optimization problem presents a *complex structure* (CS) when it involves decisions of different types/nature (i.e. strategic, tactical or operational) and/or presents some hierarchical leader-follower structure. The set of constraints may usually be partitioned into *global constraints*, linking variables associated with the different types/nature of decision, and constraints involving each type of variables *separately*. Optimization problems with complex structure lead to extremely challenging problems since a global optimum with respect to the whole sets of decision variables and of constraints must be determined.

Significant progress has been made in optimization to solve academic problems. Nowadays large-scale instances of some NP-hard problems are routinely solved to optimality. *Our vision within INOCS is to make the same advances while addressing CS optimization problems.* To achieve this goal we aim to develop global solution approaches at the opposite of the current trend. INOCS team members have already proposed some successful methods following this research lines to model and solve CS problems (e.g. ANR project RESPET, Brotcorne et al. [61, 62], Gendron et al. [63, 64, 65], and Strack et al. [66]). However, these are preliminary attempts and a number of challenges regarding modeling and methodological issues have still to be met.

3.2 Modeling problems with complex structures

A classical optimization problem can be formulated as follows:

$$\begin{array}{ll} \min & f(x) \\ s.t. & x \in X. \end{array} \tag{1}$$

In this problem, X is the set of feasible solutions. Typically, in mathematical programming, X is defined by a set of constraints. x may be also limited to non-negative integer values.

The INOCS team plans to address optimization problem where two types of decision are addressed jointly and are interrelated. More precisely, let us assume that variables x and y are associated with these decisions. A generic model for CS problems is the following:

$$\begin{array}{ll} \min & g(x, y) \\ s.t. & x \in X, \\ & (x, y) \in XY, \\ & y \in Y(x). \end{array} \tag{2}$$

In this model, X is the set of feasible values for x. XY is the set of feasible values for x and y jointly. This set is typically modeled through linking constraints. Last, $Y(x)$ is the set of feasible values for y for a given x. In INOCS, we do not assume that $Y(x)$ has any properties.

The INOCS team plans to model optimization CS problems according to three types of optimization paradigms: large scale complex structures optimization, bilevel optimization and robust/stochastic optimization. These paradigms instantiate specific variants of the generic model.

Large scale complex structures optimization problems can be formulated through the simplest variant of the generic model given above. In this case, it is assumed that $Y(x)$ does not depend on x. In such models, X and Y are associated with constraints on x and on y, XY are the linking constraints. x and y can take continuous or integer values. Note that all the problem data are deterministically known.

Bilevel programs allow the modeling of situations in which a decision-maker, hereafter the leader, optimizes his objective by taking explicitly into account the response of another decision maker or set of decision makers (the follower) to their decisions. Bilevel programs are closely related to Stackelberg (leader-follower) games as well as to the principal-agent paradigm in economics. In other words, bilevel programs can be considered as demand-offer equilibrium models where the demand is the result of another mathematical problem. Bilevel problems can be formulated through the generic CS model when $Y(x)$ corresponds to the optimal solutions of a mathematical program defined for a given x, i.e. $Y(x) = \arg\min\{h(x,y) | y \in Y_2, (x,y) \in XY_2\}$ where Y_2 is defined by a set of constraints on y, and XY_2 is associated with the linking constraints.

In robust/stochastic optimization, it is assumed that the data related to a problem are subject to uncertainty. In stochastic optimization, probability distributions governing the data are known, and the objective function involves mathematical expectation(s). In robust optimization, uncertain data take value within specified sets, and the function to optimize is formulated in terms of a min-max objective typically (the solution must be optimal for the worst-case scenario). A standard modeling of uncertainty on data is obtained by defining a set of possible scenarios that can be described explicitly or implicitly. In stochastic optimization, in addition, a probability of occurrence is associated with each scenario and the expected objective value is optimized.

3.3 Solving problems with complex structures

Standard solution methods developed for CS problems solve independent subproblems associated with each type of variables without explicitly integrating their interactions or integrating them iteratively in a heuristic way. However these subproblems are intrinsically linked and should be addressed jointly. In *mathematical optimization* a classical approach is to approximate the convex hull of the integer solutions of the model by its linear relaxation. The main solution methods are (1) polyhedral solution methods which strengthen this linear relaxation by adding valid inequalities, (2) decomposition solution methods (Dantzig Wolfe, Lagrangian Relaxation, Benders decomposition) which aim to obtain a better approximation and solve it by generating extreme points/rays. Main challenges are (1) the analysis of the strength of the cuts and their separations for polyhedral solution methods, (2) the decomposition schemes and (3) the extreme points/rays generations for the decomposition solution methods.

The main difficulty in solving *bilevel problems* is due to their nonconvexity and nondifferentiability. Even linear bilevel programs, where all functions involved are affine, are computationally challenging despite their apparent simplicity. Up to now, much research has been devoted to bilevel problems with linear or convex follower problems. In this case, the problem can be reformulated as a single-level program involving complementarity constraints, exemplifying the dual nature, continuous and combinatorial, of bilevel programs.

4 Application domains

4.1 Energy

In energy, the team mainly focuses on pricing models for demand side management, on bids definition in the energy market and on the design and pricing of electric car charging stations.

Demand side management methods are traditionally used to control electricity demand which became quite irregular recently and resulted in inefficiency in supply. We have explored the relationship between energy suppliers and customers who are connected to a smart grid. The smart grid technology allows customers to keep track of hourly prices and shift their demand accordingly, and allows the provider to observe the actual demand response to its pricing strategy. We tackle pricing problems in energy according to the bilevel optimization approaches. Some research works in this domain are supported by bilateral grants with EDF.

The increasing number of agents, with different characteristics interacting on the energy market leads to the definition of new types of bidding process. We have modeled this problem as a bilevel one where the lower level is the instance allocating the bids (the ISO).

The proliferation of electric cars in cities has lead to the challenging problem of designing and pricing charging stations in order to smooth the demand over time. We are modeling this problem as a bilevel one where the lower level represents the choice of users in a preference list.

4.2 Transportation and logistics

In transportation and logistics, the team addresses mainly integrated problems, which require taking into account simultaneously different types of decision. Examples are location and routing, inventory management and routing or staff scheduling and warehouse operations management. Such problems occur from the supply chain design level to the logistic facility level.

4.3 Telecommunications

In telecommunications, the team mainly focuses on network design problems and on routing problems. Such problems are optimization problems with complex structure, since the optimization of capacity installation and traffic flow routing have to be addressed simultaneously.

5 Social and environmental responsibility

The research works developed in the INOCS team have environmental and societal impacts through the application areas they target. At the environmental level, the works on the optimization of transportation systems aim at reducing the impact of transportation on society. The applied works in energy aim at a better use of the smart grid and the optimization of electricity production from renewable sources. At the societal level, the works developed in the framework of the ANR AGIRE project takes into account musculoskeletal disorders in the activity of employees within a warehouse. Finally, in health, the works conducted on group testing allow the development of effective campaigns of testing of the population in preventive medicine for example.

6 Highlights of the year

6.1 Awards

- Hugo Callebaut: ORBEL Award 2023 (Best master thesis in operations research in Belgium).

7 New software, platforms, open data

7.1 New software

7.1.1 GroupTesting

Keywords: Linear optimization, Group Testing, Graph algorithmics

Functional Description: Group testing is a screening strategy that involves dividing a population into several disjoint groups of subjects. In its simplest implementation, each group is tested with a single test in the first phase, while in the second phase only subjects in positive groups, if any, need to be tested again individually.

To contribute to the effort to tackle the COVID-19 sanitary crisis, we developed this software which allows to create groups of individuals to test via the group testing technique while minimizing a linear combination of the expected number of false negative and false positive classifications.

The test design problem is modeled as a constrained shortest path problem on a specific graph and we design and implement an ad hoc algorithm to solve this problem. We validate the algorithm on instances based on Santé Publique France data on COVID-19 screening tests.

Contact: Frederic Semet

7.1.2 INOCSBox

Keywords: Linear optimization, Operational research, Toolbox

Functional Description: This software is a toolbox that contains algorithms that are frequently used to solve optimization problems tackled by (but not only) the team.

The objective of the toolbox is to contain a set of code skeletons that allow researchers to integrate adequate data structures and basic algorithms for different structures complexity that appears in the optimization problems we study. The current version of the toolbox contains classical heuristic tools (generic local search) to solve, among others, the vehicle rouring problem and its variants. It also contain a code to exactly and heuristically solve the Shortest Path Problem with Ressource Constraints that is usually encountered in the resolution of problem with Branch-and-Price algorithms.

The future objective is to include automatic reformulation tools for bi-level optimization problems and state-of-the-art codes for the development of decomposition methods.

Contact: Tifaout Almeftah

8 New results

During the year 2023, we addressed different problems/challenges related to the three lines of research: large scale complex structure optimization, bilevel programming and game theory, robust/stochastic programming. The main contributions are summarized in the next sections. In addition, besides these contributions, additional results [12, 15, 17, 18, 26] were obtained which are not discussed hereafter in order to keep the presentation focused on the main achievements.

8.1 Large scale complex structure optimization

Participants: Luce Brotcorne, Diego Cattaruzza, Bernard Fortz, Martine Labbé, Maxime Ogier, Frédéric Semet.

8.1.1 Loads scheduling for demand response in energy communities

Energy communities are promising measures aimed at promoting local energy generation and consumption, which are needed to meet the energy transition targets. In [28], the focus is on the optimization of the collective self-consumption rate in energy communities by scheduling members' loads. The community remains connected to the public grid and comprises prosumers, traditional consumers, and distributed storage units. Prosumers can exchange their energy with the public grid or other members. The proposed strategy aims at implementing a Demand Side Management (DSM) program taking advantage of controllable loads' characteristics. A mixed integer linear programming (MILP) formulation of the problem allows, on the one hand, to give the optimal planning for electrical devices' operations. On the other hand, it provides optimal solutions for managing the storage units, peer-to-peer exchanges, and interactions with the public grid to minimize the energy flows from the public grid over time. However, this MILP only allows for solving small problem instances. Thus, we develop a column generation-based heuristic for large problem instances. Our numerical experiments based on real data collected in the south of France show that joining an energy community saves money on energy bills and reduces the total energy drawn from the primary grid by at least 15%.

8.1.2 How to achieve fair and efficient cooperative vehicle routing?

In addition of allowing self-consumption reduction, communties often allows the socialisation of the total cost among its members. In this setting, a recurrent question is related to the design of fair cost allocation mechanisms. In [24], a cooperative is modeled as a business entity whose primary purpose is to provide benefits, services, and goods to its members, who both own and democratically control it. In the context of a cooperative, a fleet typically consists of vehicles owned by self-concerned, individually rational owners who prioritize their own efficiency and the fairness of the system. This fairness refers to how their individual gain aligns with the gain of others. In this paper, we focus on the routing of such cooperative fleets. If we consider only the efficiency of the fleet in terms of minimizing its total cost, the problem studied corresponds to the Multiple Traveling Salesman Problem (MTSP). However, our interest lies in finding both efficient and fair solutions, so we propose two new variants of this problem that integrate and maximize the egalitarian and elitist social welfare. Additionally, to enhance the balance between fleet efficiency and fairness, we propose the systematic elitist and systematic egalitarian social welfare optimization algorithm. Through simulation results, we observe a wide diversity of routes depending on the approach considered. Therefore, a cooperative may choose a model that best balances criteria of efficiency maximization and fairness for its fleet based on its specific requirements.

8.1.3 Improving neighborhood exploration into MOEA/D framework to solve a bi-objective routing problem

Vehicle Routing Problems (VRPs) are classical optimization problems in transportation and logistics. In INOCS, we address complex routing problems generalizing the VRP, combining the VRP with another optimization problem, or hybridizing VRP with machine learning approaches. In [23], a MOEA/D framework including a Local Search (LS) based mutation and knowledge discovery mechanisms is the core algorithm used to solve a bi-objective VRP with Time Windows (bVRPTW) where the total traveling cost and the total waiting time of drivers have to be minimized. We enhance the classical LS exploration strategy of the neighborhood from the literature of scheduling and propose new metrics based on customers distances and waiting times to reduce the neighborhood size. We conduct a deep analysis of the parameters to give a fine-tuning of the MOEA/D framework adapted to the LS variants and to the bVRPTW. Experiments show that the proposed neighborhood strategies lead to better performance on both Solomon's and Gehring and Homberger's benchmarks.

8.1.4 Models and methods for two-level uncapacitated facility location problems

Neighborhood search methods are also considered in [47] which tackles Two-level Uncapacitated Facility Location Problems with Single-assignment constraints (TUFLP-S), a problem that arises in industrial applications in freight transportation and telecommunications. First, we recall the real-life application that motivates this research work. Then, we present an integer programming formulation for this variant with modular costs of the TUFLP-S, and we describe an adaptation of variable neighborhood search to the classical TUFLP-S and the variant with modular costs. Focusing on the TUFLP-S, we introduce mathematical programming models based on reformulation techniques and on the relaxation of the integrality of some of the variables associated with location decisions. We then present a Lagrangian relaxation approach for the TUFLP-S, based on solving a single-level uncapacitated facility location problem (UFLP) as the Lagrangian subproblem. We also describe a matheuristic based on a mixed-integer programming-based large neighborhood search. Synthetic computational results on instances derived from the industrial application as well as on large, hard, artificial instances are reported throughout the paper.

8.1.5 Synchronized deliveries with a bike and a self-driving robot

An innovative application of the VRP is considered in [29]. Inspired by the current practices at JD.com (the largest online retailer by revenue in China), we investigate a delivery problem that we call the traveling salesman problem with bike and robot (TSPBR), where a cargo bike is aided by a self-driving robot to deliver parcels to customers in urban areas. We present two mixed-integer linear programming models and describe a set of valid inequalities to strengthen their linear relaxation. We show that these models can yield optimal solutions of TSPBR instances with up to 60 nodes. To efficiently find heuristic solutions, we also present a genetic algorithm based on a dynamic programming recursion that efficiently explores large neighborhoods. We computationally assess this genetic algorithm on instances provided by JD.com and show that high-quality solutions can be found in a few minutes of computing time. Finally, we provide some managerial insights to assess the impact of deploying the bike-and-robot tandem to deliver parcels in the TSPBR setting.

8.1.6 A column generation approach to solve the joint order batching and picker routing problem including picker congestion

Order picking is a crucial process in warehouse operations. In a human-operated warehouse, pickers prepare different customer orders. From a managerial perspective, two major decisions need to be made: (i) grouping orders to be collected together by a picker, and (ii) for each picker, determining the route to retrieve the needed items. The Joint Order Batching and Picker Routing Problem (JOBPRP integrates both decisions into a single problem, usually minimizing either total distance or time. In the literature, the JOBPRP usually assumes a situation without any congestion caused by the pickers, however unrealistic when there are many pickers in a warehouse. In practice, congestion causes inefficiency, increases costs, reduces performance, and leads to accidents. To estimate congestion levels, we divide the planning horizon of the picking activity into different time intervals and timing variables are introduced. If two or more pickers are in the same sub-aisle during the same time interval, a delay in travel time is imposed. Because picking activities are performed by humans, practical considerations must be taken into account when defining a feasible picking route, e.g. a picker cannot unnecessarily wait and cannot follow complicated or long paths between two consecutive picking positions. To solve the JOBPRP including the effect of picker congestion, an extended mathematical formulation is presented, with the main objective of minimizing the total time, including delay. A heuristic solving approach is proposed based on solving of the linear relaxation of the formulation by an exact column generation procedure. In each iteration, a negative reduced column is produced using a dedicated labelling algorithm, exploring routes associated to congestion level for each sub-aisle and time interval. To evaluate the modelling and the performance of the solutions provided by the proposed approach, a discrete event simulation tool is developed. Several experiments are performed to compare the results with optimal JOBPRP solutions not considering congestion [45].

8.1.7 The intractability of the picker routing problem

The Picker Routing Problem (PRP), which consists in finding a minimum-length tour between a set of storage locations in a warehouse, is one of the most important problems in the warehousing logistics literature. Despite its popularity, the tractability of the PRP in conventional multi-block warehouses remains an open question. The technical note in [58] aims to fill this research gap by establishing that the PRP is strongly NP-hard.

8.1.8 Commodity constrained split delivery vehicle routing problems

We propose a survey [20] on vehicle routing problems with multiple commodities. In most routing problems, only one commodity is explicitly considered. This may be due to the fact that, indeed, a single commodity is involved, or multiple commodities are transported, but they are aggregated and modeled as a single commodity, as no specific requirement imposes their explicit consideration. However, there exist cases in which this aggregation is not possible due to the characteristics of the commodities or to the fact that it would lead to sub-optimal routing plans. The survey focuses on the analysis of the settings of the problems and the features of the commodities that require explicit consideration of disaggregated commodities in routing problems. We show that problem settings are inherently different with respect to the single commodity problems, and this has a consequence on both models and solution approaches, which cannot be straightforwardly adapted from the single commodity cases. We propose a classification of the routing problems with multiple commodities and discuss the motivations that force considering the presence of multiple commodities explicitly. Specifically, we focus on the modeling perspective by proposing a general formulation for routing problems with multiple commodities and showing how this formulation can be adapted to the different features that characterize the problem classes discussed in the survey. Also, for each major class of problems, promising future research directions are discussed by analyzing what has been studied in the current literature and focusing on challenging topics not covered yet.

We address two specific routing problems with multiple commodities. The commodity constrained Split Delivery Vehicle Routing Problem (C-SDVRP) is a routing problem where customer demands are composed of multiple commodities. A fleet of capacitated vehicles must serve customer demands in a way that minimizes the total routing costs. Vehicles can transport any set of commodities and customers are allowed to be visited multiple times. However, the demand for a single commodity must be delivered by one vehicle only. In this work, we developed a heuristic with a performance guarantee to solve the C-SDVRP. The proposed heuristic is based on a set covering formulation, where the exponentially-many variables correspond to routes. First, a subset of the variables is obtained by solving the linear relaxation of the formulation by means of a column generation approach which embeds a new pricing heuristic aimed to reduce the computational time. We test the heuristic algorithm on benchmark instances from the literature. The comparison with the state-of-the-art heuristics for solving the C-SDVRP shows that our approach significantly improves the solution time, while keeping a comparable solution quality and improving some best-known solutions. In addition, our approach is able to solve large instances with 100 customers and six commodities, and also provides very good quality lower bounds [57].

A extended variant of the C-SDVRP is the Multi-Commodity two-echelon Distribution Problem (MC2DP). In the MC2DP, multiple commodities are distributed in a two-echelon distribution system involving suppliers, distribution centres and customers. Each supplier may provide different commodities and each customer may request several commodities as well. In the first echelon, capacitated vehicles perform direct trips to transport the commodities from the suppliers to the distribution centres for consolidation purposes. In the second echelon, each distribution centre owns a fleet of capacitated vehicles to deliver the commodities to the customers through multi-stop routes. Commodities are compatible, i.e., they can be mixed in the vehicles. Finally, customer requests can be split by commodities, that is, a customer can be visited by several vehicles, but the total amount of each commodity has to be delivered by a single vehicle. The aim of the MC2DP is to minimise the total transportation cost to satisfy customer demands. We propose a set covering formulation for the MC2DP where the exponential number of variables relates to the routes in the delivery echelon. We develop a Branch-Price-and-Cut algorithm (BPC) to solve the problem. The pricing problem results in solving an Elementary Shortest Path Problem with Resource Constraints (ESPPRC) per distribution center. We tackle the ESPPRC with a label setting dynamic programming algorithm which incorporates ng-path relaxation and a bidirectional labelling search. Pricing heuristics are invoked to speed up the procedure. In addition, the formulation is strengthened by integrating capacity cuts and two families of valid inequalities specific for the multiple commodities aspect of the problem. Our approach solves to optimality 439 over the 736 benchmark instances from the literature [60]. The optimality gap of the unsolved instances is 2.1%, on average.

8.1.9 Lower and upper bounds for the joint batching, routing and sequencing problem

Warehouses are the scene of complex logistic problems integrating different decision layers. This work addresses the Joint Order Batching, Picker Routing and Sequencing Problem with Deadlines (JOBPRSP-D) in rectangular warehouses. To tackle the problem an exponential linear programming formulation is proposed. It is solved with a column generation heuristic able to provide valid lower and upper bounds on the optimal value. We start by showing that the JOBPRSP-D is related to the bin packing problem rather than the scheduling problem. We take advantage of this aspect to derive a number of valid inequalities that enhance the resolution of the master problem. The proposed algorithm is evaluated on publicly available data-sets. It is able to optimally solve instances with up to 18 orders in few minutes. It is also able to prove optimality or to provide high-quality lower bounds on larger instances with 100 orders [39, 49]. To the best of our knowledge this is the first work that provides optimality guarantee on large size instances for the JOBPRSP-D, the results can therefore be used to assert the quality of heuristics proposed for the same problem.

8.1.10 Machine learning applications

Feature selection is a fundamental process to avoid overfitting and to reduce the size of databases without significant loss of information that applies to hierarchical clustering. Dendrograms are graphical representations of hierarchical clustering algorithms that for single linkage clustering can be interpreted as minimum spanning trees in the complete network defined by the database. In [21], we introduce the problem that determines jointly a set of features and a dendrogram, according to the single linkage method. We propose different formulations that include the minimum spanning tree problem constraints as well as the feature selection constraints.

In [11], we study a discrete version of the classical classification problem in Euclidean space, to be called the geodesic classification problem. It is defined on a graph, where some vertices are initially assigned a class and the remaining ones must be classified. This vertex partition into classes is grounded on the concept of geodesic convexity on graphs, as a replacement for Euclidean convexity in the multi-dimensional space. We propose two new integer programming models along with branch-and-bound algorithms.

8.2 Bilevel programming and game theory

Participants: Luce Brotcorne, Diego Cattaruzza, Bernard Fortz, Martine Labbé, Hélène Le Cadre, Frédéric Semet.

8.2.1 Moving from linear to conic markets for electricity

The massive integration of renewable energy and the growing involvement of prosumers have changed the energy landscape, calling for an urgent restructuring of the electricity market. Game theory is a powerful tool to analyse the outcome of situation of conflicts involving a large number of heterogeneous agents with selfish interest. In this setting, we propose a new forward electricity market framework that admits heterogeneous market participants with second-order cone strategy sets, who accurately express the nonlinearities in their costs and constraints through conic bids, and a network operator facing conic operational constraints. In contrast to the prevalent linear-programming-based electricity markets, we highlight how the inclusion of second-order cone constraints improves uncertainty-, asset-, and network-awareness of the market, which is key to the successful transition towards an electricity system based on weather-dependent renewable energy sources. We analyze our general market-clearing proposal in [27] using conic duality theory to derive efficient spatially-differentiated prices for the multiple commodities, comprised of energy and flexibility services. Under the assumption of perfect competition, we prove the equivalence of the centrally-solved market-clearing optimization problem to a competitive spatial price equilibrium involving a set of rational and self-interested participants and a price setter. Finally, under common assumptions, we prove that moving towards conic markets does not incur the loss of desirable economic properties of markets, namely market efficiency, cost recovery, and revenue adequacy. Our numerical studies focus on the specific use case of uncertainty-aware market design and demonstrate that the proposed conic market brings advantages over existing alternatives within the linear programming market framework.

8.2.2 Grid impact aware TSO-DSO market models for flexibility procurement: coordination, pricing efficiency, and information sharing

Information sharing and coordination mechanisms impact the properties of the resulting market equiliria. Five market models for the procurement of flexibility by Transmission (TSO) and Distribution System Operators (DSOs), based on several TSO-DSO coordination schemes, including a disjoint distribution, disjoint transmission, common, fragmented, and multi-level market are proposed in [25]. The properties of these models are then analyzed. In particular, the common market is first proven to be more efficient than the other market models. Then, different methods are proposed to adequately price TSO/DSO interface flows, when procuring cross-grid flexibility. It is then shown that, when interface flows are optimally priced, the fragmented and multi-level market solutions converge to those of the common market, reaching optimal efficiency. To prevent the need for any network information sharing among system operators in the different coordination schemes, decomposition methods based on bi-level programming and the Alternating Direction Method of Multipliers (ADMM) are proposed. A developed case study, considering an interconnected transmission-distribution system, corroborates the mathematical findings by highlighting the greater efficiency of the common market, the effect of adequate interface pricing on reducing procurement costs, and the capability of the decomposition methods to reach optimal market solutions with limited information exchange.

8.2.3 Strategic resource pricing and allocation in a 5G network slicing Stackelberg game

The duality results from standard optimization setup that we applied to noncooperative games in [25] can be extended to strategic pricing and resource allocation problems for communication networks. In [16], we consider a marketplace in the context of 5G network slicing, where Application Service Providers (ASP), i.e., slice tenants, providing heterogeneous services, are in competition for the access to the virtualized network resource owned by a Network Slice Provider (NSP), who relies on network slicing. We model the interactions between the end users (followers) and the ASPs (leaders) as a Stackelberg game. We prove that the competition between the ASPs results in a multi-resource Tullock rent-seeking game. To determine resource pricing and allocation, we devise two innovative market mechanisms. First, we assume that the ASPs are pre-assigned with fixed shares (budgets) of infrastructure, and rely on a trading post mechanism to allocate the resource. Under this mechanism, the ASPs can redistribute their budgets in bids and customise their allocations to maximize their profits. In case a single resource is considered, we prove that the ASPs' coupled decision problems give rise to a unique Nash equilibrium. Second, when ASPs have no bound on their budget, we formulate the problem as a pricing game with coupling constraints capturing the shared resource finite capacities, and derive the market prices as the duals of the coupling constraints. In addition, we prove that the pricing game admits a unique variational equilibrium. We implement two online learning algorithms to compute solutions of the market mechanisms. A third fully distributed algorithm based on a proximal method is proposed to compute the Variational equilibrium solution of the pricing game. Finally, we run numerical simulations to analyse the market mechanism's economic properties and the convergence rates of the algorithms.

8.2.4 Modeling and analysis of a nonlinear security game

We formulate a security game in a context of mixed armament acquisition, involving a finite set of Nations in strategic relationship, with utility functions which are nonlinear and non-differentiable on the boundary of their sets of definition. Since we want to study the long-term effect of the Nations' investment in nuclear weapons, we focus on the steady-state analysis of the game. This requires us to extend the classical results from Rosen on compact-convex games, to unbounded convex games, relying on the coercivity property of the Nations' utility functions. In addition, we prove the existence and uniqueness, under mild assumptions, of an interior point Nash Equilibrium solution of the game. Simulations are performed in case of a duopoly, highlighting the efficiency loss reduction and stabilizing effect of nuclear armaments by comparison with the conventional-only setting [32, 55].

8.2.5 Bilevel integer linear models for ranking

Item and set orderings help with data management. Depending on the context, it is just as important to order a list of items (customers from different provinces, companies from different sectors, players from different teams) as it is to order a list of sets of these items (provinces, sectors, teams). It is evident that the order that is chosen for the items is not independent of the order that is chosen for the sets. It is possible that several set orders are sensible for the same item order and vice versa, that several item orders are sensible for the same set order. In [22], we propose a bilevel model to calculate an adequate order of items when an order of sets is available and another bilevel model to calculate an adequate order of sets when an order of items is available. In addition, it is shown how to reduce both bilevel models to single level models.

8.2.6 Min–max optimization of node-targeted attacks in service networks

In [19], we consider resilience of service networks that are composed of service and control nodes to node-targeted attacks. Two complementary problems of selecting attacked nodes and placing control nodes reflect the interaction between the network operator and the network attacker. This interaction can be analyzed within the framework of game theory. Considering the limited performance of the previously introduced iterative solution algorithms based on non-compact problem models, new compact integer programming formulations of the node attack optimization problem are proposed, which are based on the notion of pseudo-components and on a bilevel model. The efficiency of the new formulations is illustrated by the numerical study that uses two reference networks (medium-size and large-size), and a wide range of the sizes of attacks and controllers placements.

8.2.7 Bilevel pricing model for cloud computing

Cloud computing has transformed numerous sectors of businesses, governments, and individuals' lives with its benefits of processing power, resource simplicity, scalability, and accessibility. Predictions anticipate a significant upsurge in global data traffic by 2025, driven by an increase in demand for cloud computing. Although cloud computing is energy-efficient compared to private computers, it is still wasteful. Data centers often underutilize servers, which continue to consume considerable amounts of energy even when idle. The inefficiency originates in the overstocking of computers due to consumer behavior and service-level buffering.1 To face this problem, we propose a cloud sharing system to enhance resource efficiency. The system's framework is formulated as a mixed integer bilevel problem, which features two distinct follower types representing the different types of customers in the public cloud, namely, long-term consumers with monthly subscriptions and short-term consumers who seek on-demand access. The cloud service manager's (CSM) goal, operating as the leader, is to incentivize long-term consumers to share their resources through rewards to allocate shortterm consumers without requiring new resources. Resources energy consumptions measures are included in the objective functions of the leader. We have defined new cuts and have developped a branch and cut algorithm to solve the problem.

8.2.8 Bilevel pricing model for electric car charging problems

We consider a provider of electric vehicle charging that operates a network of charging stations and wishes to use dynamic pricing to maximize profit and reduce the impact on the electric grid. We propose a bilevel model with a single leader and multiple disjoint followers. The customers are followers, and each makes decisions independently from the others. The provider is the leader, sets the prices for each station at each time slot, and ensures there is enough energy to charge. The behavior of each customer is represented by the combination of a preference list of (station, time) pairs and a reserve price. In this way, the proposed model accounts for the heterogeneity of customers with respect to price sensitivity and charging preferences. We solve the bilevel optimization problem using a reformulation based on optimality conditions and compare our results to other approaches in the literature. The proposed reformulation is able to solve large-scale instances, and the computational results show that the maximum consumption peak can be significantly reduced with only a slight degradation of the provider's profit.

In the same spirit another work is related to the charging of autonomous electrical cars. A special attention is devited to the interactions between the transportation and electrical grid networks. A new model based on an extension of the pick-up and delivery problem is proposed.

8.2.9 Integrating new shared mobility systems within public transportation

The overall objective of the EuropanSUM project is to facilitate the transformation of mobility in 15 European cities by 2026 and in 30 European cities by 2030. This transformation involves the integration of new shared mobility modes with public transport, focusing on innovation, interconnectivity, environmental sustainability, safety, resilience and replicability. The aim is to ensure the affordability and reliability of these modes for end users, while maintaining financial sustainability that strengthens the competitiveness of European businesses.

In this setting we develop new bilevel joint pricing models to incetivize the users to combine new shared mobility modes with public transportation. Several path offers will be provided to the users.

8.3 Robust/Stochastic programming

Participants: Luce Brotcorne, Diego Cattaruzza, Bernard Fortz, Martine Labbé, Hélène Le Cadre.

8.3.1 Mutli-agent reinforcement learning for strategic bidding in two stage electricity markets

INOCS has recently started a research track on the study of Multi-Agent Reinforcement Learning (MARL) in stochastic networks of agents. Within this area, our goal is to study the dynamics of electricity markets involving multiple competitive generators through MARL approaches. We start by formulating the electricity market as a two-stage stochastic game, involving a finite set of conventional and renewable energy producers, which bid on the day-ahead market, and an Independent System Operator (ISO), which is responsible for the clearing of the market. We assume that a predetermined part of the producers are non-strategic, bidding at their marginal costs, while the others might bid strategically trying to learn the outcome of the clearing. In the first stage, the strategic producers optimize simultaneously their bids by minimizing their expected costs (opposite of the expected profits), which is the difference between their production cost and the payment they receive from the ISO. The renewable energy producers' objective functions include a penalty assigning a cost to the imbalances caused by their forecast errors. In the second stage, the ISO receives the bids of all the producers. It clears the market by determining the activated volumes for each producer and a price minimizing the total cost under capacity constraints, including a conditional value at risk (CVaR) constraint for the renewable producers, capturing the risk aversion level that the requested volume violates their uncertain capacity. We derive closed form expressions for the producers' best-responses considering pay-as-clear and pay-as-bid as pricing schemes, and simulate the market dynamics, using MARL. To that purpose, we rely on modified versions of two actor-critic algorithms: Deep Deterministic Policy Gradient (DDPG) and Soft Actor-Critic (SAC). The simulations show how the producers adapt dynamically their strategies to learn the best bidding strategy, under limited information exchange. Finally, we identify conditions for the convergence of MARL algorithms to local equilibria of the stochastic game. First results in this area have been presented in [35, 41].

8.3.2 Learning market equilibria using performative prediction: balancing efficiency and privacy

MARL is a widely researched technique for decentralized control in complex large-scale systems with interacting agents. When predictions support decisions they may influence the outcome they aim to predict. We call such prediction performative, i.e., the prediction influence the target. A conceptual novelty is an equilibrium notion called performative stability in the literature. We apply this new concept to a peer-to-peer electricity market modeled as a network game, where End Users (EUs) minimize their cost by computing their demand and generation while satisfying a set of local and coupling constraints. Their nominal demand constitutes sensitive information, that they might want to keep private. We prove that the network game admits a unique Variational Equilibrium (VE), which depends on the private information of all the EUs. A data aggregator is introduced, which aims to learn the EUs' private information. The EUs might have incentives to report biased and noisy readings to preserve their privacy, which creates shifts in their strategies. Relying on performative prediction, we define a decision-dependent game G^{stoch} to couple the network game with a data market in [38, 54]. Two variants of the Repeated Stochastic Gradient Method (RSGM) are proposed to compute the Performatively Stable Equilibrium (PSE) solution of G^{stoch}, that outperform RSGM with respect to efficiency gap minimization, privacy preservation, and convergence rates in numerical simulations.

8.3.3 Towards forecast markets for enhanced peer-to-peer electricity trading

In [37], we examine the impact of the coupling between an introduced data market, in which agents can purchase a forecast of their renewable energy sources' generation levels to improve their estimation quality, and a peer-to-peer electricity market, enabling prosumers to trade energy in a decentralized manner with their peers, amidst the growing trend of decentralization and uncertainty of Renewable Energy Sources (RES) in electricity markets. The study formulates the P2P trading as a generalized Nash equilibrium problem and identifies conditions for achieving a maximized efficiency of the peer-to-peer electricity market, one of which is prosumers' participation in the forecast market. Along these lines, the analysis demonstrates that prosumers have incentives to participate in the forecast market and outlines the conditions, considering the case in which the forecasts are given in the form of a Gaussian distribution. Numerical examples using Pecan Street data demonstrate the theoretical findings and provide illustrations for the general case, as well as highlight the mutual benefits of market coupling for forecast sellers and electricity market agents.

8.3.4 Exact and heuristic solution Ttchniques for mixed-integer quantile minimization problems

We consider mixed-integer linear quantile minimization problems that yield large-scale problems that are very hard to solve for real-world instances. We motivate the study of this problem class by two important realworld problems: a maintenance planning problem for electricity networks and a quantile-based variant of the classic portfolio optimization problem. For these problems, we develop valid inequalities and present an overlapping alternating direction method. Moreover, we discuss an adaptive scenario clustering method for which we prove that it terminates after a finite number of iterations with a global optimal solution. We study the computational impact of all presented techniques and finally show that their combination leads to an overall method that can solve the maintenance planning problem on large-scale real-world instances provided by the EURO/ROADEF challenge 2020 and that they also lead to significant improvements when solving a quantile-version of the classic portfolio optimization problem [14].

8.3.5 The case for stochastic online segment routing under demand uncertainty

In [31], we present a novel algorithmic approach to optimize traffic engineering in segment routing networks, accounting for demand uncertainty. In particular, we propose a stochastic approach to online segment routing which uses a conditional value at risk when accounting for the traffic matrix uncertainty. This approach can perform significantly better than the worst-case approach often considered in the literature. We also show that depending on the demand volatility, our stochastic approach can be further optimized in that it is sufficient to account for only a part of the demand without sacrificing traffic engineering quality.

9 Bilateral contracts and grants with industry

Participants: Luce Brotcorne, Hélène Le Cadre.

9.1 Bilateral grants with industry

Program PGMO funded by the Fondation Mathématiques Jacques Hadamard and EDF R&D. Stackelberg Games for Flexibility (Dis)Aggregation (2022 – 2024).

10 Partnerships and cooperations

10.1 International initiatives

10.1.1 Associate Teams in the framework of an Inria International Lab or in the framework of an Inria International Program

BIO-SEL
Title: Bilevel Optimization in Security, Energy and Logistics

Participants: Martine Labbé, Frédéric Semet.

Duration: 2020–2023
PIs: Martine Labbé (Université Libre de Bruxelles), Vladimir Marianov (PUC Chile)

Partners: Pontificia Universidad Catolica de Chile Santiago (Chile)
Summary: This projet is devoted to bilevel optimization problems with application in the security, energy, and logistics domains. Stackelberg games, including one defender and several followers, bidding problems in energy supply markets and product selection problems will be considered. Mixed integer optimization models and efficient algorithms to solve them will be developed.

GALANGAL
Title: Game Theoretic Learning and Optimization for Networked Electricity Markets

Participants: Luce Brotcorne, Bernard Fortz, Hélène Le Cadre.

Duration: 2023–2025
PIs: Hélène Le Cadre (Inria), Michel Gendreau (Polytechnique Montréal, Canada)
Partners: Polytechnique Montréal (Canada), Edinburgh University (Scotland)
Summary: Game Theory is the study of interacting decision makers. A large part of the work in this area has focused on equilibrium computation, but another relevant question is how agents might reach an equilibrium, especially given that no single agent has full information on the state of the system or full authority over the strategies of the other agents. GALANGAL research directions are split into three axes: (i) learning market equilibria preserving statistical privacy using performative prediction, (ii) deep reinforcement learning to control interconnected buildings, (iii) equilibrium tracking, towards robust markets.

10.1.2 STIC/MATH/CLIMAT AmSud projects

SOGGA
Title: Stochastic Optimization, Generalized Games and Applications

Participants: Luce Brotcorne, Hélène Le Cadre.

Duration: 2024–2025
Coordinator: Dider Aussel (Université de Perpignan, France)
Partners: University of Perpignan, Universidad de Chile and Universidad de O'Higgins (Chile), Universidad del Pacifico (Peru), Inria Lille
Summary: SOGGA proposes to focus in four theoretical research lines: (i) continuity-like properties in equilibrium problems, (ii) regularity in generalized equilibrium problems, (iii) bilevel games with decision-dependent uncertainty (Luce Brotcorne), (iv) algorithms and mechanism design in learning games (Hélène Le Cadre).

10.1.3 Participation in other International Programs

Title: CityFreight – Freight Logistics in Sustainable Cities

Participant: Frédéric Semet.

Partner Institution(s):
- University of Bergen, Center for Climate and Energy Transformation
- The Norwegian Public Roads Administration
- Sparebanken Vest
- City of Bergen

- Vestland Country, Bergen Chamber of Commerce and Industry, Nordic Edge AS (Norway)
- Centrale Lille
- The Polytechnic University of Turin (Italy)
- Sichuan University, Chengdu (China)

Duration: 2020–2024

Additionnal info/keywords: The primary objective of this project is to provide public authorities, particularly in smaller, topologically complicated, cities and initially the City of Bergen, with a toolbox for realistically evaluating major decisions that would make a city more energy efficient and sustainable in terms of freight transportation

10.2 International research visitors

10.2.1 Visits of international scientists

Pamela Bustamante

- **Status:** Ph.D. Student
- **Institution of origin:** Pontifica Universidad Catolica de Chile
- **Country:** Chile
- **Dates:** Until January 2023
- **Context of the visit:** Stackelberg games
- **Mobility program/type of mobility:** research stay – Ph.D. co-supervision

Sophia Calderon Pimienta

- **Status:** Master Student
- **Institution of origin:** O'Higgins Universidad
- **Country:** Chile
- **Dates:**From February to April 2023
- **Context of the visit:** Predict and Optimize - Bilevel optimization
- **Mobility program/type of mobility:** research stay

Clara Chini Nielsen

- **Status:** Ph.D. Student
- **Institution of origin:** Technical University of Denmark
- **Country:** Denmark
- **Dates:**From march to June 2023
- **Context of the visit:** Field service routing problem
- **Mobility program/type of mobility:** research stay

Alejandro Jofre

- **Status:** Professor
- **Institution of origin:** CMM

- **Country:** Chile
- **Dates:** February 2023
- **Context of the visit:** Learning games
- **Mobility program/type of mobility:** research stay – Masters internship co-supervision

Walter Rei

- **Status:** Professor
- **Institution of origin:** Quebec University at Montréal
- **Country:** Canada
- **Dates:** August 2023–September 2023
- **Context of the visit:** Stochastic optimization
- **Mobility program/type of mobility:** research stay

10.2.2 Visits to international teams

Research stays abroad

- **Francesco Morri**, Polytechnique Montréal (Canada), one month visit, funding GALANGAL Associate Team.
- **Gaël Guillot**, University of Edinburgh (Scotland), two weeks visit, funding GALANGAL Associate Team.

10.3 European initiatives

10.3.1 Horizon Europe

SUM

Title: Seamless Shared Urban Mobility

Duration: 2023–2026

Partners: Inria INOCS (project coordinator), Delft University (The Netherlands), NTUA, Ertico, Polis, Vedecom, Technical University of Munich, City of Munich, Municipality of Pentali, sixt, Freenow, Krakow Municipality, Jagiellonian University, Ret, Fredrikstad Municipality, Nextbike Cyprus, Chalmers University of Technology, MOBYx, Cunisa, Coimbra Municipality, ZF, TU Coimbra, Jerusalem Municipality, Tel Aviv University, Sigma6, Larnaca Public Transport, Siemens Mobility B.V., HYKE, University of Twente, TPG.

Summary: The overall objective of the SUM project is to facilitate the transformation of mobility in 15 European cities by 2026 and in 30 European cities by 2030. This transformation involves the integration of new shared mobility modes with public transport, focusing on innovation, interconnectivity, environmental sustainability, safety, resilience and replicability. The aim is to ensure the affordability and reliability of these modes for end users, while maintaining financial sustainability that strengthens the competitiveness of European businesses.

10.3.2 H2020 projects

CHIST–ERA SEC–OREA

Title: Supporting Energy Communities – Operational Research and Energy Analytics

Duration: 2022–2025

Partners: Inria INOCS, Université Libre de Bruxelles (Belgium), University College of Dublin (Ireland), Riga Technical University (Lithuania)

Summary: SEC–OREA aims to enable local energy communities (LECs) to participate in the decarbonisation of the energy sector by developing advanced efficient algorithms and analytics technologies. The SEC–OREA projects has enabled the hiring of two Ph.D. students within INOCS: Juan Sepulvea and Cristian Aguayo.

10.4 National initiatives

10.4.1 ANR

ANR project AGIRE (2020-2024): "Decision system for smart management of resources in warehouses" in collaboration with Ecole des Mines de Saint-Etienne (Gardanne), Université Gustave Eiffel (Champs-sur-Marne), HappyChic (Tourcoing). This project addresses human resources management in warehouses which supply either sale points (B2B) or final consumers (B2C). Nowadays, such warehouses are under pressure. This is mainly due to the no inventory policy at the sale points and to the constant growth of e-commerce sales in France and Europe. In terms of logistics, this translates into an increasing number of parcels to prepare and to ship to satisfy an order, which is known typically a few hours before. Moreover, the total number of products to be packed varies very significantly from day-to-day by a factor of at least 3. The novelty of the project is twofold: (1) The human factor is explicitly be taken into account. It is integrated in the mathematical models and algorithms that are developed for the project. The aim is to improve the quality of employees' work ensuring the efficiency of the logistic system; (2) Problems at different decision levels are integrated and tackled jointly. At the tactical level, the main issues are workload smoothing and the management of the storage zone. At operational level, the major issues concern the rearrangement of the picking zone, the picking tours, and the dynamic reorganization of activities to manage uncertainties.

ANR project ADELE (2022-2025): “Resource Allocation in City Logistics with Demand Uncertainty” in collaboration with LCOMS (Univ. of Lorraine), Toulouse Business School, Colisweb. A central issue in city logistics (CL) is to design logistics systems that move goods to, from, and within urban areas while meeting sustainability goals. A central role is played by the orchestrator. The orchestrator is the stakeholder that operates and organizes a CL system when multiple stakeholders are implied. In ADELE, we tackle the planning problem faced by the orchestrator in coordinating and managing the resources offered by carriers or logistics service providers. The problem aims to determine what logistics facilities should be used and when and where the vehicles of the carriers should be assigned to cover the demand in the most efficient way. A key feature is that demand is uncertain. We consider two main variants depending on whether the CL system is one or two tiers. ADELE aims to develop new efficient mathematical models and decision support methods. we aim to design and implement ad-hoc optimization algorithms based on mathematical modeling. This project is a continuation of the INRIA Innovation Lab Colinocs.

10.5 Regional initiatives

STaRS project SITAR (2022-2025): The SITAR project is funded by the Région Hauts-de-France. The research within SITAR is split into two axes: (1) modeling and analysis of an optimal taxation problem, involving sanctions, formulated as a Stackelberg game involving a partial equilibrium problem at the lower level. The set of equilibria will be characterized analytically. Different settings with multi-commodity competition and different out-neighbors communication patterns will be considered. Applications will be made to the gas market. (2) development and performance analysis of learning algorithms for equilibrium tracking. A fundamental open problem is game theory is the computation of a specific equilibrium among all the possible ones, e.g., the optimal one with respect to (the possible combination of) different criteria, e.g., efficiency loss minimization, accuracy of the equilibrium approximation maximization, convergence rate minimization. The existing algorithms have convergence guarantees toward an arbitrary, possibly inefficient (with respect to those criteria), equilibrium. We aim to contribute to this second axis by deriving distributed algorithms for the computation of an optimal equilibrium in noncooperative games, and extend the results to the time-varying setting to track the sequence of optimal equilibria. The SITAR project has enabled the hiring of a 18 months postdoc researcher, Fedy Pokou, who will join the INOCS Team in February 2024.

Participants: Luce Brotcorne, Diego Cattaruzza, Bernard Fortz, Martine Labbé, Martine Le Cadre, Maxime Ogier, Frédéric Semet.

11 Dissemination

11.1 Promoting scientific activities

11.1.1 Scientific events: organisation

General chair, scientific chair

- General chair of SynchroTrans 2023, Lille, 21-22 september 2023: Diego Cattaruzza, Maxime Ogier, Frédéric Semet.
- General chair of GO 2023, Spa, Belgium, 2-5 July 2023: Bernard Fortz.

Member of the organizing committees

- 10^{th} International Congress on Industrial and Applied Mathematics (ICIAM 2023): Martine Labbé.
- LIV Brazilian Symposium on Operational Research (LIV SBPO): Martine Labbé.
- Bilevel Optimization Conference 2023: Martine Labbé.

11.1.2 Scientific events: selection

Member of the conference program committees

- The 23^{rd} Conference of the International Federation of Operational Research Societies (IFORS2023): Bernard Fortz.
- CoDIT 2023 : Frédéric Semet
- ROADEF 2023 : Luce Brotcorne, Diego Cattaruzza, Maxime Ogier, Frédéric Semet

Reviewer

- The Genetic and Evolutionary Computation Conference (GECCO) 2023: Diego Cattaruzza.
- European Control Conference (ECC) 2023: Hélène Le Cadre.
- Control and Decision Conference (CDC) 2023: Hélène Le Cadre.

11.1.3 Journal

Member of the editorial boards

- Computers & Operations Research Optimization: Luce Brotcorne – Member of the Editorial Advisory Board.
- International Transactions in Operations Research: Luce Brotcorne – Associate editor.
- Journal of Optimization Theory and Applications (JOTA): Diego Cattaruzza, associate editor; Bernard Fortz, associate editor; Martine Labbé, area editor.
- Open Journal of Mathematical Optimization: Martine Labbé, member of the steering committee.
- Transportation Science: Martine Labbé, member of the advisory board.
- International Transactions in Operations Research: Bernard Fortz, associate editor; Martine Labbé, associate editor.
- European Journal of Computational Optimization: Bernard Fortz, associate editor; Martine Labbé, associate editor.
- Networks: Bernard Fortz, associate editor.
- INFORMS Journal on Computing: Bernard Fortz, associate editor.

Reviewer - reviewing activities Annals of Operations Research, Applied Computing and Informatics, Central European Journal of Operations Research, Computers & Operations Research, Computational Optimization and Applications, Discrete Applied Mathematics, EURO Journal on Transportation and Logistics, European Journal of Operational Research, IISE Transactions, INFORMS Journal on Computing, International Journal of Management Science and Engineering Management, International Transactions in Operational Research, Journal of Optimization Theory and Applications, Mathematical Programming Computation, Networks, Omega, Operations Research, Optimization and Engineering, RAIRO - Operations Research, Transportation Science, IEEE Transactions on Automatic Control: Luce Brotcorne, Diego Cattaruzza, Bernard Fortz,Martine Labbé, Hélène Le Cadre, Maxime Ogier, Frédéric Semet.

11.1.4 Invited talks

Multi-Agent Reinforcement Learning for Strategic Bidding in Two Stage Electricity Markets. IMACS23 – 21^{st} IMACS World congress, Rome, Italy, Sep 11, 2023: Francesco Morri.

11.1.5 Leadership within the scientific community

- PGMO: Luce Brotcorne, member of the scientific committee.
- INFORMS, Energy Natural Resources and the Environmentatl Section: Luce Brotcorne,secretary & treasurer.
- EURO Working Group "Pricing and revenue management": Luce Brotcorne, coordinator.
- EURO Working Group "Vehicle Routing and Logistics Optimization (VEROLOG)": Frédéric Semet, member of the board.
- ORBEL (Belgian Operations Research Society): Bernard Fortz, member of the administration board.
- GdR Recherche Opérationnelle et Décision: Frédéric Semet, member of the board.

11.1.6 Scientific expertise

- ANID, Chile Evaluation Group: Luce Brotcorne.
- Scientific committee of France-Netherlands Exchange Program: Luce Brotcorne - Member.
- Evaluation committee for INRIA/MITACS Exchange Program: Luce Brotcorne - Member.
- Evaluation committee COST GTRI: Luce Brotcorne - Member.
- NSERC Evaluation Group 1509: Bernard Fortz.
- Hiring Committee for the Professor Position on Modeling and Optimization of Electricity Systems and Markets, CORE, LIDAM, UCLouvain, Louvain-la-Neuve, Belgium: Hélène Le Cadre.
- Hiring Committee for the Associate Professor Position in Computer Science, University of Lille, France: Diego Cattaruzza.
- IVADO International Advisory Committee, Canada : Matine Labbé - Member.
- Scientific orientation committee of the Interuniversity Centre on Entreprise Networks, Transportation and Logistics (CIRRELT), Canada: Bernard Fortz, Frédéric Semet - Members.
- Research Council of Norway, Norway: Frédéric Semet - Panel member.

11.1.7 Research administration

- Vice–president of the Inria Evaluation Committee: Luce Brotcorne.
- Elected Member of the Inria Evaluation Committee: Hélène Le Cadre.
- Member of the "Commission Emploi Recherche" (CER) at Inria Lille: Hélène Le Cadre.
- Corresponding Member for Inria Lille of the "Mission Jeunes Chercheurs": Hélène Le Cadre.
- Deputy-director of CRIStAL: Frédéric Semet.
- Member of the OPTIMA Scientific Council: Diego Cattaruzza.
- Member of Scientific Council of Centrale Lille: Diego Cattaruzza.

11.2 Teaching - Supervision - Juries

11.2.1 Teaching

- Master: Bernard Fortz, Recherche Opérationnelle et Applications, 30hrs, M1, University of Mons (Charleroi campus), Belgium.
- Master: Bernard Fortz, Continuous Optimization, 24hrs, M1 & M2, Université libre de Bruxelles, Belgium.
- Master: Frédéric Semet, Supply Chain Management, 30hrs, M2, Centrale Lille.
- Master: Frédéric Semet, Operations Research, 28hrs, M2, Centrale Lille.
- Master: Luce Brotcorne, Optimisation, 14hrs, M1, Polytech Lille.
- Master: Luce Brotcorne, Recherche opérationnelle, 16hrs, M1 apprentissage, Polytech Lille.
- Master: Diego Cattaruzza, Frédéric Semet, Prescriptive analytics and optimization, 64hrs, M1, Centrale Lille.
- Master: Diego Cattaruzza, Object-Oriented Programming, 48hrs, M1, Centrale Lille.
- Master: Diego Cattaruzza, Operations Research, 16hrs, M1, Centrale Lille.
- Licence: Diego Cattaruzza, Maxime Ogier, Object-Oriented Programming, 40hrs, L3, Centrale Lille.
- Licence: Frédéric Semet, Advanced programming and Complexity, 24hrs, L3, Centrale Lille.
- Licence: Diego Cattaruzza, Maxime Ogier, Object-Oriented Programming, 44hrs, L2, Centrale Lille.
- Licence: Bernard Fortz, Algorithmique 1, 12hrs, L1, Université libre de Bruxelles, Belgium.
- Licence: Bernard Fortz, Algorithmique et Recherche Opérationnelle, 24hrs, L3, Université libre de Bruxelles, Belgium.

11.2.2 Supervision

- PhD completed: Matteo Petris, Column generation approaches for integrated operationnal problems, September 2023, Diego Cattaruzza, Maxime Ogier, Frédéric Semet.
- PhD completed: Ilia Shilov, Game-Theoretic Approaches for Peer-to-Peer Energy Trading, September 2023, Hélène Le Cadre, Ana Busic (Inria Paris/ENS Paris), Bartek Blaszczyszyn (Inria Paris/ENS Paris).
- PhD in progress: Cristian Aguayo, Models and Algorithms for Energy Disptaching in Local Energy Communities, from July 2021, Bernard Fortz.

- PhD in progress: Tifaout Almeftah, Models and algorithms for group testing, from December 2021, Diego Cattaruzza, Martine Labbé, Frédéric Semet.
- PhD in progress: Haider Ali,Optimal techniques for charging autonomous electric vehicles with renewable energy sources, from October 2021, Luce Brotcorne, Bruno François (Centrale Lille).
- PhD in progress: Hugo Callebaut, Segment routing optimization, from September 2022, Bernard Fortz.
- Phd in progress: Clement Legrand, Intégration de Machine Learning pour la résolution de MO-VRPTWs. Diego Cattaruzza, Marie-Eleonore Kessaci (Polytech Lile), Laetitia Jourdan (University of Lille).
- PhD in progress: Aitor Lopez Sanchez, Distributed, Scalable, and Efficient Fleet Coordination for Agriculture Mobile Robots, from September 2022, Frédéric Semet, Marin Lujak.
- PhD in progress: Francesco Morri, Game-Theoretic Learning in Intelligent Marketplaces, from October 2022, Hélène Le Cadre, Luce Brotcorne.
- PhD in progress: Thibault Prunet, Models and algorithm for tactical problems in warehouses with human factor considerations, from February 2020, Nabil Absi (Ecole desMines de Saint Etienne), Valeria Borodin (Ecole des Mines de Saint Etienne), Diego Cattaruzza.
- PhD in progress: Simon Renard, Integration of machine learning and branch and bound algorithms, from October 2023, Bernard Fortz.
- PhD in progress: Luis Pablo Rojo, Incentive mechanisms for electric vehicle charging, from October 2021, Luce Brotcorne, Michel Gendreau (Polytehcnique Montréal, Canada), Miguel Anjos (University of Edinburgh, UK).
- PhD in progress: Juan Sepulveda, New optimization models and algorithms to represent energy exchanges in local energy communities, from December 2021, Hélène Le Cadre, Luce Brotcorne.
- PhD in progress: Pablo Torrealba Gonzalez, Batching and picker routing problems in warehouses taking into account human factors, from February 2021, Dominique Feillet (Ecole des Mines de Saint Etienne), Maxime Ogier, Frédéric Semet.
- PhD in progress: Wenjiao Sun, Exact methods for integrated routing and scheduling problems, from October 2021, Maxime Ogier, Frédéric Semet.
- PhD in progress: Natalia Isabel Wolf Garcia, Towards energy-based pricing strategies for the cloud, from April 2023, Luce Brotcorne, Bernard Fortz.

11.2.3 Juries

- Hector Gatt, IMT Atlantique, Construction d'une méthodologie et d'un outil associé pour la conception et la planification d'un réseau de bus: Luce Brotcorne – Reviewer.
- Quentin Jacquet, Institut Polytechnique de Paris, Stackelberg games, optimal pricing and application to electricity markets: Luce Brotcorne – Reviewer.
- Harol Mauricio Gamez, PhD, Univerity of Antwerp, Scattered storage assignment optimization: towards more efficient order fulfillment in e-commerce warehouses: Diego Cattaruzza – Reviewer.
- Ruben D'Haen, PhD, Univerity of Hasselt, Heuristic algorithms for the online integrated optimisation of order picking and vehicle routing decisions: Diego Cattaruzza – Reviewer.
- Zacharie Ales, ENSTA Paris, Contributions to solving hard combinatorial optimization problems (HDR): Bernard Fortz – Reviewer.
- Chen Dang, Université PSL, Heuristics Learning for Solving Network Optimization Problems: Bernard Fortz – Member.

- Ilia Shilov, ENS Paris, Game-Theoretic Approaches for Peer-to-Peer Energy Trading: Hélène Le Cadre – Member (co-advisor).
- Fred Michael Gonsalves, IMT Atlantique, Leveraging Machine Learning and Operations Research to Enhance Cruise Ship Energy Efficiency: Hélène Le Cadre – Member.
- Manuel Trotta, Université Clermont Auvergne, Pickup and delivery problems with autonomous and electric vehicles : Frédéric Semet – Chairman of the committee.
- Daniil Khachai, Université de Bordeaux, Algorithmes efficaces pour les problèmes de routage avec des contraintes spécifiques: Frédéric Semet – Reviewer.

12 Scientific production

12.1 Major publications

[1] N. Absi, D. Cattaruzza, D. Feillet, M. Ogier and F. Semet. 'A heuristic branch-cut-and-price algorithm for the ROADEF/EURO challenge on Inventory Routing'. In: *Transportation Science* (2019). URL: https://hal-emse.ccsd.cnrs.fr/emse-02163171.

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12.2 Publications of the year

International journals

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