



Air Liquide's Delaware Research and Technology Center in the United States.

Photo credit: Don Pearse Photographers, Inc.

Air Liquide

Multinational company's Computational and Data Science R&D team supports an extensive, varied, dynamic research portfolio.

The world leader in gases, technologies and services for industry and health, Air Liquide is present in 80 countries with approximately 67,000 employees and serves more than 3 million customers and patients. Oxygen, nitrogen and hydrogen are among the essential small molecules for life, matter and energy. Essential small molecules embody Air Liquide's scientific territory and have been at the core of the company's activities since its creation in 1902.

With the 2016 acquisition of Airgas, Air Liquide has entered a new phase in its development and growth. By combining the Airgas omnichannel approach of physical branch locations, e-business and telesales with Air Liquide innovation capabilities (including digital), the Air Liquide Group is accelerating its customer-centric transformation.

Air Liquide serves a wide range of industrial sectors, including automotive and manufacturing, food and pharmaceuticals, oil and gas, steelmaking, semiconductor fabrication and chemical production along with research and technology organizations, including universities. Air Liquide offer its customers – from independent craftsmen to large industrial companies – a range of solutions: industrial and specialty gases, application technologies, welding and safety equipment and related services. Present in the continuum of healthcare from hospital to home, Air Liquide serves 1.4 million patients around the world.

The variety of essential small molecules that Air Liquide offers (including specialty gases, mixtures and new molecules that it designs and manufactures) and the diversity of its customer base requires various product supply chains. Air Liquide's cylinder fill plants package gases for delivery to its customers and patients. For higher volume and cryogenic needs, Air Liquide delivers liquefied gases in bulk to permanent on-site storage tanks at its customers' locations. For its largest volume customers, Air Liquide directly supplies gas from its production plants via extensive pipeline networks in the world's largest industrial basins (e.g., the U.S. Gulf Coast and the Benelux region in Europe).

As articulated in its NEOS strategic program for 2016–2020, Air Liquide's customer-centric transformation is founded upon four strategic pillars: operational

By Jeffrey E. Arbogast and Athanasios Kontopoulos

All About the Roundtable

excellence, selective investments, open innovation and a worldwide network organization. In Air Liquide's Computational & Data Science R&D Global Lab, we apply our innovative and entrepreneurial spirit – the creative oxygen that sustains our growth – and advanced methods in operations research (O.R.) and analytics to support these strategic pillars and address our common challenges in the energy and environmental transition, the healthcare evolution and the digital transformation.

O.R. and Analytics at Air Liquide

Over the years, Air Liquide's activities in O.R. and analytics have broadened from advanced process control to optimization and data science. As the focus evolves from operational excellence (e.g., efficiency and reliability) to support business growth (including sales, marketing and finance), the need for broadening expertise continues with a focus on statistics and financial economics. In research groups located in Paris, Delaware and Shanghai, we in Computational & Data Science R&D serve at the scientific core of these activities, engaging with a range of internal and external partners to remain at the forefront of technology. In addition to O.R. and analytics activities, our research includes connected devices, computational fluid dynamics and molecular modeling. Our research portfolio extends from exploratory research in line with broad scientific and technology trends impacting our business to key projects focused upon clear and present business and customer needs.

At Air Liquide, innovation in O.R. and analytics is a collaborative effort beyond R&D. Our Alizent entity, dedicated to Industrial IoT, develops, deploys and supports interactive monitoring and control solutions for returnable assets (e.g., cylinders), remote assets (e.g., customer storage tanks, delivery vehicles/drivers), and production assets of internal

The Roundtable consists of the institutional members of INFORMS with member company representatives typically the overall leader of O.R. activity. The Roundtable is composed of about 50 organizations that have demonstrated leadership in the application of O.R. and advanced analytics. The Roundtable culture is peer-to-peer, encouraging networking and sharing lessons learned among members.

The Roundtable meets three times a year. Roundtable goals are to improve member organizations' OR/MS practice, help Roundtable representatives grow professionally and help the OR/MS profession to thrive. Further information is available at <http://roundtable.informs.org>.

The Roundtable also has an advisory responsibility to INFORMS. According to its bylaws, "The Roundtable shall regularly share with INFORMS leadership and advise the INFORMS Board on its views, its suggested initiatives and its implementation plans on the important problems and opportunities facing operations research and the management sciences as a profession and on the ways in which INFORMS can deal proactively with those problems and opportunities." The Roundtable meets with the INFORMS president-elect each spring to discuss practice-related topics of interest to him or her, and with the entire INFORMS Board each fall to discuss topics of mutual concern.

This series of articles aims to share with the INFORMS membership at large some information and insights into how O.R. is carried on in practice today.

and external clients alike. Our digital fabs foster cross-disciplinary collaboration with our operations on strategic topics with a particular focus on data and our customer-centric transformation.

Air Liquide's worldwide network of modern R&D centers provides a diverse environment for innovation with various national, scientific and business line backgrounds present. Our team members in O.R. and analytics come from a variety of backgrounds including chemical, industrial, mechanical and electrical engineering along with statistics and computer science. Some team members follow their project work into business and management roles outside of R&D, while others pursue a technical career path recognized as experts in our international expertise program. In R&D, we have valuable opportunities to work among and across different business lines and operational entities, with whom close proximity is essential to the successful application of O.R. and analytics to benefit our customers and business.



Rendering of Air Liquide's Paris-Saclay Research Center in France.

Photo credit: Michel Remon of Golem Images

Roundtable Profile

Open innovation is one of the ways that R&D accelerates innovation. In Computational & Data Science R&D, we are particularly engaged with the innovation ecosystem in North America and Europe, sponsoring research at leading academic institutions including Carnegie Mellon University and École Polytechnique, among others. Our Paris-Saclay Research Center is engaged within the Paris-Saclay innovation cluster that includes leading universities, engineering and business schools, research institutes, and industrial research and development centers. Our Delaware Research & Technology Center is located in close proximity to Philadelphia and the innovation clusters of the northeastern United States. Through our collaboration with Virginia Tech, Air Liquide is a leader among the industrial members of the Center for Excellence in Logistics and Distribution (CELDi), a multi-university research consortium. Our external engagement enables us to gain valuable insights from research and applications in the chemical and process industries and beyond.

A particular example of open innovation is our sponsorship of the 2016 ROADEF/EURO Challenge on the inventory routing problem (IRP), a key optimization challenge for both industry and the scientific community. The open challenge is organized every two years by ROADEF and EURO, the French and European counterparts to INFORMS respectively, to solve an industrially-relevant research problem proposed by the sponsor.

Worldwide Applications of O.R. and Analytics

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 our operations center using remote telemetry.

To achieve operational efficiencies and customer centricity enabled by the VMI relationship, we develop and deploy advanced enterprise planning and scheduling tools in a mixed VMI/CMI context. Beyond the routing of tractor-trailers to fulfill given orders, such an IRP solution requires effective, reasonable forecasts of customer demand to determine both the timing and the quantity of each customer delivery. The IRP problem offers interesting challenges for both scientific research and industrial practice.

Our sponsorship 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. The insights that we continue to gain complement our own extensive history on the topic, which includes applications of ant colony optimization, local search heuristics and column generation.

Our optimization work extends to the tactical and strategic level in the design of bulk and packaged gas supply chains. This includes the sizing of distribution fleets, the location of sites (production, filling and transportation depots), the allocation of customers to those sites and the sizing of on-site customer storage. Entities worldwide of various sizes have applied these planning tools to promote operational excellence in the reliable, efficient supply of product to Air Liquide's customers. Enterprise-wide optimization in the context of production-distribution coordination is of particular interest.

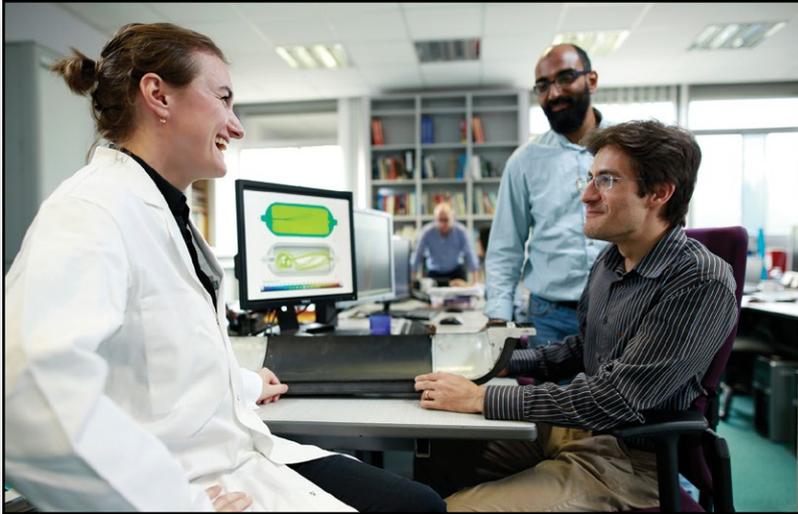
Air Liquide's "Smart and Innovative Operations" (SIO) program integrates digital tools to analyze operating data from its production plants, exemplified at the new remote operation and optimization center in Lyon, France. Deployed globally, the SIO program focuses on automating and centralizing operations, optimizing the performance of each site and anticipating malfunctions. Consistent, fundamental model templates facilitate the deployment of SIO applications in optimization and data analytics. We have built a core optimization engine in AIMMS that includes model templates for unit operations (e.g., compression, distillation and liquefaction) for users to combine into a "digital twin" of their particular plant or pipeline network. We share knowledge in internal conferences on advanced process control and optimization.

With the SIO program, our operations have established new "operation center analyst" roles with



Air Liquide bulk storage tank and cryogenic trailer for delivery.

Photo credit: Air Liquide



Computational & Data Science R&D researchers collaborating.

Photo credit: Air Liquide

responsibility to use optimization tools to define the medium-term production plans and data analysis tools to analyze energy consumption relative to similar conditions in the past, as well as to detect the weak signals that precede a malfunction on critical equipment (predictive maintenance). In-depth process knowledge and experience in production positions are general qualities that an analyst brings to the position. With this role, the community around O.R. and analytics continues to grow within Air Liquide. The community of analysts is responsible to drive the improvement of digital tools and identify future efficiency projects.

In Computational & Data Science R&D, we contribute to the development of in-house tools and the evaluation of commercial-off-the-shelf tools, helping to transform “black box” solutions into “glass box” solutions. We find that this is critical to promote sustained buy-in and use among the end-users of such tools. While we remain responsible for evaluating, developing and introducing new optimization and data science methods, responsibility for broader deployment transitions to our operational counterparts – particularly for the specific needs of Air Liquide’s pipeline operations.

Exciting Future with O.R. and Analytics

The extensive geographic network of more than 1,100 Airgas retail branches are the backbone of Air Liquide’s close proximity with customers in the United States, offering small and large businesses and individual entrepreneurs a “one-stop shop” for their cylinder gas and services needs, as well as related safety and welding hard goods. The branches are fully integrated with and are complemented by digital and telesales activities to improve customer reach and service. In addition to generating direct sales to customers independently, telesales teams support branches and field sales teams, and drive

e-business traffic to the website. The combination of this strong Airgas infrastructure with our scientific background in O.R. and analytics offers exciting opportunities to deliver value for our stakeholders and customers.

With extensive worldwide operations comprised of various supply chains and a broad customer base having varied applications of essential small molecules, Air Liquide offers unique and varied opportunities for O.R. and analytics research due to the volume and variety of data, decision

variables and constraints. Considering the pace of production and distribution operations, the high velocity of data and decisions will continue to be a challenge and an opportunity (e.g., real-time optimization of pipeline and plant operations, application of real-time traffic and up-to-date telemetry readings to adapt distribution schedules).

The veracity of data to be analyzed and applied in decision-support tools will continue to be a challenge as we apply greater volumes of data from a variety of sources (internal and external from various systems). Assuring the veracity of our solutions in light of the uncertainty inherent as we consider forecasts well into the future remains a key challenge. This particularly requires scientific expertise in O.R. for such techniques as discrete event simulation, adjustable robust optimization and stochastic optimization.

At Air Liquide, innovation is part of an open, user-centric ecosystem based on science, technologies, customer experience and the incubation of new activities. The ongoing customer-centric transformation strategy is modifying ways of working, consuming and communicating. O.R. and analytics are a keystone of this transformation in managing assets and interacting with customers, with Computational & Data Science R&D responsible for evaluating and developing new methods to be transferred for widespread application throughout Air Liquide. **ORMS**

Jeffrey E. Arbogast (jeffrey.arbogast@airliquide.com), Ph.D., is an Air Liquide International Expert in Computational & Data Science R&D based in Delaware and is Air Liquide’s representative to the INFORMS Roundtable. **Athanasios Kontopoulos**, Ph.D., is an Air Liquide International Senior Expert and Scientific Director of the Computational & Data Science R&D Global Lab based in Paris-Saclay. The authors thank **Jean André** and **Bin Yu**, Air Liquide International Experts based in Paris-Saclay and Delaware, respectively, for their feedback and contributions to this article.

The veracity of **data to be analyzed** and applied in **decision-support tools** will continue to be **a challenge** as we **apply greater volumes** of data from a **variety of sources.**