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To cite this version:

Eric Bourreau, Roberto Wolfler Calvo, Jean Andre. Introduction to the Special Section: ROADEF/EURO Challenge 2016-Inventory Routing Problem. Transportation Science, 2020, 54 (2), pp.299-301. 10.1287/trsc.2019.0972 . lirmm-03619109

HAL Id: lirmm-03619109
https://hal-lirmm.ccsd.cnrs.fr/lirmm-03619109

Submitted on 24 Mar 2022

Introduction to the Special Section: ROADEF/EURO Challenge 2016—Inventory Routing Problem

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The ROADEF/EURO challenge[1] is a contest jointly organized by the French Operational Research and Decision Aid Society (ROADEF) and the European Operational Research Society (EURO). The contest has appeared on a regular basis since 1999 and always concerns an applied optimization problem proposed by an industrial partner (e.g., Google (Artigues et al. 2018), SNCF (Société nationale des chemins de fer français; Afsar et al. 2016), Electricité de France (Özcan et al. 2013), and Amadeus (Artigues et al. 2012), to cite the last ones). The 2016 edition of the ROADEF/EURO Challenge was managed by an organizing committee composed of academic researchers from different French universities (Eric Bourreau, Laboratoire d'Informatique, de Robotique et de Microélectronique de Montpellier (LIRMM), Montpellier; Safia Kedad Sidhoum, Centre d'Etudes et de Recherche en Informatique et Communication (CEDRIC), Conservatoire National des Arts et Métiers (CNAM), Paris; David Savourey, Laboratoire HeuDiaSyC, Université de Technologie de Compiègne, Compiègne; Vincent Jost, Laboratoire G-SCOP (Sciences pour la Conception, l'Optimisation et la Production), Grenoble, for ROADEF; and Marc Sevaux, Laboratoire des Sciences et Techniques de l'information de la Communication et de la Connaissance (Lab-STICC), Université de Bretagne Sud, Lorient, for EURO). This year, the industrial partner was Air Liquide, a global leader in gases, technologies, and services for industry and health. Air Liquide is present in 80 countries with approximately 66,000 employees and serves more than 3.6 million customers and patients. Oxygen, nitrogen, and hydrogen are essential small molecules for life, matter, and energy. They embody Air Liquide's scientific territory and have been at the core of the company's activities since its creation in 1902.

In the past, the bulk of Air Liquide's liquefied gas customers managed their own inventories and called-in orders, operating in a customer-managed inventory (CMI) context. Many have now transferred this responsibility to Air Liquide, where this vendor-managed inventory (VMI) relationship enables improved insight on the real-time customer demand rate and inventory level, generally transmitted automatically to their operations center using remote telemetry. This mixed VMI/CMI problem has many complexities that go far beyond the problem of capacitated vehicle routing with time windows well studied in the literature. For many years, this highly combinatorial problem with rich business constraints has been strongly explored internally based on exact and approximate approaches (ant colonies, local search heuristics, and column generation).

To make new breakthroughs, the Air Liquide Computational and Data Science Research and Development Laboratory[2] decided to leverage open innovation and open new horizons with the sponsorship of the ROADEF/EURO Challenge on this problem. They especially appreciated in this challenge format the time frame (two years) given to the competitors to tackle this difficult problem and to propose sound solutions in an iterative way.

During the first year of the competition process, Air Liquide provided several sets of problem instances to the candidates through the challenge. These data were provided to the candidates according to the following timeline: A first set of instances, Set A, was available to the candidates from the beginning of the challenge in September 2015 until the end of the enrollment/qualification period in January 2016. During this period, a sprint contest was launched during the first months to give candidates (and organizers) the opportunity to gain an estimation of the solution quality. Solution files could be sent by the candidates on a voluntary basis, and the team having the best score won the sprint prize. Nicolas Catusse from Grenoble INP won this prize (€1,000). The sprint phase ended in November 2015. In January 2016, the candidates had to send an abstract describing their method and runtime application. A first evaluation based on the Set A instances was performed to select a short list of qualified teams for the final round (€2,500 win for the best team in the qualifications). The second set of instances, Set B, was made available after the announcement of the qualified teams in February 2016. These instances were harder than the ones of the previous set to provide to the selected candidates an opportunity to fine-tune their methods. This so-called final phase ended by June 2016, with a deadline for sending the second and last version of the program and an extended abstract describing the final method. A third and last set of instances, Set X, not revealed to the candidates, was used in conjunction with Set B to determine the ranking of all the finalists. The results were announced during the 2016 EURO conference. The winner was Ahmed Kheiri from Cardiff University (€7,500). Tamara Jovanovic from L'École des Mines d'Alès won the junior prize (€2,500). Finally, the second year of the challenge was dedicated to the scientific part in a last round from July 2016. A scientific prize based on a technical report and an oral presentation at the EURO meeting was awarded by a scientific committee managed by Roberto Wolfler Calvo. The scientific prize was shared by a Ecole des Mines Saint Etienne and Ecole Centrale Lille, whose method is presented in this issue, and Tamara Jovanovic, who proposed a new lower bound dedicated to the specific objective function available during the challenge. Overall, across the seven awards, the financial sponsorship from Air Liquide reached €25,000.

Beyond the funding sponsorship, much time was spent by the Air Liquide team, namely, Michele Quattrone, Rodrigue Fokouop, and Jean André, first and foremost dedicated to the specifications of the problem. During several months before the competition, in close coordination with the organizing committee, a compromise was built between, on one hand, the accessibility to a large audience and, on the other hand, the richness of the real-life operational constraints in the industrial gas business. This is one of the reasons in particular why they focused on the healthcare business, which delivers bulk volumes of liquid oxygen to 7,500 hospitals worldwide. They also worked on elaborating a first version, accessible for a first round, and a second version including additional features such as multisourcing and layover customers. Along with the specifications, a constraint and objective checker was developed to provide to the competitors a transparent and fair basis of comparison. They made a specific effort to make the problem as understandable as possible with a very basic instance (few customers, over few days) accessible and playable through a serious game, which was a first in the history of the ROADEF/EURO Challenge. This serious game has been used since then in many university courses and lectures across the world to illustrate the specificities of this problem.

One of the first great, immediate benefits of the challenge for Air Liquide was to be able to interact with competitors, with more than 40 teams from more than 16 countries (Brazil, China, Mexico, the United States, Canada, and European countries) interested in the challenge. Questions from the competitors were very enlightening on the improvements we needed to make on the constraint modeling and the instances' consistency. Then, the different phases (sprint, qualification phase, and final) helped us to discover very skilled academic teams and start-ups (such as Conundra, which reached the second rank) that proposed new methods to solve this problem. To investigate the full impact of these methods, collaborations have been investigated with some of the winning teams. Beyond this short-term impact, the long-term benefit coming from the challenge is that it has set up industrial-grade reference cases in the academic community against which people can benchmark themselves.

The characteristics of the problem proposed by the challenge that are new with respect to the literature on the inventory routing problem (IRP) are many. The main ones are the following: a nonlinear objective function (logistic ratio), multiday shifts, multisourcing, and the scheduling of drivers and routing of vehicles at the same time. This latter characteristic imposes the need to define the starting times of the routes, which can be at any time of the day, and the quantities to refill. The last, but not least, characteristic is the size of the instances, because the large instances have a huge number of customers (up to 300 customers) over long time horizons (more than 30 days).

In this special section of *Transportation Science* devoted to the ROADEF/EURO Challenge, there are four selected papers, from six submissions received. One paper presents a hyperheuristic, whereas the three other papers are based on matheuristics. All of the latter include in their solution methods the resolution of a subproblem with an exact approach (e.g., by solving to optimality a linear programming (LP) model and/or a mixed integer programming (MIP) problem).

The first paper, "Heuristic Sequence Selection for Inventory Routing Problem" by Ahmed Kheiri (2020), the winner of the competition, presents a hyperheuristic combining machine learning and optimization heuristics, which is based on the idea of dynamically exploring the neighborhood by combining sequences of basic heuristics. This approach was quite new compared with the classical local search, which is natively static in the choice of heuristics. Each path (i.e., sequence of heuristics) is built by a hidden Markov model, and each arc connecting two heuristics is chosen based on the previous iterations, because the value associated to the link is reinforced by previous results. The algorithm chooses each step of the path among a set of 16 basic heuristics. Thanks to this hybrid approach, the author was able to provide the best solution over all instances.

A second paper, "A Heuristic Branch-Cut-and-Price Algorithm for the ROADEF/EURO Challenge on Inventory Routing" by Nabil Absi, Diego Cattaruzza, Dominique Feillet, Maxime Ogier, and Frédéric Semet (Absi et al. 2020), proposes a matheuristic based on column and cut generation (branch and price and cut). The columns generated by the pricing represent the routing, and the authors decide to route timed shifts (i.e., the list of customers to satisfy and the timing). The quantity is decided in the master problem. To deal with the fractional objective function, they linearise with the Dinkelback approach. The pricing algorithm is heuristic, whereas the solution of the master problem is approximated. Moreover, the authors reinforce the master problem by adding several valid inequalities. This paper won the scientific prize ex aequo and the team was a collaboration between Centrale Lille and Ecole des Mines de Saint-Etienne.

A third paper, "A Matheuristic Algorithm for the Inventory Routing Problem" by Zhouxing Su, Zhipeng Lü, Zhuo Wang, and Una Benlic (Su et al. 2020), ranked third, decomposes the problem into two subproblems. The routes are adjusted in the master problem, whereas timing and quantities are decided in the two subproblems. The master problem is solved and improved by a local search algorithm, which is based on six neighborhoods. To decide which neighborhood should be explored, the authors apply a mechanism of learning from the past iterations. Timing and quantities are decided by solving MIP and LP problems. The MIP model considers a route and optimizes the start time of this route and its operation. The model is based on a special time–space graph and can be solved by a pseudopolynomial time algorithm. Quantities, represented by continuous variables, are decided by an LP model. The team is a collaboration between a UK start-up and Huazhong University of Science and Technology.

The fourth paper, "A Matheuristic with Fixed-Sequence Reoptimization for a Real-Life Inventory Routing Problem" by Yun He, Christian Artigues, Cyril Briand, Nicolas Jozefowiez, and Sandra Ulrich Ngueveu (He et al. 2020), proposes a matheuristic, and it is based on a similar idea of decomposing the problem into two parts. The authors propose several methods to build the routes: namely, two greedy heuristics and a column generation–based heuristic. A column is a timed route in a way similar to that in the second paper. The second phase is based on the idea of using an algorithm to improve timing and quantities at the same time once the sequence of customers (routing part) has been decided. The authors call this problem fixed-sequence mixed integer linear fractional programming. To deal with the fractional objective function, the authors use Dinkelback approach. The team is a collaboration between the LAAS, University of Toulouse and the LCOMS, University of Lorraine.

The first paper provides the best results by far, which underlines that for solving real-life instances, the approaches based on exact algorithms are still insufficient. This means that there is a gap to close between exact approaches and heuristics in terms of the complexity of the constraints tackled and the size of the instances solved. Moreover, let us note that among all the proposed algorithms, there is only one approach able to provide a lower bound. Therefore, in conclusion, this edition of the ROADEF/EURO Challenge continues to influence the direction of scientific research by providing industrially relevant benchmark cases that include key practical challenges missing from previously published work on the IRP.

Endnotes

[1] See http://www.roadef.org/challenge/2016/en/index.php.

[2] See https://www.informs.org/ORMS-Today/Public-Articles/August-Volume-44-Number-4/Roundtable-Profile-Air-Liquide.

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