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Operations Research & Management Science

Teodor Gabriel Crainic
Michel Gendreau
Antonio Frangioni *Editors*

Combinatorial Optimization and Applications

A Tribute to Bernard Gendron

Springer

International Series in Operations Research & Management Science

Volume 358

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ISSN 0884-8289 ISSN 2214-7934 (electronic)
International Series in Operations Research & Management Science
ISBN 978-3-031-57602-7 ISBN 978-3-031-57603-4 (eBook)
https://doi.org/10.1007/978-3-031-57603-4

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

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Bernard Gendron and Operations Research

Teodor Gabriel Crainic, Antonio Frangioni, and Michel Gendreau

1 Introduction

In July 2022, we lost our dear friend and colleague, Professor Bernard Gendron, who made major contributions with long-lasting impacts to the science and practice of *Operations Research* (*OR*) and *Combinatorial Optimization* (*CO*). This book aims to be both a fitting way to honour the memory and scientific legacy of Professor Gendron, and a useful reference for researchers and graduate students in OR, CO, and related fields.

Inspired by the exceptional contributions made by Professor Gendron, and written by acknowledged researchers who collaborated closely with him, the book presents a state-of-the-art view of the field through a combination of surveys, expository articles, and focused methodological and applied chapters. The range of topics addressed is as broad as the interests of Professor Gendron, and includes modelling, algorithmic, and application aspects of packing, facility location, network design, scheduling, routing, and transportation planning. The content of the book is

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T. G. Crainic et al. (eds.), *Combinatorial Optimization and Applications*,
International Series in Operations Research & Management Science 358,
https://doi.org/10.1007/978-3-031-57603-4_1

briefly presented in Sect. 3, following a short in-memoriam text. We conclude this introductory chapter with a few words of thanks.

2 Bernard Gendron (1966–2022): Friend and Colleague[1]

On July 17, 2022, our friend and colleague Bernard Gendron passed away, after an unforgiving illness. Bernard was Professor of Operations Research in the Département d'informatique et de recherche opérationnelle (DIRO—Computer Science and Operations Research) of Université de Montréal and a senior CIRRELT member (the Interuniversity Research Centre on Enterprise Networks, Logistics and Transportation).

Bernard started displaying his innate talent for research and making important contributions to Operations Research, Combinatorial Optimization, and Transportation Science while working toward his master's degree at DIRO. His master's thesis addressed a challenging, recently-defined, logistics problem through network-design modelling and a parallel exact enumerative algorithm. In this, Bernard was an important member of the team that started the Montreal research work on parallel optimization, and one of the pioneers developing such methodology to address transportation and logistics planning challenges. The Canadian Operational Research Society (CORS) acknowledged the quality of the research, and Bernard's writing skills, by awarding him the First Prize of the 1992 student-article competition.

Bernard followed with an exceptional Ph.D. dissertation, still at DIRO, on multicommodity capacitated fixed charge network design applied to planning transportation and logistics systems. The thesis included several important contributions to the understanding, modelling, and solution of network design problems, as well as to the development of parallel optimization, for which he received the 1995 Best Dissertation Award of the Transportation Science Section of INFORMS. Impressed by the quality of his work, DIRO hired Bernard as a tenure-track faculty member, even before his dissertation defence.

In the years that followed, Bernard pursued a very active academic career combining top-level research with teaching and transfer activities. In these, he showed that he was a true great Operations Research scientist, harmoniously blending applications and methodology to push the science envelope and address relevant and challenging problems of substantial industrial and societal interest. From the very beginning of his research work, Bernard was highly motivated by such applications, in particular in transportation and logistics (system and service network design for freight carriers and distribution networks, location of facilities, and forestry problems), scheduling of tasks and personnel, and fixed and wireless telecommunication networks planning and management. As it is typical of the field, addressing practical problems led him to study and develop the relevant methodological part of Operations Research and Mathematical Programming, focusing on

[1] Earlier versions of this text have been published in a number of journals and web sites.

Combinatorial Optimization and Integer Programming, e.g., graph theory, location, network design, and routing.

To address the highly challenging problems raised by the generic and applied models he studied, Bernard left no stone unturned and explored a wide range of mathematical optimization methodologies. He cunningly employed existing techniques and proposed significant methodological advances in as diverse fields as Lagrangian relaxation, column generation, Benders' decomposition, logic-based constraint programming, cutting planes and enumerative (Branch & Bound & Cut) algorithms, and meta- and math-heuristic solution methods. Since the early days of his career, he was a pioneer and an avid proponent of parallel optimization.

In applied and methodological work alike, Bernard deployed his creativity and considerable knowledge to both modelling and algorithmic development. For the applications he addressed, Bernard searched for the mathematical formulation that would simultaneously capture the essence of the problem at hand and be amenable to an efficient solution method, in order to yield the numerical results required by the application. To reach this goal, Bernard applied the significant understanding and tools developed studying the more abstract, generic problem classes in Combinatorial Optimization, reformulation techniques and polyhedral analysis, in particular.

Bernard had both a passion and a special knack for continuously revisiting so called "old" models and problems, and finding new and original reformulations and solution approaches. He never stopped studying general models with many practical applications, and proposing novel ways of viewing, decomposing, and approaching them. The many variants of the multicommodity network flow and design problems formed one of the fields of work about which he was most passionate, yielding some of his more important and long-lasting contributions to science and Operations Research. The chapters detailing the various network design formulations (Crainic et al. 2021) and exact solution methods (Crainic & Gendron 2021), in the "Network Design with Applications to Transportation and Logistics" book he recently co-edited (Crainic et al. 2021), synthesizes his immense heritage in the field. This unabated curiosity is the hallmark of a truly exceptional researcher, such as he was.

A large part of Bernard's work was performed in the context of very lively international collaborations with colleagues from top institutions and companies from around the world. These include MIT in Boston, EPFL in Lausanne, ILOG in Paris, École Centrale in Lille, and the universities of Pisa, Lisbon, Nice-Sophia-Antipolis, Clermont-Ferrand (Blaise-Pascal), Versailles, and Valenciennes, among others. These international collaborations also gave rise to several participations in specialized doctoral schools as both organizer and lecturer.

Bernard's talent as a researcher created many interesting opportunities. Among these, he held two important chairs: an industrial one on data intelligence for logistics, supported by the company Purolator and the Natural Sciences and Engineering Research Council of Canada, and a chair on green technologies, funded by the government of Quebec, dealing with the transformations in the transportation sector.

Besides his primary interest in science and research, Bernard cared immensely for the scientific and academic community, both in Montreal and abroad. Over time, this led him to accept a number of duties and tasks in a variety of roles. In 2008, Bernard was selected to become the first director of CIRRELT, the Interuniversity Research Centre on Enterprise Networks, Logistics and Transportation. Born from the merger of various research groups in five different universities, CIRRELT flourished under Bernard's skillful stewardship of eight years and became one of the leading research centres in logistics and transportation in the world. A few years later, Bernard was asked to become Adjunct Vice-Rector of Research, Discovery, Creation, and Innovation of Université de Montréal in 2021. Unfortunately, illness prevented him from accomplishing as much as he aimed for in that position.

Bernard displayed the same energy and gift for stewardship with respect to learned societies, which brought him great appreciation and respect in the community. He held many positions within CORS, from President of the Montreal section to Council member to President (2004–2005). CORS recognized Bernard's outstanding contributions to Canadian Operations Research by bestowing him three major distinctions: the Award of Merit (2010), the Service Award (2006), and the Practice Prize (2004).

Bernard was also deeply committed to the INFORMS community, in particular those interested by transportation and logistics and the interplay between Operations Research developments and the performance of applications. He was thus first elected President of the Transportation Science Section of INFORMS (2001–2002, after serving as Vice-President, 2000–2001, and Secretary-Treasurer, 1998–2000), before becoming the first President of the Section on Transportation Science and Logistics (2002–2003).

Bernard was very active in scientific publishing. After serving as Associate Editor of *INFOR* from 2004 to 2006, he was its Editor in Chief from 2006 to 2014. He has also been Area Editor in "Combinatorial Optimization" of *RAIRO-Operations Research* since 2019, and a member of the editorial boards of *Constraint Programming Letters* and the *EURO Journal on Transportation and Logistics* since 2006 and 2012, respectively. Always at the forefront of transformations, he was also one of the founders and the Section Editor in "Computational Aspects and Applications" of the *Open Journal of Mathematical Optimization*, the first completely Gold Open Access journal in the OR area. Bernard was also involved in the organization of several conferences and workshops as member of their organizing or scientific committees. These scientific events include, among others, the *CORS/INFORMS International Meeting* of 2009, the *IFORS Triennial Meeting* in 2017, as well as several editions of the *Odysseus*, *CPAIOR*, and *Optimization Days* conferences.

Throughout his career, Bernard has been deeply committed to his students, both graduate and undergraduate. Bernard not only shared his knowledge, but he also wanted to give them the opportunity to grow as scientists and human beings. Younger colleagues also recall his reassuring presence as a mentor and an example of a true academic.

All those who have known Bernard have a deep respect for his scientific abilities and his numerous professional accomplishments, but they especially dearly remember the man who Bernard was: warm, smiling, and with an incomparable laughter. His hard-working attitude never was disjoint from his heart-felt, true respect of others; together with his renowned sense of humor, this made him a wonderful colleague to both have full-night work stints with, and share small talk about hockey or the history of Quebec over a beer. We will sorely miss him.

3 Contents of the Book

The book is subdivided into two parts. The first one comprises twelve chapters and is dedicated to methodologically-oriented developments. The chapters address some fundamental families of OR and CO problems, in particular knapsack, packing, spanning trees, facility location, and network design. They focus on models and integer-programming formulation issues, which increase the difficulty to address the corresponding problem, e.g., multiple network echelons, interwoven layers of decision, and complex capacity-utilization measures or cost structures, as well as on associated algorithmic challenges and developments, including decomposition algorithms, comprising Lagrangian (dual) and Benders' (primal) approaches.

The seven chapters of Part II of the book are dedicated to developments that are more closely tied to specific real-world applications in complex settings, including health-staff scheduling and routing, city logistics, fleet management and scheduling, pricing and location of infrastructure, and optimization of public transport systems. We now provide a more detailed introduction to each of the chapters, where we also highlight the connection of the corresponding research line with the work of Bernard Gendron. In so doing, we have greatly benefited from the material provided by the authors of each chapter. Hence, this introductory chapter owes in fact to all the authors of the book.

3.1 Part I: Methodological Developments

Chapter 2, *Variable Neighbourhood Search with Dynamic Exploration for the Set Union Knapsack Problem*, by Igor Machado Coelho, Saïd Hanafi, Raca Todosijevic, Bernard Gendron, and Mustapha Ratli. The authors address a problem setting where one is given a set of elements, each with a positive weight, and a set of items, each with a positive profit and a corresponding set of associated elements. An item may be included in the knapsack only if all its associated elements are included. The goal is to select the items to be included in the knapsack such that the total profit of the selected items is maximized and the capacity of the knapsack is not exceeded. The chapter proposes a Variable Neighbourhood Search meta-heuristic and shows, on a set of benchmark instances from the literature, that this method is competitive with the state-of-the-art heuristics for the problem. The research presented in this chapter was initiated during the period when Bernard Gendron, a friend rather than just a colleague for the authors, was co-director of the Laboratoire International Associé LIA/IRP between LAMIH CNRS 8201 and CIRRELT, and extended within the framework of the French chair in Brazil of Saïd Hanafi. Bernard Gendron was always interested in addressing advanced knapsack problems through meta-heuristics, so the authors believe themselves fortunate to have had his valuable contributions to the results presented in this chapter.

Chapter 3, *Common-Flow Formulations for the Diameter Constrained Spanning Tree Problem*, by Luis Gouveia, Markus Leitner, and Ivana Ljubic. This chapter proposes and computationally evaluates new formulations for specific variants of the Spanning and Steiner Tree Problems with diameter constraints. The research described in the chapter is closely related to important parts of the scientific work of Bernard Gendron, who has laid important foundations for many network optimization problems by making invaluable contributions in studying and improving standard multi-commodity flow formulations for various network design, location, and routing problems. In particular, Bernard Gendron has shown in some of his seminal works how disaggregation techniques can be applied to solve network flow problems with piecewise linear costs, and the concepts of common and uncommon flows studied in this chapter can be seen as an application of disaggregation techniques to multicommodity flows.

Chapter 4, *Models and Methods for Two-Level Uncapacitated Facility Location Problem*, by Bernard Gendron, Paul-Virak Khuong, and Frédéric Semet. This chapter is a synthesis of the research work carried out by Bernard Gendron with his co-authors over 15 years on two-level facility location problems. The initial motivation to explore this line of research came from an applied project performed in cooperation with a multi-channel company to design its distribution network. In addition to the scientific results obtained, the chapter highlights some of the scientific interests of Bernard Gendron. First, the initial motivation for this research is an illustration of how, as an operations researcher, he was deeply interested in applying OR techniques to address real-life problems. Second, he liked to focus on modelling and studying the properties of the models. He has never stopped questioning and proposing new modelling ideas. The chapter describes the extensive work done on the different models for two-level facility location problems and the linear relaxation bounds that can be obtained. Last, the chapter presents a Lagrangian-based approach to the problem considered, which was one of Bernard Gendron's favorite techniques, since it can lead to very efficient matheuristics with a performance guarantee. This work provides foundations on which future research can be conducted along two lines. First, regarding the problem extension to the case where the distribution network design is based on contracts with different carriers in a multi-period context. Second, in terms of methods, the study of new approaches to efficiently address the two-level facility location problem with modular costs has great practical interest.

Chapter 5, *Facility Location: A Guide to Modeling and Solving Complex Problem Variants via Lagrangian Relaxation*, by Sanjay Dominik Jena. The author wishes to dedicate this chapter to Bernard Gendron, who was not only his former Ph.D. supervisor, but especially a colleague and a friend. The topic of this chapter mirrors the focal point of their joint research: Lagrangian relaxation methods for complex facility location problems, driven by industrial requirements. The work in this chapter extends beyond the previous joint research, including some recent work inspired, in one way or another, by Bernard Gendron's enduring influence, and in particular by his passion and relentless pursuit for stronger mixed-integer formulations, facility location, and Lagrangian relaxation.

Chapter 6, *Bin Packing Problems for Capacity Planning and Last Mile Applications*, by Maria Elena Bruni, Teodor Gabriel Crainic, and Guido Perboli. This chapter is focused on the representation of capacity restrictions within consolidation-based freight transportation and logistics planning, and the important role bin packing methodologies may play to enhance the accuracy and relevance of OR models and methods for the strategic and tactical planning of such firms and systems. The research work touches directly two of the major fields of interest and contributions of Bernard Gendron: location problems and, especially, network design. It also recalls his continuous desire to explore new modelling and algorithmic avenues. The authors heartfeltly dedicate this chapter to Bernard Gendron, who was not only a colleague but a dear friend. In their own words: "While writing it, the many opportunities of discussing these scientific issues with him came to mind: seminars, conferences, but also over lunch or dinner and while we were gathered around the coffee machine or sipping a glass of wine. We think that the best way to remember Bernard and his legacy is to recall his heart; the heart that gave him the passion to move forward in research when a solution seemed out of reach; the heart with which he shared his knowledge with students; the heart with which he gave himself to friends and colleagues; the heart with which he loved his wife and family. We are certain that reading these lines now he will be laughing, with that contagious laughter we all remember so well. He is for ever in our minds and hearts."

Chapter 7, *Models for Network Flow and Network Design Problems with Piecewise Linear Costs*, by Bernard Fortz, Bernard Gendron, and Luis Gouveia, presents a review of some pioneering work of Bernard Gendron on multicommodity flow and network design problems with piecewise linear costs. The chapter emphasizes the importance of methodological advances in developing models for these problems, pointing out relevant modelling contributions by Bernard Gendron on this topic. In particular, the ideas of variable and constraint disaggregation, allowing to develop structural valid inequalities or to eliminate variables in an efficient pre-processing step, are illustrated with several examples. The chapter therefore provides an introduction to, and complements, other chapters of the book that emphasize the careful and innovative ways in which Bernard Gendron has developed and applied decomposition techniques such as Lagrangian relaxation and Benders' decomposition to these models.

Chapter 8, *A New Technique for Modeling Piecewise Linear Costs in Network Design Problems*, by Mike Hewitt and Fabien Lehuédé. The chapter is concerned with modelling piecewise linear cost functions within Scheduled Service Network Design (SSND) problems, a setting often encountered in planning consolidation-based transportation systems, in particular when the unit rates to be paid depend on the quantity of flow to be shipped. The authors show the great potential of the approach they propose compared to the classical ones, in a line of research that follows on and extends Bernard Gendron's work on network optimization with piecewise linear costs, from its pioneering results on linear relaxation, disaggregation, and cutting-plane approaches (Croxton et al. 2003a,b), to generalizations to Network Flow and Multicommodity Capacitated Network Design (MCND) problems (Croxton et al. 2007; Frangioni & Gendron 2009; Gendron & Gouveia 2017; Frangioni & Gendron 2021). Recalling that the SSND is a MCND defined on the time-space network, the authors dedicate their work "to Bernard in memory of both his kindness and research".

Chapter 9, *Multi-layer Network Design for Consolidation-based Transportation Planning*, by Teodor Gabriel Crainic. Multi-layer networks are used to model complex, multi-component systems, frequently encountered in transportation and telecommunication planning, each component being represented by a network layer and an arc in a given layer being defined with respect to a set of arcs in one or several other layers. Multi-layer network design aims to simultaneously design all layer-specific networks to satisfy at minimum overall cost a given set of origin-destination demands. The chapter recalls and enhances the basic definitions and formulations (Crainic et al. 2022), discusses the challenges arising from the connectivity relations and requirements among the design, flow, and attribute decision variables associated with the arcs of interconnected layers, and proposes new formulations for rich networks, with more than two layers and connectivity relations involving several layers simultaneously. The chapter is closely related to the work of Bernard Gendron. In the words of the author "Bernard was my first and one of the brightest PhD students I had the privilege to supervise. We became very good friends and research partners, exploring together many exciting areas of OR, including location (e.g., Gendron and Crainic 1995), parallel optimization (e.g., Gendron and Crainic 1994a,b; Bourbeau et al. 2000), and network design (e.g., Crainic et al. 2021; Crainic and Gendron 2021). In research, Bernard aimed, "locally", for a refined and relevant representation of the problem at hand supported by a powerful solution approach, and, "globally", for a better understanding and continuing development of our profession's methodological treasure chest, as illustrated in Crainic et al. (2022)".

Chapter 10, *Separable Lagrangian Decomposition for Quasi-Separable Problems*, by Antonio Frangioni, Bernard Gendron, and Enrico Gorgone, compares different forms of decomposition for problems whose Lagrangian relaxations can be efficiently computed due to partial, but not complete, separability, once the complicating constraints are relaxed; a new reformulation of the master problem, related to the Lagrangian Decomposition approach, is shown to be computationally superior to both non-separable and trivially-separable versions. The chapter builds on the very specific knack—it could perhaps even be called a passion—that Bernard Gendron had for decomposition methods and the very many different structures that they can reveal even for the same problem. This started early in his career (Crainic et al. 2001), it was a constant line of research, yielding very significant methodological results (e.g., Frangioni and Gendron 2009; Frangioni and Gendron 2013), and possibly reached a culmination in later works (e.g., Crainic et al. 2022), where new forms of decomposition are proposed for the very same "classical" problem, displaying a remarkable capability of innovating even for problems studied for more than 20 years. This has been one of the leading sources of inspirations leading to the development of the ambitious `SMS++` project (Frangioni et al. 2024), which precisely aims at making this form of sophisticated solution algorithms more accessible to researchers and practitioners. In this, as in many other cases, the legacy of Bernard Gendron's work will keep inspiring future researchers.

Chapter 11, *Decomposition-based Algorithms for Mixed-integer Linear Programs with Integer Subproblems*, by Mariá-Isabel Restrepo Ruiz, Bernard Gendron, and Louis-Martin Rousseau. This chapter studies a special class of problems whose Benders' reformulation exhibits integer variables both in the master problem and the subproblems, while a number of master-problem variables are subject to cardinality constraints. Two novel decomposition-based algorithms exploiting that structure are proposed to address these problems. Their efficiency and effectiveness are tested on two classes of problems: multi-commodity facility location and multi-activity shift scheduling problem. The work in this chapter came from the wish to extend and test some of the ideas developed in the first author's Ph.D. thesis, and thus address two of the main research interests of Bernard Gendron: the development of decomposition methods and the solution of practical large-scale problems. As often in the work of Bernard Gendron, the ideas and approaches proposed therein will be useful to address other practical problems with similar characteristics, continuing to honour the memory of Bernard Gendron and the numerous contributions he made to OR.

Chapter 12, *Perspectives on Using Benders Decomposition to Solve Two-Stage Stochastic Mixed-Integer Programs*, by Mike Hewitt and Walter Rei, discusses accelerating enhancements to the standard Benders' decomposition approaches applied to two-stage stochastic programs. Two strategies are proposed and studied related to, either transferring information from the subproblems to the master, thus strengthening the latter's formulation, or applying the reverse approach sending information from the master to the subproblems, thus improving the quality of the cuts that can be obtained from them. This is related to Bernard Gendron's research, widely recognized for numerous contributions to the field of discrete optimization, particularly for the innovative work on integer programming methods based on decomposition strategies for fixed-charge network design formulations. Although the work presented in this chapter was not done in direct collaboration with Bernard Gendron, it embodies the kind of methodological developments he championed.

Chapter 13, *Decomposition Methods for Choice-Based Optimization Models*, by Shadi Sharif Azadeh, Meritxell Pacheco and Michel Bierlaire. In Choice-Based Optimization (CBO) problems, individual's decisions are explicitly incorporated in the CO framework. The probabilistic expression of the choice model with endogenous variables, such as price and capacity, causes nonlinearity and non-convexity. A Lagrangian decomposition method, coupled with scenario decomposition and scenario grouping, is proposed to address his challenge. This work originated with a collaboration with Bernard Gendron, which started in 2015, when he was having his sabbatical at the École Polytechnique Fédérale de Lausanne (EPFL). In the words of the authors, “his vast and deep knowledge of large-scale optimization was crucial for investigating different decomposition methods for the CBO framework, and eventually settling on Lagrangian decomposition, since this approach allows to address the tractability of the CBO problems for large-scale instances. Additionally, Bernard Gendron suggested that the proposed method can potentially be combined with other decomposition techniques (e.g., Benders’ decomposition), according to the model requirements, which will in the future allow to further enhance and expand the applicability of the method to the application areas discussed in the chapter introduction, such as revenue management and transportation-related problems”.

3.2 Part II: Application-Oriented Developments

Chapter 14, *The Static Elevator Dispatching Problem with Destination Control*, by Camille Richer, Michel Bierlaire and Fabian Torres, deals with vehicle dispatching in vertical transportation systems, where individuals must be assigned to vehicles to be transported between different floors. The chapter focuses on the case of perfect information on passenger arrivals and their origin and destination floors. The authors present a novel network-flow model with two objectives, reducing the average passenger-journey times and cutting down on the energy use of the elevator group. The sensitivity of the problem to parameter variation is studied and possible gains in energy consumption are identified. In the words of the authors, “Bernard Gendron and Michel Bierlaire have been close friends since 1993, when they were working on their Ph.D.s. Their paths have crossed many times, mainly during conferences around the world, but it was only recently that they had the opportunity to work together on a research project, during Bernard’s academic visit to EPFL in 2016. Some of this research is published and is also the subject of Chap. 13 in this book. Although Bernard was not directly involved in it, the contents of this chapter are well aligned with some of Bernard Gendron’s research, in particular scheduling and transportation problems. He was interested in mixed integer programming and network-flow formulations that were primarily applied to transportation and networks. The authors would have loved to have his opinion on this complex vertical transportation system, as it exemplifies the type of problems he liked to solve.”

Chapter 15, *Flow-based Robustness in Consistent Home Care Service Delivery*, by Paola Cappanera and Maria Grazia Scutellà. This chapter addresses a complex planning problem that arises in home-care service delivery. In a multi-period time horizon, closely related decisions need to be made: scheduling of patients’ requests, patient-caregiver assignment, and caregiver routing. The solutions must be robust with respect to demand variability and ensure service regularity (consistency), which frail patients and their families particularly value. Robustness is addressed through a non-standard cardinality-constrained exact model, as opposed to an existing approximate model in the literature. In the proposed exact formulation, the uncertainty paradigm is modelled in terms of a constrained longest path on a suitably defined auxiliary graph, thus testifying the power and the relevance of network design in addressing applications related to the fields of logistics, transportation and, more specifically, health care. The authors acknowledge the outstanding results achieved by Bernard Gendron in network design models and methodologies, and his capabilities to cleverly apply them in many relevant application contexts, as testified, among other things, by the profound scientific discussions they had with him, which have been a guide for the results presented in this chapter.

Chapter 16, *Production Inventory Technician Routing Problem: a Bi-Objective Post-Sales Application*, by Alline Zanette, Michel Gendreau and Walter Rei. The chapter considers a complex problem inspired from a real-life application in post-sales maintenance services. The problem under study combines features of production-routing and technician routing-and-scheduling problems. A deterministic model aiming at minimizing costs and customer dissatisfaction is proposed and it is solved using Benders' decomposition. An extensive sensitivity analysis is performed to evaluate how much the customer satisfaction level could be improved. Bernard Gendron, with his keen interest in combinatorial problems arising in the context of supply chains, would have certainly been very interested by the production-routing problem addressed in this chapter. Furthermore, relying on a solution approach based on Benders' decomposition would have also felt very familiar to Bernard Gendron.

Chapter 17, *Express Package Delivery Optimization Using Walkers, Cargo Tricycles and Delivery Trucks*, by Patrick Meredith-Karam, Jia Hui Jiang, Sina Bahrami and Matthew J. Roorda. This chapter presents a real-world City Logistics application, using sophisticated modelling and algorithmic techniques for the optimization of express deliveries in an urban context by exploiting the synergies and complementarities among several different delivery systems. The authors state that "this work is one of the many outcomes from the Purolator Chair, a consortium of researchers from Université de Montréal, University of Toronto, U.Q.A.M., and McMaster University that Bernard Gendron led from 2018 with intellectual rigour, sincerity, and always with good nature and laughter. The research contributed to the business case for Purolator's real-life pilot e-cargo cycle program in Toronto that began in 2022. Bernard Gendron reviewed an early version of the model, gave helpful and encouraging feedback for the student researchers, and had plans to collaborate to integrate with his research and apply the work to Montreal and other cities in Canada; the authors deeply regret that he could not read the final version and see the outcomes of the Toronto e-cargo cycle pilot."

Chapter 18, *Integrated Location, Sizing, and Pricing for EV Charging Stations*, by Miguel F. Anjos, Ikram Bouras, Luce Brotcorne, Alemseged G. Weldeyesus, Clémence Alasseur, and Riadh Zorgati. The authors propose a bilevel optimization model to support decision-making relative to deploying electric vehicle (EV) charging stations, while taking into account the users' behaviour. The charging-service provider acts at the upper level by making decisions on the location, size, and dynamic pricing of the charging stations to maximize its profit. Users make up the second level and select their available charging stations according to their preference lists. The strategic bilevel optimization problem is addressed using an optimality-conditions-based single-level reformulation complemented by relaxing the complementary constraints. This chapter originated from a partnership between Bernard Gendron and Miguel Anjos, starting in 2016, to rise to the challenge of helping Hydro-Québec achieve the optimal placement of charging points for electric vehicles. The subsequent 5 years saw them thoroughly discuss every aspect of this topic that perfectly joined their expert knowledge of transportation and energy, respectively. This chapter presents work carried out by Miguel Anjos and co-authors in the wake of Bernard Gendron's passing. The authors contribute the chapter to the book in appreciation of Bernard's deep scientific impact and as a token of friendship.

Chapter 19, *Improving Service Quality of an Urban Rail Transit Line by Integrating Passenger and Freight Train Transportation*, by Krissada Tundulyasaree, Layla Martin, Rolf van Lieshout, and Tom van Woensel. This chapter also focuses on City Logistics-related issues, namely, integrating freight movements into public transport. The authors propose a model for the joint optimization of the train and rolling-stock schedules together with the freight allocation, to maximize the carrier profits from freight and passengers alike, under the user-behaviour hypothesis that passengers will choose rail only when the travel time is sufficiently short. Experimental results are extremely promising for this integrative City Logistics strategy, as the flexibility of freight allows the carrier to move it during low-demand periods, while the additional train departures increase supply and thus decrease passenger travel times. The Mixed-Integer Linear Programming model proposed mirrors Bernard Gendron's extensive research in CO, where he delved into polyhedral theory, relaxation, and decomposition methods for integer programming models. Furthermore, the chapter's emphasis on practical applications in transportation resonates with Bernard Gendron's application-inspired research, particularly in transportation, logistics, and telecommunications.

Chapter 20, *Two-stage Stochastic Optimization for the Extended Aircraft Arrival Management Problem Under Uncertainty*, by Fabian Bastin, Sonia Cafieri, Ahmed Khassiba, and Marcel Mongeau, addresses the management of aircraft arrivals in the context of extended arrival manager systems, for which uncertainty is significant when predicting expected times to start the approach phase and landing times. The authors propose a high-level multi-stage stochastic optimization formulation, considering several air-network points of interest and practical operational constraints, and study in some depth the two-stage case, which corresponds to recent studies in the field. Extended numerical experiments, performed on realistic instances, provide the means to analyse the impact of problem characteristics and modelling choices (e.g., inclusion of chance constraints in the first stage) and show, in particular, that the stochastic solutions are more robust than their deterministic counterparts. This chapter builds upon research collaboration with Bernard Gendron, who served as a co-supervisor for Ahmed Khassiba's Ph.D. thesis on aircraft arrival scheduling under uncertainty. A seasoned expert in Mixed-Integer Linear Programming, Bernard Gendron proposed improved solution strategies for such challenges, seamlessly applying his expertise from urban and road transportation to the realm of air transportation. He contributed to consolidating decomposition strategies in stochastic programming, paving the way for future developments in air traffic management. Given the ongoing growth in air traffic, Bernard Gendron's insights have been crucial for developing better OR algorithms and improving the efficiency and safety of air transportation.

Acknowledgments First and foremost, we wish to address our warmest thanks to the authors of the different chapters who accepted so graciously our invitation to contribute to the book. We also want to thank the reviewers, who dedicated time and effort to help the authors and us to improve the final product.

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Part I
Methodological Developments

Variable Neighborhood Search with Dynamic Exploration for the Set Union Knapsack Problem

Igor Machado Coelho, Saïd Hanafi, Raca Todosijevic, Mustapha Ratli, and Bernard Gendron

1 Introduction

In the set-union knapsack problem (SUKP), introduced in Goldschmidt et al. (1994), we are given a set of elements, each having a positive weight, and a set of items, where each item has a positive profit and a corresponding set of associated elements. An item is included in a knapsack of fixed weight capacity only if all its associated elements are included in the knapsack. The goal of the SUKP is to select the items to be included in the knapsack so that the total profit of the selected items is maximized and the capacity of the knapsack is not exceeded.

Formally, the SUKP is defined as follows. We are given a set N of n elements and a set M of m items. Each item $i \in M$ is characterized by its profit $c_i > 0$ and by its set of associated elements $N_i \subseteq N$. For any subset $S \subseteq M$, the profit of S is given by $\sum_{i \in S} c_i$, while the weight of S is $\sum_{j \in \cup_{i \in S} N_i} a_j$, where $a_j > 0$ is the weight of element j. The objective of the SUKP is to select a maximum profit subset of M,

Bernard Gendron is deceased at time of publication.

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T. G. Crainic et al. (eds.), *Combinatorial Optimization and Applications*,
International Series in Operations Research & Management Science 358,
https://doi.org/10.1007/978-3-031-57603-4_2