



# Sixty-one surveys in operations research

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## Abstract

We introduce the series of *Annals of Operations Research* that collects updated versions of the invited surveys that appeared in the journal *4OR - A Quarterly Journal of Operations Research*.

**Keywords** Survey · Collection · *4OR - A Quarterly Journal of Operations Research*

## 1 Foreword

There exists a long standing collaboration between *4OR - A Quarterly Journal of Operations Research* and *Annals of Operations Research* (AOR), whereby on a triennial basis, the editor-in-chief of AOR invites the editors-in-chief of *4OR* as guest editors to produce a special issue collecting the “state-of-the-art surveys” published in the past three volumes (consisting of four issues each) of *4OR*. The present issue gathers the nine surveys published by *4OR* in the triennium 2018–2020, and continues the series of five issues already published in AOR: Bouyssou et al. (2007a, 2010a), Liberti et al. (2013b, 2016b), and Crama et al. (2018a).

The success of the series has its origin in the excellence of the surveys, written by prominent researchers in their field, often addressing hot topics and presenting their latest advances and future trends. In addition, they are always nicely written and made accessible to the nonspecialist. The publication of their updated versions in AOR disseminates them to a wider audience, and is an opportunity for their authors to update, correct, and sometimes substantially improve the original version (the fact that *4OR* and AOR are both published by Springer helps with copyright issues). We address all our thanks to the authors for their willingness to re-work and re-publish their survey, as well as for their promptitude.

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## 2 About 4OR

In 2002, the Belgian and Italian Operations Research societies (respectively, ORBEL and AIRO) decided to stop publishing their historical national journals, *JORBEL* and *Ricerca Operativa*. The goal was to optimize the use of scarce resources and to jointly launch a new journal with better international visibility. The Belgian and Italian societies were soon joined by the French Operations Research society (*ROADEF*) and, with the help of Springer, they started publishing *4OR* in 2002. As its name suggests, this journal is “for” Operations Research (OR). The full name of the journal was originally *Quarterly Journal of the Belgian, French and Italian Operations Research Societies*, but soon (in 2004) changed to *4OR - A Quarterly Journal of Operations Research* so as to better reflect its growing international impact.

*4OR* is managed by a group of three editors-in-chief, one from each promoting national OR society, assisted by a board of highly qualified area editors. (For the period 2018–2020, the editors-in-chief were the authors of this editorial.) Every third year, the editors-in-chief prepare a report on the latest three years of existence of the journal (see Bouyssou et al., 2006, 2009; Crama et al. 2018b, 2021; Liberti et al., 2012, 2015).

Every year, one volume of four issues, each of around 150 pages, is published. Papers in volumes 16 (2018), 17 (2019), and 18 (2020) fall into three different categories, namely (we indicate in parentheses the total number of papers in each category):

- Invited surveys* (9): These are the state-of-the-art surveys collected in the present volume. They are written by prominent researchers upon invitation of the editors-in-chief.
- Research papers* (43): The journal publishes original research papers in all areas of OR.
- PhD thesis abstracts* (29): As a way to increase the visibility of PhD theses defended in Belgian, French, or Italian institutions, or by Belgian, French, or Italian nationals, the journal publishes two-page summaries of the theses under the responsibility of the PhD advisors.

## 3 The first five volumes

We believe that the 61 surveys published in the first 18 years of existence of *4OR* offer, in over 2000 pages, an in-depth coverage of many “hot fields” in OR. In order to give an overview of the topics the journal has covered, we briefly present here, in chronological order, the surveys that were included in the first five *Annals of Operations Research* volumes Bouyssou et al. (2007a, 2010a), Liberti et al. (2013b, 2016b), Crama et al. (2018a), referring the reader to Bouyssou et al. (2007b, 2010b), Liberti et al. (2013a, 2016a) and Crama et al. (2018c) for a more detailed description.

*The omnipresence of Lagrange* [*4OR* 1/1, Lemaréchal (2003)]: Claude Lemaréchal points out that Lagrangean relaxation is not just a technique for handling combinatorial optimization problems, but a basic method in many more optimization issues.

*The dial-a-ride problem: models and algorithms* [*4OR* 1/2, Cordeau & Laporte (2003)]: Jean-Francois Cordeau and Gilbert Laporte present an exhaustive introduction to door-to-door delivery problems arising in social services.

*Lifting, superadditivity, mixed integer rounding and single node flow sets revisited* [*4OR* 1/3, Louveaux & Wolsey (2003)]: Quentin Louveaux and Laurence Wolsey show that a

combination of integer rounding and lifting techniques provides a unified way to obtain many of the valid inequalities for mixed 0–1 sets that have been proposed in the literature.

*Models and solution techniques for frequency assignment problems* [4OR 1/4, Aardal et al. (2003)]: Karen Aardal, Stan van Hoesel, Arie Koster, Carlo Mannino, and Antonio Sassano give a thorough overview of the different modeling ideas developed for the various situations in which a frequency assignment problem arises in wireless communication.

*Combinatorial auctions* [4OR 2/1, Abrache et al. (2004)]: Jawad Abrache, Teodor Gabriel Crainic, Michel Gendreau, and Monia Rekik review several contributions from the Operations Research literature on a particular type of auctions in which participants are allowed to bid on bundles of multiple heterogeneous items.

*Ethics in OR/MS: past, present and future* [4OR 2/2, Brans & Gallo (2004)]: Jean-Pierre Brans and Giorgio Gallo discuss fundamental questions on the social role of Operations Research/Management Science tools and the new challenges posed by the growing complexity of the problems humanity is facing today.

*Combinatorial optimization and hierarchical classifications* [4OR 2/3, Barthélemy et al. (2004)]: Jean-Pierre Barthélemy, François Brucker, and Christophe Osswald review several extensions of traditional hierarchical classification techniques from a combinatorial optimization point of view, and study the complexity of the underlying optimization problems.

*Counting and enumeration complexity with application to multicriteria scheduling* [4OR 3/1, T'kindt et al. (2005)]: Vincent T'kindt, Karima Bouibede-Hocine, and Carl Esswein study several aspects of multicriteria scheduling, with special emphasis on the complexity of problems linked with counting and enumerating optimal solutions.

*An overview of bilevel optimization* [4OR 3/2, Colson et al. (2005)]: Benoît Colson, Patrice Marcotte, and Gilles Savard review the good progress that is being made in handling special classes of problems in which the objective involves the optimal solution to another second level problem, or admit even more levels.

*Complexity and algorithms for nonlinear optimization problems* [4OR 3/3, Hochbaum (2005)]: Dorit Hochbaum analyzes the effort needed to produce optimal solutions with pre-specified accuracy for nonlinear continuous optimization problems, and presents polynomial time methods for several nonlinear network problems.

*Production planning with load dependent lead times: an update of research* [4OR 3/4, Pahl et al. (2005)]: Julia Pahl, Stefan Voß, and David L. Woodruff give a detailed account of techniques for supply chain management in contexts where it is required to produce goods in a timely manner so as to be able to meet a demand varying in time and space.

*Some operations research methods for analyzing protein sequences and structures* [4OR 4/2, Błazewicz et al. (2006)]: Piotr Łukasiak, Jacek Błazewicz, and Maciej Miłostan review Operations Research techniques that were relatively recently introduced in biology, especially in the protein analysis area, to support biologists.

*Integrating operations research in constraint programming* [4OR 4/3, Milano & Wallace (2006)]: Michela Milano and Mark Wallace describe how constraint programming, viewed as a natural formalism for modeling problems, allows linear programming to be combined with propagation and novel and varied search techniques. Rego (2006): César Rego and Fred Glover present the general framework of the ejection chain and filter-and-fan methods, powerful neighborhood structures fundamental to the performance of local search and metaheuristic algorithms for combinatorial optimization.

*An updated survey on the linear ordering problem for weighted or unweighted tournaments* [4OR 5/1, Charon & Hudry (2007)]: Irène Charon and Olivier Hudry survey results, conjectures, and open problems dealing with the combinatorial and algorithmic aspects of the linear ordering problem.

*Combinatorial optimization and green logistics* [4OR 5/2, Sbihi & Eglese (2007)]: Abdelkader Sbihi and Richard W. Eglese introduce the area of green logistics and describe the main topics in this field which can be formulated as combinatorial optimization problems.

*Generalized Nash equilibrium problems* [4OR 5/3, Facchinei & Kanzow (2007)]: Francisco Facchinei and Christian Kanzow discuss the main properties and solution algorithms for the generalized Nash equilibrium problem, an important model that has its roots in the economic sciences but is being fruitfully used in many different fields.

*Exact algorithms for routing problems under vehicle capacity constraints* [4OR 5/4, Baldacci et al. (2007)]: Roberto Baldacci, Paolo Toth, and Daniele Vigo review the most recent developments that had a major impact in the current state-of-the-art of exact algorithms for the capacitated vehicle routing problem.

*A decade of application of the Choquet and Sugeno integrals in multi-criteria decision aid* [4OR 6/1, Grabisch & Labreuche (2008)]: Michel Grabisch and Christophe Labreuche examine the main advances on the use of the Choquet and Sugeno integrals in multi-criteria decision aid over the last decade.

*On the use of graphs in discrete tomography* [4OR 6/2, de Werra et al. (2008)]: Dominique de Werra, Marie-Christine Costa, Christophe Picouleau, and Bernard Ries present a tutorial paper on a graph theoretical model for the basic image reconstruction problem which stems from discrete tomography.

*Mathematical optimization in intensity modulated radiation therapy* [4OR 6/3, Ehrgott et al. (2008)]: Matthias Ehrgott, Çigdem Güler, Horst W. Hamacher, and Lizhen Shao survey optimization models, methods, and theories in mathematical optimization which were recently successfully introduced in the design of intensity modulated radiotherapy treatments.

*Variable neighborhood search: methods and applications* [4OR 6/4, Hansen et al. (2008)]: Pierre Hansen, Nenad Mladenovic, and José Moreno Pérez review the main aspects of variable neighborhood search metaheuristics, a framework based upon systematic changes of neighborhoods.

*Constraint programming-based column generation* [4OR 7/2, Gualandi & Malucelli (2009)]: Stefano Gualandi and Federico Malucelli survey recent applications and advances of the constraint programming-based column generation framework, where the master subproblem is solved by traditional Operations Research techniques, while the pricing subproblem is solved by constraint programming.

*The core of games on ordered structures and graphs* [4OR 7/3, Grabisch (2009)]: Michel Grabisch gives a unified view of the results that have been obtained by defining a game on a subcollection of the power set of the set of players, examining the implications on the mathematical structure of the core.

*Intra-domain traffic engineering with shortest path routing protocols* [4OR 7/4, Altun et al. (2009)]: Aysegül Altun, Bernard Fortz, Mikkel Thorup, and Ümit Hakan review optimization techniques that have been developed for managing intra-domain routing in networks operated with shortest path routing protocols, and the state-of-the-art research that has been carried out in this direction.

*Extended formulations in combinatorial optimization* [4OR 8/1, Conforti et al. (2010)]: Michele Conforti, Gérard Cornuéjols, and Giacomo Zambelli survey the size of perfect formulations for combinatorial optimization problems, with special emphasis on situations where the addition of a polynomial number of extra variables allows a formulation with a polynomial number of inequalities.

*Robust portfolio asset allocation and risk measures* [4OR 8/2, Scutellà & Recchia (2010)]: Maria Grazia Scutellà and Raffaella Recchia discuss the mathematical models, and related

algorithmic approaches, that have recently been proposed to address uncertainty in portfolio asset allocation, focusing on robust optimization methodology.

*Recent progress of local search in handling the time window constraints of the vehicle routing problem* [4OR 8/3, Hashimoto et al. (2010)]: Hideki Hashimoto, Mutsunori Yagiura, Shinji Imahori, and Toshihide Ibaraki review recent results on how to handle hard and soft time window constraints of the vehicle routing problem, putting emphasis on its different definitions and algorithms.

*Makespan minimization in online scheduling with machine eligibility* [4OR 8/4, Lee et al. (2010)]: Kangbok Lee, Joseph Y.-T. Leung, and Michael L. Pinedo examine online scheduling problems in parallel machine environments with various types of machine eligibility constraints, and the makespan as objective function.

*Probabilistic decision graphs for optimization under uncertainty* [4OR 9/1, Jensen & Nielsen (2011)]: Finn Jensen and Thomas Nielsen survey probabilistic decision graphs for modeling and solving decision problems under uncertainty, providing an introduction to influence diagrams and to alternative representation languages.

*Airport runway scheduling* [4OR 9/2, Bennell et al. (2011)]: Julia Bennell, Mohammad Mesgarpour, and Chris Potts review the main solution techniques (dynamic programming, branch and bound, heuristics and meta-heuristics) that are used for scheduling aircraft landings and take-offs.

*Political districting: from classical models to recent approaches* [4OR 9/3, Ricca et al. (2011)]: Federica Ricca, Andrea Scozzari, and Bruno Simeone introduce and discuss selected optimization models and algorithms for political districting, which gave rise to the main lines of research on this topic in the Operations Research literature of the last five decades.

*Mixed integer nonlinear programming tools: a practical overview* [4OR 9/4, D'Ambrosio & Lodi (2011)]: Claudia D'Ambrosio and Andrea Lodi review available tools for solving mixed integer nonlinear programming problems, with the aim of giving the reader a flavor of the difficulties one can face in this field.

*Learning from conflicts in propositional satisfiability* [4OR 10/1, Hamadi et al. (2012)]: Youssef Hamadi, Saïd Jabbour, and Lakhdar Sais discuss the application of machine learning techniques to SAT solving.

*The symmetric quadratic knapsack problem: approximation and scheduling applications* [4OR 10/2, Kellerer & Strusevich (2012)]: Hans Kellerer and Vitaly Strusevich discuss fully polynomial time approximation schemes for the Symmetric Quadratic Knapsack Problem and the Half-Product Problem, and their application to various scheduling problems.

*Relaxations of mixed integer sets from lattice-free polyhedra* [4OR 10/3, Del Pia & Weismantel (2012)]: Alberto Del Pia and Robert Weismantel give an introduction to a recently established link between the geometry of numbers and mixed integer optimization.

*Semidefinite relaxations for partitioning, assignment and ordering problems* [4OR 10/4, Rendl (2012)]: Franz Rendl introduces the field of semidefinite optimization for non-experts. The basic concepts are explained on a mostly intuitive level. A variety of semidefinite optimization models are presented on a selection of graph optimization problems.

*Bilevel programming and price setting problems* [4OR 11/1, Labbé & Violin (2013)]: Martine Labbé and Alessia Violin present the main concepts, models, and solution methods of pricing optimization problems which can be modeled as bilevel programs.

*Combining metaheuristics with mathematical programming, constraint programming and machine learning* [4OR 11/2, Talbi (2013)]: El-Ghazali Talbi gives a rational, categorized view of the field of hybrid metaheuristics, discussing in particular the case of hybridization with mathematical programming and constraint programming.

*Using multi-objective evolutionary algorithms for single-objective optimization* [4OR 11/3, Segura et al. (2013)]: Carlos Segura, Carlos Coello, Gara Miranda, and Coromoto León present the main methods that allow the use of multi-objective schemes for single-objective optimization, and discuss several open topics and some possible paths of future work in this area.

*Global optimization based on local searches* [4OR 11/4, Locatelli & Schoen (2013)]: Marco Locatelli and Fabio Schoen deal with the use of local searches within global optimization algorithms, and present how the associated issues have been faced in the existing literature.

*Merit functions: a bridge between optimization and equilibria* [4OR 12/1, Pappalardo et al. (2014)]: Massimo Pappalardo, Giandomenico Mastroeni, and Mauro Passacantando review the literature about merit functions for variational inequalities, quasi-variational inequalities and abstract equilibrium problems.

*On scheduling with the non-idling constraint* [4OR 12/2, Chrétienne (2014)]: Philippe Chrétienne gives an overview of the main results obtained on the complexity of scheduling under the non-idling constraint, i.e., when the jobs assigned to each machine must be processed with no intermediate delay.

*Deriving compact extended formulations via LP-based separation techniques* [4OR 12/3, Lancia & Serafini (2014)]: Giuseppe Lancia and Paolo Serafini introduce a unified view of compact extended formulations applied to combinatorial optimization problems.

*Simulation optimization: a review of algorithms and applications* [4OR 12/4, Amaran et al. (2014)]: Simulation optimization refers to the optimization of an objective function subject to constraints, both of which can be evaluated through a stochastic simulation. Satyajith Amaran, Nick Sahinidis, Bikram Sharda, and Scott Bury review some of the diverse applications that have been tackled by these methods and speculate on future directions in the field.

*Large-scale unit commitment under uncertainty: an updated literature survey* [4OR 13/2, Tahanan et al. (2015)]: Milad Tahanan, Wim van Ackooij, Antonio Frangioni, and Fabrizio Lacalandra survey the methods for the uncertain Unit Commitment problem, in all its variants, starting with a review on the deterministic versions of the problem, and then categorizing the approaches to the uncertain version.

*When polynomial approximation meets exact computation* [4OR 13/3, Paschos (2015)]: Vangelis Paschos outlines a recent research area aiming at building a new approximation paradigm by matching two distinct domains: the polynomial approximation and the exact solution of NP-hard problems by algorithms with guaranteed and non-trivial upper complexity bounds.

*Shared mobility systems: an updated survey* [4OR 13/4, Laporte et al. (2015)]: Gilbert Laporte, Frédéric Meunier, and Roberto Wolfler Calvo classify problems arising in the optimization of shared mobility systems for bicycles and cars, under five main headings: station location, fleet dimensioning, station inventory, re-balancing incentives, and vehicle repositioning.

*Vehicle routing problems with multiple trips* [4OR 14/3, Cattaruzza et al. (2016)]: Diego Cattaruzza, Nabil Absi, and Dominique Feillet provide a unified view of mathematical formulations, exact algorithms, and heuristic approaches for the multi-trip vehicle routing problem and other families of routing problems where multiple trips are sometimes allowed.

*Recent results on assigned and unassigned distance geometry with applications to protein molecules and nanostructures* [4OR 14/4, Billinge et al. (2016)]: Simon Billinge, Phillip Duxbury, Douglas Goncalves, Carlile Lavor, and Antonio Mucherino introduce distance geometry, a body of knowledge originated by seminal results of Menger and Blumenthal, focusing



on recent developments and on two main applications related to three-dimensional conformations of biological molecules and nanostructures.

*Optimization in liner shipping* [4OR 15/1, Brouer et al. (2017)]: Berit Dangaard Brouer, Christian Vad Karsten, and David Pisinger review several data-driven optimization problems arising in liner shipping: network design, container routing, speed optimization, empty container repositioning, stowage planning, disruption management, and bunker purchasing.

*Recent contributions to linear semi-infinite optimization: an update* [4OR 15/3, Goberna & López (2017)]: Miguel Angel Goberna and Marco Antonio López review the theory of deterministic and uncertain linear semi-infinite optimization, presenting numerical approaches, describing a number of recent applications in a variety of fields, and discussing extensions to related optimization areas.

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